NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Technical Reference
Electrical Engineering Safety
EES005

NSW DPI Technical Reference
Electrical Protection and Earthing

Coal Mine Health and Safety Act 2002
Coal Mine Health and Safety Regulation 2006

December 2006 (version 1)

Disclaimer

NSW DEPARTMENT OF PRIMARY INDUSTRIES

PREFACE

Electrical installations and associated equipment and machinery at mines are generally more complex than those found in most business and residential installations. Accordingly mining electrical installations should be designed by qualified electrical engineers with relevant experience in the mining industry. The safe use of electricity is dependent on well engineered electrical protection systems and well engineered earthing systems. Indeed without these systems electricity would be too dangerous to use.

Electrical protection and earthing design is considered to be a specialist task. It is therefore necessary to ensure that any electrical protection and earthing design is carried out by competent, qualified people.

This Technical Reference will be used by Mine Safety Operations to assess the effectiveness of coal operation electrical protection and earthing arrangements as part of the Engineering Management Plan.

This Technical Reference can also be used by coal operators as guidance to the safety measures applicable to practices for life-cycle management of electrical protection and earthing at coal operations that can be incorporated into the Electrical Engineering Management Plan. These safety measures will further align electrical circuit protection and earthing design in the mining industry with measures in the non mining industry whilst catering for the special needs of the mining environment and equipment. It provides practical advice on achieving the outcomes required by the Occupational Health and Safety Act 2000, the Coal Health and Safety Act 2002 and associated regulations. It sets out guidance for the management of Electrical Explosion Protected Equipment to be incorporated as part of the Electrical Engineering Management Plan.

This Technical Reference will assist employers, self-employed persons, employees, contractors and other parties involved with electrical protection and earthing.

Coal operators can use this Technical Reference to assess the effectiveness of their present arrangements for dealing with electrical protection and earthing.

John Francis Waudby

Senior Inspector of Electrical Engineering

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Chapter 1 Establishment

1.1 Title

This is the DPI Electrical Engineering Safety Technical Reference – Electrical Protection and Earthing.

1.2 Purpose

This Technical Reference is intended to provide a framework for DPI officers to assess coal operation arrangements for electrical protection and earthing as part of the Electrical Engineering Management Plan. It can also be used by coal operators as guidance material for implementing, managing or reviewing their electrical protection and earthing arrangements.

This Technical Reference describes acceptable arrangements that can be tailored to suit the particular needs of an operation. It identifies some of the core hazards, risks and control measures relevant to electrical circuitry. It is intended to protect the safety of workers, others in the workplace and property.

The outcomes sought to be achieved by this Technical Reference are to protect people and property from the hazards occurring during electrical equipment failures and include:

- Electrocution
- Electric Shock
- Electrical burn injuries
- Arc blast injuries
- Injuries sustained through operation of the apparatus
- Unintended operation of the apparatus
- Ignitions of flammable mixtures of gas or dust
- Fire

1.3 Scope

This Technical Reference extends to all locations in coal operations in New South Wales. These areas include general surface, treatment plants, underground, both outbye and in hazardous zones. It deals with high voltage levels, low voltage and extra low voltage equipment.

This Technical Reference also applies to mains supplied plant, privately owned generating plants, installations supplied by privately owned generating plants, self contained electrical apparatus and electric welding equipment (excluding the welding “work” circuit).

This Technical Reference is supplemented by the following Technical References:

- EES001 NSW DPI Technical Reference - Electrical Engineering Management Plan
- EES002 NSW DPI Technical Reference - Control and Supervision of Electrical Work

- EES003 NSW DPI Technical Reference - Practices for the Life-Cycle of Management of Explosion Protected Equipment
- EES004 NSW DPI Technical Reference – Practices for Portable Electrical Apparatus
- EES006 NSW DPI Technical Reference - Removal and Restoration of Power

1.4 Authority

This is an Electrical Engineering Safety Technical Reference and is recommended by the Department of Primary Industries.

1.5 Definitions

Back up protection. Protection provided as a supplement to the main protection of the system being protected, which is required to operate in the event of a failure of the main protection

Circuit means an electrical network providing one or more closed paths

Competent person means a person who has acquired through training, qualification, experience, or a combination of them, the knowledge and skills to carry out the task.

Earth Continuity Protection. Form of protection normally provided to confirm the integrity of the earth conductors in the cables supplying equipment. It operates when the earth loop resistance exceeds a predetermined value, or when the resistance value between pilot and earth falls below a predetermined value.

Electrical equipment means electrical apparatus, appliance, machine, fitting, or cable in which conductors are used to transmit and utilise electricity.

Electrical protection means a relay or apparatus whose function is to detect defects or conditions of an abnormal or dangerous nature in any electrical circuit, apparatus or power system and to initiate appropriate control circuit action.

Earth Electrode or Earth Grid. A conductive part or a group of conductive parts in intimate contact, and providing electrical connection, with earth.

Earth Leakage Current. Current which flows between an energised conductor and an earth conductor to the general body of the earth as a result of reduction in the value of insulation resistance.

Earth Leakage protection. Protection provided to detect earth leakage current and isolate the electrical supply from any fault zone.

Earthing Conductor. A protective conductor connecting the main earth terminal or bar to the earth electrode.

Earth fault lockout protection. Protection which prevents a circuit being energised if the insulation resistance to earth of one or more of the conductors is below a predetermined value.

Fixed cable means a cable consisting of a single conductor or a combination of conductors insulated from one another and which is not designed to afford relative motion between its terminal points while it is energised.

Flexible cable means a cable consisting of a stranded conductor or a combination of conductors insulated from one another and which is designed to afford relative motion between its terminal points while it is energised.

Main earth leakage. Earth leakage protection that is expected to operate first under fault conditions – the earth leakage protection generally installed to protect the final load circuit only.

Mains mean conductors or cables connecting mains switch-gear with an electrical power distribution or load centre.

Mains switch-gear means power circuit switching or interrupting devices in combination with associated control, instrumentation, metering, protective and regulating devices, or assemblies of any such devices, and associated inter-connections, accessories and supporting structures used primarily in the transmission, distribution and conversion of electric power.

Mobile apparatus means machinery not being portable apparatus but capable of being readily moved about while it is carrying out its function.

Overload in relation to any electrical apparatus, means the current, voltage, power or torque of the apparatus in excess of the rating.

Plant includes any machinery, equipment or appliance.

Portable apparatus means electrical apparatus capable of being carried manually while it is being used but does not include a caplamp. It covers such items as hand-held portable or transportable welders, portable power tools, appliances and flexible extension cords.

Protection Device. Device comprising one or more sub assemblies of components and designed to provide the type of protection covered by the requirements. It is a piece of equipment whose primary function is to detect an electrical abnormality or failure and to automatically initiate the removal of the problem.

Rating in relation to any electrical apparatus, means the designated limit or limits for the characteristics of voltage, current, temperature, power or torque within which the apparatus is designed to operate.

Residual current device (RCD) means a device intended to isolate supply to protected circuits, socket outlets or electrical equipment in the event of a current flow to earth which exceeds a predetermined value. Note: when selecting an RCD, there is a need to consider the electrical supply characteristics. That is, is it sinusoidal, dc or some other form of alternating current? An RCD selected for one type of supply may not operate correctly on another type of supply.

Short Circuit Current. A flow of current between active conductors or active conductor and earth which do not follow the intended path but bypasses the normal load. This current will be limited only by the impedance of the supply and cables. A destructive flowing current.

Tripping Ratio. Ratio of the prospective earth fault current to the operating value of the earth fault protection.

1.6 Applicable legislation

The Occupational Health and Safety Act 2000

The Occupational Health and Safety Regulation 2001

The *Coal Mine Health and Safety Act 2002*

The *Coal Mine Health and Safety Regulation 2006*

1.7 Referenced Standards and Guidelines

AS/NZS 1768 Lightning protection

AS/NZS 2081 Series - Electrical equipment for coal and shale mines—Electrical protection devices

AS/NZS 3000: Electrical installations (known as the Australian/New Zealand Wiring Rules)

AS 3007 Series - Electrical installations - Surface mines and associated processing plant

AS/NZS 3012 Electrical installations—Construction and demolition sites

AS/NZS 3760 In-service safety inspection and testing of electrical equipment

AS/NZS 4871 Series - Electrical equipment for coal mines, for use underground - General requirements

Electricity Council of New South Wales publication EC5 Guide to Protective Earthing

Institute of Electrical and Electronic Engineers, Inc Green Book IEEE Std 142-1991

Institute of Electrical and Electronic Engineers (USA) Standard 80 Guide to Safety in Substation Grounding.

Substation earthing guide - 1995, Electricity Supply Association Australia

1.8 Acronyms

AS – Australian Standard

AS/NZS – Australian New Zealand Standard

EPR – Earth Potential Rise

1.9 Other referenced legislation

The *Electricity (Consumer Safety) Act 2004*

1.10 Who is affected by this Technical Reference?

All operators of coal operations in New South Wales where there is an electrical installation that is connected to the network of an electricity supply authority or where there is an electrical installation with the source of electricity is a stand-alone power system such as photovoltaic cells (solar panels), wind or water turbines, diesel or petrol generators.

All individuals, unincorporated businesses and corporations involved in utilizing electricity at NSW coal operations including those who design, install and implement electrical safety systems and those who commission, test, operate and maintain the systems.

Chapter 2 Electrical Protection

2.1 Introduction

To put the need for electrical protection in context it is instructive to quote from the paper *"Electric Arcing Burn Hazards"* by Stokes and Sweeting[1].

> *"Modern electric fuses are marvelous devices for protecting life and equipment from the potential power of uncontrolled electricity. Since the coming of electricity in the 1870's, they have been in the front line of electrical defense. Indeed, it is fair to say that without the virtually fail-safe protection of the electric fuse, there would be no modern electrical industry. Electricity would be regarded as far too dangerous for widespread use".*

Although this statement relates to fuses it is obvious that it has some resonance for all types of electrical protection and methods of opening circuits – without electrical protection systems electricity would be far too dangerous for use in the work place.

All electrical circuits have a basic requirement that the conductors of the electric current be of adequate size to carry normal and fault current loads without being damaged or degraded by excessive heating. Furthermore all electric current conductors are required to be insulated to prevent unwanted current flow from one conductor to another or from one or more conductors to earth.

The purposes of electric power system protection devices are:

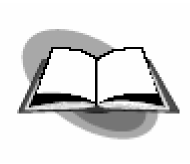
- To detect excessive current levels in power system conductors
- To detect excessive current flows to earth due to insulation failure
- Two further purposes specific to mobile machinery are:
    - To detect cable insulation failure; and
    - To confirm earth continuity.
    - These must be effected before application of power.

Electrical protection is a primary control for many of the electrical key risk areas and is used to minimise the risk of:

- Electrocution
- Death or injury from electric shock (including from secondary causes such as falls as a result of an electric shock)
- Electrical burns (including burns from radiation, current flow, and plasma. It also includes arc blast injuries)
- Fires
- Explosions due to gas or catastrophic failure of electrical enclosures.

[1] Stokes, DA., Sweeting, DK. *"Electric Arcing Burn Hazards"*, IEEE Transactions on Industry Applications, page 134, Vol. 42, No.1, January/February 2006

2.2 Legislation



Clause 19(1)(h)
Requires electrical protection to be fitted to all circuits and to interrupt the supply when a fault occurs and that protection devices are properly constructed. Special protection has to be provided on certain types of circuit.

Electrical protection is required by legislation and is applicable to ALL coal operations. In general, every circuit and sub-circuit (circuits that are outgoing from a switchyard, distribution board, DCB and the like) at a coal operation must have short circuit protection and earth leakage protection to minimise the risk of damage to equipment and injury to personnel. The optimisation of availability will also be required. All electrical circuits from the Local Supply Authority connection point to areas such as, but not limited to, switchyards, offices, workshops, washery and underground are included.

Legislation can be interpreted as requiring electrical protection to be provided to detect and clear:

- Short circuits between active conductors
- Short circuits between active conductors and earth
- Earth leakage faults
- Earth leakage currents in excess of 30 milliampere for hand held tools and portable equipment
- Mobile equipment fed by flexible cables is to be provided with earth continuity protection
- Mobile equipment fed by trailing cables to have earth fault lockout protection

The general duty of care requirements in legislation should also lead to the installation of other electrical protection such as overload and over temperature.

2.3 Types of electrical protection

Note: information and guidance from historically recorded scenarios relating to electrical protection are indicated as an **Information Note** in blue text.

This Technical Reference refers to devices which are designed to detect the following types of faults when the words Protective Devices are used:

- Instantaneous short circuit current
- Overcurrent
- Earth fault current
- Earth leakage current
- Earth leakage current (personnel protection)
- Earth continuity (open circuit or short circuit)
- Reduction of phase to earth insulation (Earth fault lockout)

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- Overload
- Over temperature

2.4 Philosophy

For a safe electrical distribution system the design of equipment (including cables) the earthing system and the electrical protection must be integrated in a holistic manner. Underground mines have unique challenges and the holistic design is underpinned by the basic philosophy of the first fault must be a low energy earth fault. The basic philosophy of the first fault being a low energy earth fault is worthy of applying to surface installations, especially for mining machinery fed by flexible reeling, trailing or feeder cables. This has implications for equipment design, especially cables, method of earthing and protection devices.

2.5 Basic principles

When designing, selecting, installing or maintaining earthing and protection the following basic principles must be considered for ALL operations:

- First fault to be a low energy earth fault
- See and clear the first fault
- See and clear 3 phase short circuit faults
- See and clear 2 phase short circuit faults
- See and clear a two phase arcing fault
- Earth leakage protection should be fitted to every circuit and sub-circuit.
    - See and clear earth leakage faults on power circuits
    - See and clear earth leakage faults on "field" control circuits operating above ELV
    - See and clear earth leakage faults on all non intrinsically safe circuits in a hazardous zone
    - See and clear earth leakage fault currents above 30milliampere on socket outlets
    - See and clear earth leakage fault currents above 30 milliamperes on circuits that supply mobile or transportable appliances (eg transportable pump) where earth continuity protection is not provided, or where continuity protection is provided and maximum prospective touch voltage can be above those prescribed in AS 3007.2
    - Earth leakage devices to be operated in a fail safe mode
- See and clear O/L's on final load circuits as a minimum
- Clear the fault as quickly as possible
    - No cable or apparatus shall deteriorate due to electrical heating from faults

- Clear over currents before equipment damage especially before catastrophic failures (explosion of equipment)
- Coal face plant earth leakage settings should not have any intentional time delay

- Provide back up protection
- Trip systems to be highly reliable
- Phase to phase faults at the secondary side of transformers shall be seen and cleared by the transformer's primary protection
- For transformers - Safeguard against dangers arising from the charging of lower voltage components by contact with or leakage from higher voltage components
- For IT systems the protection devices should comply with AS/NZS 2081

Information Note: Electrical equipment shall be protected and safeguarded to avoid danger from excessive temperatures, sparking, touch potential, exposure of live conductors or malfunction.

Information Note: All electrical equipment plant must be designed, installed, commissioned, operated, maintained (including servicing, repairing and overhauling) and decommissioned in such manner as to control any risks from fire, explosion, electric shock or unintended movement of equipment. In particular all surface electrical installations must comply with the relevant parts of Australian Standard *3000 (SAA Wiring Rules)* and Australian Standard *3007 (Electrical installations--Surface mines and associated processing plant)*.

Information Note: For every electrical circuit there shall be provided effective means of automatically cutting off the supply of electricity from that circuit in the event of any electrical fault occurring in any part of that circuit.

Information Note: Every circuit shall be protected by an automatic circuit breaker controlling each pole and equipped with suitable overload protection or a fuse.

Information Note: Ensure that every circuit breaker or any fuse shall be adequate to make and break the maximum fault current that can occur from time to time at the point in the electrical system where the circuit breaker is installed.

Information Note: The electric power supply inside an underground mine shall be controlled by a main switch and fuse on each pole or a main circuit breaker capable of automatically cutting off the supply in the event of an overload. This equipment shall be located at the surface within 100 metres of the shaft mouth or mine entrance.

Information Note: At points where trailing cables are joined to main cables a fixed terminal box with switch capable of entirely cutting off the supply to the trailing cable shall be provided. The terminal box shall be provided with an interlock to prevent the cable from being connected or disconnected while the power is switched on.

Information Note: There shall be provided in relation to every flexible cable effective means of switching off the supply of electricity from the cable at the apparatus by which it is connected to a fixed cable.

Information Note: Electrical protection is provided to interrupt the supply of electricity:

- In the event of a short circuit between any active conductors
- In the event of a single fault to earth on:

  - Electrical equipment supplied at a voltage exceeding 110 volts; or
  - Mobile or portable apparatus supplied at a voltage exceeding 32 volts
- To any hand-held tool in the event of an earth fault that causes a current exceeding 30 milliamperes to flow.

Information Note: Final sub circuits for motors, lighting, heating, etc shall be protected from overload.

2.6 Management

A well designed and constructed power system will not provide a safe and reliable operation unless it is properly managed. An electrical power distribution system regardless of size and complexity will require time and attention from qualified electrical engineers.

The electrical protection of a coal operation power system must be managed in a manner which addresses the following issues:

- A philosophy of protection, including scope, limitations and assumptions
- Specific data available for all protective devices in use
- Nominated Supply Authority incoming fault level
- Procedures for corrective action if the Incoming Nominated Fault Level changes
- Control measures to ensure changes to the operations are managed
- Review process to verify levels of protection are being maintained
- Record operation of protective devices and keep those records
- Defect management – e.g. if a 30milliampere earth leakage device is not functioning the circuit shall be isolated until the defect is remedied
- Maintenance and injection testing of protection
- Changes to electrical protection can only be made after authority form a qualified electrical engineer

2.6.1 STRUCTURAL ELEMENTS FOR INCLUSION IN THE MANAGEMENT OF *SHORT CIRCUIT PROTECTION*

2.6.1.1 Fault study

When an electrical distribution system is being designed, a “fault current coordination study” shall be conducted and circuit protective devices shall be sized and set according to the results of the study.

Over time the electrical system configurations will change due to the changing needs of the coal operation. If the coordination and capabilities of the electrical equipment are not reviewed prior to the changes, faults could result in unnecessary tripping of a main breaker or, even worse, an explosion of equipment that is not rated for the new operating conditions. An equipment explosion could result from the interrupting capacity of the circuit breaker being exceeded.

The demand for electricity is steadily increasing. Consequently supply authorities are becoming increasingly capable of delivering much higher fault currents at the point of supply.

Therefore protective devices that were properly applied at the time they were installed may have become inadequate after system changes and the protective system may no longer be coordinated.

2.6.1.2 Single line diagram

An accurate single line diagram of an electrical power distribution system is an invaluable tool. The single line diagram using standard symbols indicates the course and component parts of an electric circuit or system of circuits. The single line diagram is a road map of the distribution system that traces the flow of power into and through the system.

Electrical protection schemes for all power systems are dependent on up to date, correct and unambiguous identification of all power circuits. It is essential that a completely reliable and accessible documentation of the power system be maintained.

Critical information should be placed on the drawing or be available through some system of cross reference. Nodes shall be identified on the drawing with data relating to fault levels at each node.

An up to date copy (or copies) of the Power System single line diagrams must be displayed in a prominent location. All text and symbols shall be clearly legible.

Single Line Diagrams shall include the following information:

- Isolation point
- Fault level at point of supply
- Cable sizes and types
- Location of distribution board(s)
- Identification of power, lighting and mixed circuits (description and cable number/circuit number)
- Circuit breaker type and rating
- Earth leakage devices
- Junction boxes (except in office areas etc. where building wire is used)

Single line diagrams shall be kept at the relevant distribution board, substation etc. Where distribution boards contain marking of circuits in any form other than the single line diagram those markings shall not conflict with information shown on the single line diagram.

All changes to the power system shall be noted on the affected Single Line Diagrams. Revisions to documents shall include the date the system was modified, a brief description of the modification, the person responsible for the revision and the approval of a qualified electrical engineer.

The qualified electrical engineer shall assess the implication of any change with respect to protection devices and settings. This may require a revision of the mine Power System Study before approval of the change is granted.

Changes of a regularly occurring nature such as cable lengths which vary as underground mining progresses need not be regarded as revisions to the above documents unless protection settings are required to be modified as a result of such changes.

Frequently the single line diagram, with all of the listed information, becomes too crowded for information to be used effectively in some of the operational activities. A set of drawings may be used and each of the set may be used for a specific activity such as:

- Switching functions
- Load flow controls
- Relay and relay logic data
- Impedance diagrams

Information Note: The "Single Line Diagram of the System" does not need to include final sub circuits of a Distribution Board provided that non of the final sub circuits enter a hazardous zone.

Information Note: The fault levels calculated at all nodes shall be displayed or cross referenced on the single line diagram.

Information Note: The fault levels for different scenarios shall be displayed on the single line diagram or cross referenced on the single line diagram.

Information Note: The protective devices need not be detailed on the single line diagram but they must be available from a cross reference on the single line diagram.

Information Note: The protective device which drives a circuit breaker need not have settings of that device detailed on the single line diagram but the device settings must be available from a cross reference on the single line diagram.

Information Note: A separate plan shall be kept showing the position, size, and duty of all permanent machinery and fixed cables at the mine.

Example specification for single line diagrams

The single line diagram(s) shall include:

- Incoming line(s) from the Local Supply Authority
- All circuits at voltages greater than 1kV
- All underground circuits at 415/433V
- All underground circuits at 120/125V which are not wholly contained within an enclosure
- 3-phase fault level at the supply point (isolator, receptacle, motor etc.) of each equipment item
- 3-phase fault level at the secondary side of all transformers
- Cable length in metres (where length may vary, the maximum length shall be shown)
- Cable size in square millimetres
- Cable type
- Circuit breaker and contactor type (manufacturer and model)
- Protection device type (manufacturer and model) except where incorporated in a circuit breaker

- Description of connected loads and kW rating (eg "25kW Winder"), plus manufacturer and model where relevant (eg "Joy 55/55-SC Shuttle Car")
- Earth fault restriction devices, type and value
- Transformer type, rating, ratio and impedance
- Fault limiting fuses and current rating

The system voltages shall be identified by different colours and a legend included on the drawing sheet. Preferred colours are as follows:

66kV	Magenta
11kV	Red
3.3kV	Violet
1kV	Blue
415V	Orange
240V	Cyan
125V	Pink

Up to date copies of the single line diagrams for all power circuits shall be kept and made readily available to electrical staff. All power and lighting circuits in the washery, substation buildings, offices, workshops and all surface facilities (including temporary structures) shall be documented.

2.6.1.3 Fault levels calculated at all nodes

Maximum prospective fault levels shall be calculated at every node. The installation of electrical equipment at all locations at a mine shall be performed in an engineering manner. Equipment which is not rated for the duty it is to perform shall not be used.

A specification for the supply or use of equipment shall be created prior to purchase or supply of that equipment. The nominated fault level at the site of the connection of any new installation will form part of the specification for supply of the new equipment. The nomination of fault levels is often a requirement of Australian and International Standards.

Information Note: The "Fault Level Protection Study "does not need to include final sub circuits of a Distribution Board provided that none of the final sub circuits enter a hazardous zone.

2.6.1.4 Protective devices nominated at all sites

Protective devices installed within the power distribution system shall be identified. This identification shall be sufficient for the end user to access data pertaining to the protective device for the safe and effective operation of the protective device.

2.6.1.5 Information for the operation of protective devices

The specifications, installation, commissioning, operation, setting and resetting, maintenance and decommissioning of all protective devices requires information from the manufacturer. This information shall be available at any time during the use of the protective device. Operational curves will be required during all reviews, incident investigations and power supply system modifications.

The qualified electrical engineer shall determine the settings of all protection devices.

2.6.1.6 Settings of all devices

Nominated settings of devices shall be available on all protective devices for:

- The setting of a replacement device in the event of a failure
- Review of the system protection
- During routine maintenance, confirmation that the device is set at the expected level and tampering has not occurred

2.6.1.7 Justification of all device settings

The fault study will identify maximum and minimum prospective fault levels. From this the settings for all protective devices within the power distribution system can be determined. These settings will be calculated using a series of “Assumptions” within a nominated “Scope” and with fixed “Limitations”. Justification shall be addressed as an issue in confirming that the system component settings will provide a safe electrical installation.

Examples of items requiring justification:

- For maximum prospective fault current, what is the setting value of the protective device? Setting a protective device at the maximum prospective fault current is NOT acceptable.
- What is the level of hazard created if an arcing fault occurs with a timed trip setting? This is of particular importance for equipment used in a hazardous zone as explosion protection properties are easily compromised in an arc fault situation.
- How is a trip setting selected for the detection of arcing faults?
- What “safety factor” is applied to settings?

Information Note: The structure of the Electrical Protection in relation to Speed, Selectivity, Levels of Redundancy, Sensitivity and Stability shall be defined.

- What levels of time grading are to be used
- How many levels of grading are used for each zone
- What percentage of calculated values are used as actual setting values
- Setting value < 50% of calculated value “Best Practice”
- 50% <Setting value < 66% of calculated values “Adequate”
- Setting value > 83% of calculated values “Inadequate”

Information Note: Ratio of prospective three phase short circuit fault level to the actual setting of the protective device, 2: 1, is “Best Practice”.

2.6.1.8 Limitations of cable lengths specified

The mining industry electrical distribution system is continuously moving and the types of machines and cables used are designed for ease of extension or retraction. In many instances the underground mining operations are moving away from the point of supply. Surface mining operations may have the point of supply relocated to follow the source of the major load. The point of supply will probably be the connection point from the Local Supply Authority.

Prior to each extension or retraction of the mine electrical distribution system the review of the electrical protection settings shall confirm that at the conclusion of the changes electrical engineering safety is maintained.

Limits shall be set for the maximum and minimum lengths and cross sectional area of cable to be installed and/or removed which will allow safety to be maintained without the modification of the setting of the protective devices.

Information Note: The various combinations of cable length and cross sectional area for DCB and machinery operation in the Hazardous zone shall be nominated. Effective control of the cross sectional area and length in each situation shall be implemented.

2.6.1.9 Protection curves for all devices

Performance curves for each protective device shall be an item to be retained as part of the manufacturer's information required for the safe operation of all devices.

Information Note: At a Distribution Board where final sub circuits are protected by a miniature circuit breaker supplying loads to other than a hazardous zone, each circuit breaker does not require a protection curve for that circuit but the circuit does require suitable protection that will detect a short circuit at the extremity of the circuit configuration.

Information Note: All protective devices which provide graded protection for a node shall have their curves plotted on a single graph to identify suitable grading at all levels of fault current at that node.

2.6.1.10 Equipment thermal curves

The Philosophy of electrical protection includes a requirement that, "No cable or apparatus shall deteriorate due to electrical heating from faults". Thermal curves (or other manufacturers data) for equipment shall be used in conjunction with protection curves to demonstrate that thermal damage will not occur.

Information Note: Equipment damage curves need not be produced for apparatus rated less than 10kW.

2.6.1.11 Coordination

There are two major objectives in protection relaying:

1. Firstly, a protective relay serves to provide equipment protection. That is, to locate and isolate the fault or electrical problem quickly in order to minimise damage.
2. Second, the protective device closest to the problem should operate first to clear the problem, and no other device should operate unless the closest one fails.

In order to achieve these objectives each relay must function as it was designed and the relays must function in conjunction with the other protective devices in the system. Having all the protective devices function as one overall protective system is called "Coordination".

It is important that coordination of protective devices is implemented within any constraints placed by this Technical Reference. If protection devices regularly trip in an uncoordinated manner it can lead to unsafe fault finding and of restoration of power practices.

Where good coordination can not be achieved the results and associated actions for restoring power must be included in any consultation with the workforce.

2.6.1.12 Auditing of device settings

Since there are frequent changes to the power distribution system due to movement of mining machinery such as continuous miners and longwalls, protection parameters need to be constantly reviewed to ensure the integrity of the system at all times.

Scheduled reviews and audits of the electrical protection system for device settings and device coordination shall be performed. Records of all audits of protection equipment shall be maintained.

Each record shall detail the item of equipment, referenced drawing or document, discrepancies between device attributes (e.g. settings, type) and documentation, date, name and signature of the person who carried out the audit and be reviewed by a qualified electrical engineer.

Discrepancies between protection devices, protection settings and associated drawings and documentation shall be rectified promptly.

Information Note: The current setting of circuit breakers shall be adjusted by an authorised person only.

2.6.1.13 Protection device design and manufacture standards

Electrical protective devices shall not be used unless they comply with the mine's standards of engineering practice. Australian and International standards relate to protection components such as CT's.

2.6.1.14 Allocation of responsibility for system

The system operational personnel managing mine electrical protection shall have Standards of Engineering Practice as a guidance structure for the safety of the electrical installation at the operation.

The overall responsibility for the standards and functionality of the system shall be allocated to a position within the management structure of the operation. That position should be an electrical engineer with qualifications in electrical engineering, suitable for registering by the Institution of Engineers Australia.

For an underground mine it is expected that the Manager of Electrical Engineering shall have overall responsibility.

Any changes to electrical protection settings must only be done after authorisation by a qualified electrical engineer.

2.6.1.15 Maintenance

Manufacturer's recommendations shall be considered in the creation of a maintenance scheme for the electrical protective devices at the operation.

2.6.1.16 Performance testing

Primary injection testing causing detection, actual tripping and removal of the circuit under test from the power system is the most positive test method for confirmation of functionality. This shall be carried out at the install/commission phase and at regular intervals thereafter.

Protection testing may be required after a major electrical fault or if there is reason to suspect the integrity of a protection device or its associated circuit breaker.

All electrical protection devices identified in the operation's Power System Study shall be tested at the completion of the overhaul of the equipment in which the protection device is fitted and before the equipment is returned to service or to store. Testing shall be by primary injection where possible or else by secondary injection. The results shall be recorded.

2.6.1.17 Particular issues with arcing faults

Again it is instructive to quote from the paper *"Electric Arcing Burn Hazards"* by Stokes and Sweeting[2].

> *"Typical (low-voltage) arc voltages of several hundreds of volts are involved, and these act to reduce the actual arcing current, sometimes to less than half the prospective value.*
>
> *In HV circuits, the arc restrikes rapidly and the current normally continues to flow until the protection operates. The actual fault current is also generally a close approximation of the prospective fault current, unless current limiting devices such as HV fuses are present…*
>
> *In low-voltage systems, with small creepage paths across the insulation between phases and earth, the insulation degraded by the arcing process has been observed to breakdown under normal voltage stress. In low-voltage circuits, these processes have been observed to produce repeated pulses of self- interrupted arcing followed by delayed flashovers."*

The above information is certainly instructive in determining the trip level setting of short circuit protection.

Stokes and Sweeting, in their conclusions in the paper identify potential issues with the selection of low-voltage protection devices. They state on page 140:

> *"Low-voltage system protection can be required to operate with repeated pulses of current, which are significantly smaller than the prospective fault current with considerable delays between the pulses… Digital relays are available, which reset rapidly when the current returns below the reset level. These relays can completely miss faults of the kind described above, unless an individual episode of arcing lasts long enough to cause a trip. Special care, is therefore, required in selecting digital relays with algorithms that can tolerate this form of fault current for low-voltage systems… Mechanical disc relays can wind back during the current pauses and fail to trip when the effective integral of the fault current duration should have resulted in a trip… Fuses have not yet been tested with this form of current, but the authors anticipate the melting times of HRC fuse elements will not be increased to the same extent as relays. On low-voltage systems, the fuse arc in series with the fault arc should decrease the time between fusing and clearing. It is not anticipated HV fuses will see this form of pulsating current."*

[2] Stokes, DA., Sweeting, DK. *"Electric Arcing Burn Hazards",* IEEE Transactions on Industry Applications, page 139, Vol. 42, No.1, January/February 2006

2.7 Structural elements for inclusion in the management of *earth leakage, earth continuity, and earth fault lockout protection* of an electrical installation

Information Note: Electrical apparatus must comply with *Australian Standard 2081 (Electrical equipment for coal and shale mines--Electrical protection devices)* when used for the purpose of providing electrical protection for earth leakage, earth continuity or earth fault lockout underground at the mine.

Information Note: Earth continuity protection. The prime role of earth continuity protection is to detect ineffective earthing and remove the power from the affected circuit. Supplementary roles include automatic removal of power when plugs are inadvertently removed whilst energised, and machine control. The standard related to this type of protection is AS/NZS 2081.2:2002 *"Electrical equipment for coal and shale mines—Electrical protection devices Part 2: Earth-continuity monitoring devices".* AS/NZS 2081.2 refers to criteria in Australian Standard AS 3007.2—2004 clause 3.2.3[3] for "prospective touch voltage/operating time characteristics", these characteristics then impose limits on the time taken to detect and clear earth faults.

It is important to realise that if earth continuity protection has an in-built delay in tripping when an ineffective earth is detected, the potential for excessive touch voltages for an unacceptable length of time can increase significantly. *Note: The standard permits a deliberately introduced delay of up to 500 milliseconds. For a 5 ampere earth fault limited system; if such a value was selected the maximum prospective touch voltage that is allowed is 90 volts rms, which in turn requires the pilot-earth loop drop out resistance to be set well below 45 ohms as specified in the standard.*

Information Note: Earth leakage protection. This detects excessive leakage current to earth and automatically disconnects the power when excessive current flows. The standard related to this type of protection is AS/NZS 2081.3:2002 *"Electrical equipment for coal and shale mines—Electrical protection devices Part 3: Earth-leakage protection systems for use on earth-fault current limited systems (IT systems)".* These devices often have the ability to adjust the trip times and it is possible to set the trip times to a level that allows unacceptable prospective touch voltage/operating time characteristics even with compliant earth continuity protection. Leakage trip currents must have a maximum setting of 10% of the rms value of earth fault limitation, for example with 5 ampere earth fault limitation the maximum earth leakage trip value should be 500millamperes.

2.7.1 PROTECTIVE DEVICES NOMINATED AT ALL SITES

Protective devices installed within the power distribution system shall be identified. This identification shall be sufficient for the end user to access data pertaining to the protective device for the safe and effective operation of the protective device.

Some earth leakage protection devices are only suitable for use on IT systems. The type of system needs to be clearly identified. AS/NZS 4871 also nominates types of devices to be installed.

[3] Australian Standard AS 3007.2—2004 Electrical installations—Surface mines and associated processing plant Part 2: General protection requirements.

Australian Standard AS/NZS 2081 sets out minimum performance standards for Earth Leakage protection devices used on IT systems

Other Australian and International Standards sets out minimum performance standards for RCD's

Information Note Earth Leakage Protection: Except on circuits approved as being intrinsically safe, a system of automatic earth leakage protection shall be provided on all circuits.

Information Note Earth Leakage Protection: All portable or mobile face machinery operating at a voltage above extra low shall be protected by automatic leakage protection.

Information Note Earth Continuity Protection: Mobile apparatus or portable apparatus which is explosion-protected and is supplied with electricity through flexible cables shall be protected to ensure that the apparatus is effectively earthed and that the connection thereto remains unbroken.

Information Note Earth Continuity Protection: Mobile or portable apparatus supplied through trailing cables and restrained types of plugs and sockets shall be protected to ensure that the apparatus is effectively earthed and that the connection thereto remains unbroken.

Information Note Earth Continuity Protection: Mobile electrical equipment that is supplied with electricity through flexible cables must be protected to ensure that the equipment is effectively earthed and that the connection to earth remains unbroken.

Information Note Earth Continuity Protection: On circuits controlling portable and mobile equipment and with currents exceeding normal loadings of twenty-five amperes there shall be provided as far as is reasonably practicable, automatic prevention of the re-closure of any switchgear against a fault.

Information Note Earth Continuity Protection: All portable or mobile face machinery operating at a voltage above extra low shall be protected by automatic earth continuity equipment capable of cutting off the voltage in the event of a break in the earth conductor of any flexible cable between the gate end junction box connected to the fixed cables and the mobile or portable machine.

Information Note Earth Fault Lock-out Protection: Electrical protection shall be provided to prevent the establishment of electric supply to mobile or portable apparatus which has been approved as explosion protected in the event of there being an earth fault on the apparatus or any flexible cable associated therewith.

Information Note Earth Fault Lock-out Protection: Electrical protection shall be provided to prevent the establishment of electric supply to mobile or portable apparatus in the event of there being an earth fault on the apparatus or any flexible cable associated therewith.

Information Note Earth Fault Lock-out Protection: Electrical protection must be provided to prevent the establishment of electric supply to explosion protected mobile or portable electrical apparatus in the event of an earth fault on the flexible cable supplying the apparatus.

2.7.2 INFORMATION FOR THE OPERATION OF PROTECTIVE DEVICES

The specifications, installation, commissioning, operation, setting and resetting, maintenance and decommissioning of all protective devices requires information from the manufacturer. This information shall be available at any time during the use of the protective device. Operational curves will be required during all reviews, incident investigations and power supply system modifications.

2.7.3 SETTINGS OF ALL DEVICES

Nominated settings of devices shall be available on all protective devices for:

- The setting of a replacement device in the event of a failure
- Review of the system protection
- During routine maintenance, confirmation that the device is set at the expected level and tampering has not occurred.

Information Note: See and clear earth leakage faults on all power circuits.

Information Note: See and clear earth leakage faults on all non-intrinsically safe circuits in hazardous zones.

Information Note: See and clear earth leakage fault currents above 30miliamperes on circuits that supply mobile or transportable appliances (e.g. transportable pumps) and where earth continuity protection is not provided or where earth continuity protection is provided and maximum prospective touch voltages can be above those prescribed in AS 3007.2.

Information Note: See and clear earth leakage fault currents above 30milliampere on 240v GPO's.

Information Note: On control circuits to field devices where the operating voltage is above ELV, see and clear earth leakage faults above 30milliamperes.

Information Note: On any system in which the earth fault current is restricted the minimum tripping ratio of 10:1 e.g. if the earth fault current is limited to 5 amperes the maximum earth leakage current trip setting is 500milliamperes.

Information Note: Hazardous zone circuits not to have intentional delay introduced.

Information Note: Best practice leakage levels in hazardous zones 30milliamperes.

Information Note: No additional time delay on Main Earth Leakage unit is "Best Practice"

Information Note: In high capacitance or HV circuits or cases of selective operation on distribution systems in non-hazardous areas, the total delay time shall not exceed 3 seconds and grading between circuit breakers shall not exceed 400milliseconds

Information Note: Electrical protection is provided to interrupt the supply of electricity in the event of a single fault to earth on mains-fed equipment operating at or above 110 volts, or to any hand-held tool in the event of an earth fault that causes a current exceeding 30 milliamperes to flow, or in the event of earth leakage currents flowing above levels determined by the mine electrical engineer or plant manager.

2.7.4 JUSTIFICATION OF ALL DEVICE SETTINGS

The protection study will identify settings for all protective devices within the power distribution system. These settings will be calculated using a series of "Assumptions" within a nominated "Scope" and with fixed "Limitations". Justification shall be addressed as an issue in confirming that the system component settings will provide a safe electrical installation. This will be particularly important in hazardous areas and where restrained plugs and receptacles are used. Calculations of maximum prospective touch voltages and allowable clearance times will need to be made, taking into consideration:

- Magnitude and type of earth fault limitation
- Pilot earth loop resistance
- Earth continuity drop out resistance
- Earth continuity time delay
- Earth leakage protection delay

2.7.5 COORDINATION

There are two major objectives in protection relaying:

1. Firstly, a protective relay serves to provide equipment protection. That is to locate and isolate the fault or electrical problem quickly in order to minimise damage.
2. Second, the protective device closest to the problem should operate first to clear the problem and no other device should operate unless the closest one fails.

In order to achieve these objectives each relay must function as it was designed and the relays must function in conjunction with the other protective devices in the system. Having all the protective devices function as one overall protective system is called "Coordination".

It is important that coordination of protective devices is implemented within any constraints placed by this Technical Reference. If protection devices regularly trip in an uncoordinated manner it can lead to unsafe fault finding and of restoration of power practices.

Where good coordination can not be achieved the results and associated actions for restoring power must be included in any consultation with the workforce.

2.7.6 AUDITING OF DEVICE SETTINGS

Scheduled reviews and audits of the electrical protection system settings and coordination shall be performed.

Records of all audits of protection equipment shall be maintained.
Each record shall detail the item of equipment, referenced drawing or document, discrepancies between device attributes (e.g. settings, type) and documentation, date, name and signature of the person who carried out the audit, and be reviewed by a qualified electrical engineer.

Discrepancies between protection devices, protection settings and associated drawings and documentation shall be rectified promptly.

Note: Some earth leakage devices can be operated in fail safe or non fail safe modes. Unless it can be demonstrated by a credible risk assessment that the device should not be operated in fail safe mode then audits shall address this particular issue.

2.7.7 DEVICE DESIGN AND MANUFACTURE STANDARDS

Electrical protective devices shall not be used unless there is compliance with an engineering design standard.

When used on A.C. power having an earth fault limitation system (IT system), Australian Standard AS/NZS 2081 sets out minimum performance standards for:

- Earth Leakage protection
- Lockout earth fault protection
- Earth continuity protection

Other Australian and International standards relate to protection components such as RCD's and CT's.

2.7.8 ALLOCATION OF RESPONSIBILITY FOR SYSTEM

The system operational personnel managing mine electrical protection shall have Standards of Engineering Practice as a guidance structure for the safety of the electrical installation at the operation.

The overall responsibility for the standards and functionality of the system shall be allocated to a position within the management structure of the operation. That position should be an electrical engineer with qualifications in electrical engineering suitable for registering by the Institution of Engineers Australia.

For an underground operation it is expected that the Manager of Electrical Engineering shall have overall responsibility.

2.7.9 MAINTENANCE

Manufacturer's recommendations shall be considered in the creation of a maintenance scheme for the electrical protective devices operating at the operation.

Information note: The maintenance scheme shall include an earth leakage testing system.

2.7.10 PERFORMANCE TESTING

Primary injection testing causing detection, actual tripping and removal of the circuit under test from the power system is the most positive test method for confirmation of functionality. This shall be carried out at the install/commission phase and at regular intervals thereafter.

For earth leakage devices used at surface operations refer to AS/NZS 3760 and AS/NZS 3012 for advice.

Earth leakage devices used for underground purposes shall be regularly tested using the test facilities provided.

On overhaul of DCB's and transformer sub stations used to supply hazardous zone equipment, testing of earth leakage, earth continuity, earth fault lockout and earth fault limiters shall be conducted to establish conformance to AS 2081.

Protection testing may be required after a major electrical fault or if there is reason to suspect the integrity of a protection device or its associated circuit breaker.

All electrical protection devices identified in the operation's Power System Study shall be tested at the completion of the overhaul of the equipment in which the protection device is fitted and before the equipment is returned to service or to store. Testing shall be by primary injection where possible or else by secondary injection. The results shall be recorded.

2.8 Specific issues in relation to protection tripping

There have been two incidents in Hunter Valley operations where shunt trip systems failed to trip off circuit breakers with significant resultant damage and increase in the risk of death or injury. Single shunt trip systems should not be the only method of automatically tripping circuit breakers in the event of a fault. Shunt trip systems need to be well engineered and their operating parameters clearly specified. Those parameters should be continuously monitored and if the operating parameters deviate outside the specification then the circuit breakers relying on that shunt trip system should automatically open. It is not acceptable to rely on an alarm only to identify that a shunt trip system is not functioning.

Information Note: Shunt tripping functions which operate protection systems shall be routinely assessed for correct functionality.

Information Note: Shunt trip systems are a safety critical system and shall be maintained accordingly.

Information Note: The capacity of a battery tripping supply shall be routinely assessed under load conditions for correct functionality.

Information Note: Battery tripping supplies shall be continuously monitored for:

- Rate of charge
- State of charge
- Electrolyte level

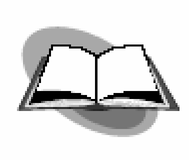
Information Note: The level of redundancy of a shunt tripping system shall be allocated consistent with the criticality of the protection tripping requirement.

Information Note: Trip systems to have a low probability of failure on demand (PDF<10^{-5}) or not rely solely on shunt trip circuits (shunt trip + undervoltage release).

Information Note: A faulty shunt trip coil on a circuit breaker shall not prevent a tripping function occurring at other protective devices which are connected to a common battery supply.

NSW DEPARTMENT OF PRIMARY INDUSTRIES

Chapter 3 Electrical Earthing



Clause 19(1)(i)

Requires effective earthing to be provided so that the risk from touch, transfer and step potential is minimised, lightning effects are not transmitted into an underground mine and that earth fault current s limited on certain circuits.

- Refer to AS/NZS 2081 for recommended levels of earth fault limitation
- Refer to the requirements of AS/NZS 3000 and AS/NZ S3007

Note:

- Earth grid is the term used in this document but grounding system grid, earth grid, and grounding grid all have a common meaning.

3.1 Introduction – Earthing and Lightning Protection

3.1.1 EARTHING

Earthing of electrical installations has two basic requirements:

- To provide a sufficiently secure low impedance path to allow circuit protection to operate when required to clear faults resulting from an insulation failure to earth
- To limit touch voltages, transfer potentials and step voltages to a level that is not dangerous

AS 3007 defines the touch voltages that are permitted and conductor sizes that are required for both protective conductors and earthing conductors. Earthing system design and installation is however not dealt with in AS 3007.

Details and methods of installation earthing with reference to touch and step voltages is given in:

- Substation earthing guide - 1995, Electricity Supply Association Australia
- Electricity Council of New South Wales publication EC5 Guide to Protective Earthing
- Institute of Electrical and Electronic Engineers (USA) Standard 80 Guide to Safety in Substation Grounding.

Electrical systems are defined by the method of referencing to ground.

There are a number of accepted methods used across the world. The most common are defined in AS 3007.

For underground mines the IT system must be used for all power distribution underground at the mine.

Information note: Electrical systems used to supply mobile apparatus on the surface at a voltage exceeding 110 volts shall be such that the current from a single fault to earth can not exceed 5 amperes where the nominal voltage exceeds 4000 volts or 50 amperes where the nominal voltage exceeds 4000 volts. On any such system the maximum touch voltage allowed is 60 volts.

Information note: Electrical systems used underground at the mine shall be such that the current from a single fault to earth can not exceed 5 amperes where the nominal voltage exceeds 4000 volts or 50 amperes where the nominal voltage exceeds 4000 volts. On any such system the maximum touch voltage allowed is 60 volts. This does not apply to lighting or control circuit underground with a rating of 1 KVA and a voltage not exceeding 250 volts and having suitable short circuit protection, or a circuit that is confined wholly within a single enclosure. **Note:** RCD's should be used as well as suitable short circuit protection. **Note:** Control circuits with field devices should be operated at ELV

Information note: An electrical system that is not intrinsically safe and has a voltage exceeding 32 volts a.c. and is used underground or is used to supply mobile apparatus on the surface at a voltage exceeding 110 volts a.c. is such that the current from a single fault to earth cannot exceed 5 amperes where the nominal voltage does not exceed 4 000 volts or 50 amperes where the nominal voltage exceeds 4 000 volts.

Information Note: Any mobile apparatus fed via flexible cables is referenced to earth by way of some form of earth fault current limiting device.

Information Note: All mains-fed electrical equipment is referenced to and all conductive parts of that equipment (other than active conductors) is connected to the general mass of earth in such a way that:

- The values of voltage and current and their duration are not dangerous
- The thermal effects of currents flowing in conductive parts do not cause danger arising from fires, fumes, arcing, explosions or the unintended operation of the equipment.

In particular for all mains-fed electrical equipment underground:

- Any reference to earth is by way of some form of earth fault current limiting device
- If the operating voltage of the equipment is less than 4 000 volts, the earth fault current is limited to 5 amperes

This does not apply to or in respect of:

- Electrical systems and apparatus approved as intrinsically safe
- Electrical circuits operating at extra low voltage
- A circuit that is confined wholly in a single enclosure
- The outgoing circuit of a welding machine

For mining surface installations the IT system must be used for all HV distribution. It may also be desirable for 3 phase LV installations.

In general for surface LV installations this should be a TN-S system.

ALL surface electrical installations must comply with AS/NZS 3000 and AS 3007.

3.1.2 LIGHTNING PROTECTION

Lightning protection is an integral part of earthing as the effects of lightning need to be discharged safely to the general mass of earth. AS/NZS 1768 Lightning Protection deals with protection of structures generally as well as critical structures such as fuel storage and explosives magazines, electrical and communications circuits — together with requirements for protection of surface and underground operations. AS/NZS 1768 should be used to determine adequate protection.

Lightning protection and earthing for the purpose of discharging lightning safely to earth should be arranged to prevent the effects of lightning from being transferred into underground workings. Additional provisions to AS/NZS 1768 may be required for underground mines such as separation of mine electrical earths from lightning earths, earthing of metallic structures that are partly on the surface and partly underground (e.g. conveyors, compressed air pipes), the placement of surge diverters at the point of incoming supply to the mine sub station and the correct connection of surge diverters to earth. Communication circuits that are used underground may need some form of lightning protection.

Special care needs to be taken where gas drainage pipes, borehole pumps and the like are located on the surface above goaf areas. A detailed analysis of the potential to transfer the effects of lightning underground must be undertaken.

Information Note - Lightning: In order to safeguard against danger arising from the effects of atmospheric electricity the electrical installations must be protected in accordance with AS/NZS 1768. In addition to minimise the risk of transferring the effects of atmospheric electricity to the underground workings, earth electrodes provided for the purposes of this clause must be separated from the mine earth electrodes and such separation in air shall be at least 3 metres and in the ground must be at least 15 metres.

Information Note - Lightning: Adequate precautions are taken to prevent dangers arising from the effects of lightning. In particular adequate precautions must be taken to prevent the effects of lightning being transferred into an underground mine.

Information Note - Lightning: In order to safeguard against danger arising from the effects of atmospheric electricity the following minimum degree of protection shall be provided at the mine surface:

- A suitable surge diverter between each phase and earth at the receiving end of every overhead line supplying the mine. The resistance of this earth termination shall be no greater than 10 ohms.
- For any building or other structure that is not steel framed and is over 10 metres in height, one or more lightning conductors as may be necessary for compliance with AS/NZS 1768. The resistance of this earth termination shall be no greater than 10 ohms.
- For underground mines, by earthing all metal work entering the mine except metal whose function is to conduct electricity.
- The above earthing arrangements must be kept entirely separate from each other and from the mine earth. The distance from the mine earth must be at least 3 metres in air and 15 metres in the ground.

Note: The enclosure of a transformer on the surface of a mine that is connected to an overhead power line may be connected to the electrodes of the surge diverters of the overhead power line and not to the mine earth.

Earthing and lightning protection is a specialised field and many electrical engineering consultants provide an earthing design and testing service and they are a useful resource in designing new earthing systems and testing existing earthing systems to ensure dangerous touch, step and transfer potentials are not possible.

3.2 Earth Grid

The actual connection to the general mass of the earth is one of the most important parts of the whole earthing system. The connection to earth or the electrode system shall have a sufficiently low resistance to help permit prompt operation of the circuit protective devices in the event of a ground fault, to provide the required safety from shock to personnel who may be in the vicinity of equipment frames, enclosures, conductors, or the electrodes themselves, and to limit transient overvoltages.

The design of earth grids is complex with many variables to be considered to derive an optimum configuration. All earthing grid systems should have an engineering design specification, installation procedures, testing and commissioning results tabulated, and a life cycle plan for the continued safe use of the electrical apparatus connected to the grid.

Information note: Equipment that forms part of an electrical earthing system is to be constructed, used and maintained in accordance with the relevant parts of AS 3007.

Information note: The earth connection resistance of any earth electrode or combination of earth electrodes provided is such that the electrode or electrodes shall not transfer a potential exceeding 50 volts to any earthing system nor have a step potential gradient exceeding 100 volts per metre.

3.2.1 EARTHING FOR UNDERGROUND MINES

For underground mines the IT system must be used for all power distribution underground at the mine. This means that at the mine surface there must be a “mine sub-station” that electrically isolates the local supply authority and the mine infrastructure. In this “mine sub-station” appropriate transformers and switchgear are provided and appropriate earthing is provided. An impedance is connected between the neutral point of the transformer(s) that supply the underground workings and a earthing grid called the “mine earth”.

The recommended impedance is resistive. The reasons for limiting the current by resistance earthing may be one or more of the following:

- Reduce the burning and melting effects in faulted equipment, such as switchgear, transformers, cables, and rotating machines
- Reduce the mechanical stresses in circuits and apparatus carrying fault currents
- Reduce the electric shock hazards to personnel caused by stray ground fault currents in the return path
- Reduce the arc blast or flash hazard to personnel who may have accidentally caused or who happen to be in close proximity to the ground fault
- Reduce the momentary line voltage dip occasioned by the occurrence and clearing of a ground fault
- Secure control of transient over-voltages

To prevent unwanted effects from being transferred from the local supply authority network into the mine the substation contains two separate earthing grids, maintained some distance apart with no electrical connection between the two.

The earthing grid beneath the sub-station is called the “system earthing grid”. A minimum of 15 metres in the ground and 3 metres in the air between the “system earthing grid” and the “mine earth” has been prescribed in the past. Separation between the “system earthing grid” and the “mine earth” is needed to isolate high “system grid” voltage rise, from the “mine earth". These distances related to separation of earthing used for discharging the effects of lightning to earth – normally the distance was meant to be between the system earthing grid and the mine earth. In some locations in NSW the 15 meter distance may be inadequate.

Substation surge arresters, fencing and surface equipment frames are tied to the "system earthing grid".

The secondary neutrals of the power supplies are tied to the "mine earth" through neutral earthing resistors.

Each AC equipment frame in the mine distribution system is connected via earth conductors to the "mine earth".

The "system earthing grid" is intended to handle lightning, other transformer primary surge conditions and primary supply line to ground faults.

The "mine earth" is maintaining equipment frames at or near earth potential and a low grid resistance is important so dangerous potentials are not developed on underground machine frames.

3.2.2 CONCEPTS ASSOCIATED WITH THE "MINE EARTH"

The correct operation of the "mine earth" relies on:

- The earth cannot be used as an earthing conductor
- The "mine earth grid" serving underground equipment is kept isolated
- Power supply to the underground distribution network is fed from a separate transformer secondary winding
- Ground fault protection is provided on each outgoing circuit from the substation

3.2.3 SYSTEM EARTHING GRID

As this grid will be the responsibility of the mine to maintain the mine will need knowledge of:

- Soil resistivity
- Earth grid potential rise (EPR). This is calculated as the product of the grid impedance and the portion of the ultimate earth fault current that flows though the grid impedance
  - o The maximum voltage rise on an installation is used when specifying isolation requirements for communication circuits or other services entering a substation
  - o EPR may also be used as an initial conservative estimate of step and touch voltages
- Step and touch potential
  - o Steeply rising voltage gradients may appear around discrete earth grid electrodes during fault conditions. Persons working in or around a substation will be exposed to a dangerous electric shock hazard for the duration of this fault
  - o The specifications of the engineering design of the earth grid may nominate a "maximum excursion voltage" for the grid during fault situations but it is unreasonable to set this value to prevent dangerous step and touch potentials

    - Tolerable levels of surface voltage gradients can be designed into the grid by using a mesh arrangement beyond the grid

- Coarse crushed rock is normally spread all over the surface of the soil within the substation grid area to provide a high resistance surface treatment to reduce the hazard from step potential to persons within this area during a severe fault
- Compliance with AS 3007.2—2004 is a requirement
- Transfer potential
    - A transfer potential problem generally occurs when a person standing at a remote location touches a conductor connected directly or indirectly through the earth to the substation earth grid
    - A transfer potential danger can occur from any metallic structure such as a fence, pipeline, underground power cable, overhead earth wire, railway line or conveyor.
- Connections
    - The earthing resistance of an electrode is made up of:
        - Resistance of the electrode
        - Contact resistance between the electrode and the soil
        - Resistance of the soil
    - The first two resistances can be made small with respect to the third and can be virtually neglected
- The connection of earthing conductors to above ground equipment must meet the criteria for conductivity, thermal capacity, mechanical robustness and long term reliability. The joints are usually the most vulnerable point in the earthing system, and must continue to withstand the electrical, thermal and mechanical stresses even in a corrosive environment

3.2.4 MAINTENANCE AND TESTING

The response of an earthing system will progressively degrade as the installation starts to deteriorate because of metal fatigue, corrosion, vandalism or inadvertent breakage due to diggings. It is not reasonable to assume that an earthing system will maintain its initial performance level indefinitely.

The frequency of periodic integrity checks will be determined by vulnerability and environmental conditions. The frequency of inspections could vary from annually to 5 yearly.

The types of inspections will be:

- Physical inspection
- Electrical performance testing
- Transfer potential hazard check
- Grid continuity check

- Test results from initial commissioning and periodic testing shall be retained to determine whether the resistance of the grid is remaining constant or increasing
- An assessment of the periodic test result trends shall determine when corrective action is required to maintain all earth grids in a safe operational state

Note: In the event that some means of disconnecting the "system ground" connection is required for measurement, testing, or repair, a disconnecting link should be used and only opened when the system is de-energised.

The primary purpose of neutral disconnecting devices in impedance grounded systems is to isolate a power source neutral from the neutral bus when the power source is taken out of service because the neutral bus is energised when a ground fault occurs. A transformer disconnected from the power bus but with an unbroken connection of its neutral to the neutral bus would have all of its terminals elevated with respect to ground during a ground fault. Disconnection of the "system earthing" connection shall be an issue addressed in Isolation Procedures of the Electrical Engineering Management Plan.

3.2.5 EQUIPMENT EARTHING

The term equipment earthing refers to the interconnection and earthing of the non electrical metallic elements of a system. Examples of components of the equipment earthing system are metallic conduit, motor frames, equipment frames, equipment enclosures and an earthing conductor.

The basic objectives of an equipment earthing system are the following:

- To reduce electric shock hazard to personnel
- To provide adequate current carrying capabilities both in magnitude and duration to accept the ground fault current permitted to flow without creating a fire or explosion hazard
- To provide a low impedance return path for ground fault current necessary for the timely operation of the protection system

Information Note Overhead earth wires: All overhead power lines operating at a voltage above 11,000 volts shall have an overhead earth wire installed over the powerlines total length to provide lightning protection.

Information Note Conductivity of conductors: Earthing conductors shall have a conductivity throughout of not less than one-half that of the largest current carrying conductor which it protects except where the current carrying conductor exceeds 70 square mm in and it supplies mobile equipment below 1200volts or fixed equipment at any voltage, then the earth conductivity need not be more than one third of the largest current carrying conductor. A metallic covering of any cable may be used as an earthing conductor.

Information Note Conductivity of conductors: Every earthing conductor installed for the purposes of immediate electrical discharge without danger shall have conductivity throughout of not less than one half that of the largest current carrying conductor which it is required to protect.

Information Note Equipotential Bonding: All metallic sheaths, coverings, handles, joint boxes, switch gear frames, instrument covers, switch and fuse covers, and boxes and all lamp holders unless efficiently protected by an insulating covering made of fire resisting material, and the frames and bed plates of generators, transformers and motors, including portable or mobile motors shall be protected to guard against dangers of shock or undue rise of potential by being efficiently connected to an effective earthing system at the surface of the mine, or by being protected in such a manner as will ensure at all times the isolation of any defective portion of any installation through the operation of a circuit breaker or cut out.

Information Note Equipotential Bonding: Refer to AS/NZS 2081 for earth fault limitation levels.

Every conductive part of the enclosure of mains-fed electrical apparatus and every conductive part of the physical protection of any cable supplying mains-fed apparatus and any conductive handle for the operation of mains-fed electrical apparatus shall be connected to earth at the surface of the mine in such a manner as to ensure immediate electrical discharge without danger.

Information Note - Equipotential Bonding: A bolted flange type fitting used to couple together items of electrical apparatus shall not form part of the earthing system unless it is bridged by a separate earth bond.

Information Note: No person shall place any circuit opening device in any earthing conductor other than a bolted link.

Information Note: Many equipment standards have particular requirements for earth conductors and bonding.

Information Note - Earth fault limitation: Earth fault limitation is used to reduce the magnitude of touch voltages and to limit the amount of energy that can be released under the most common electrical fault, which is an earth fault. It also needs to be recognised that mining electrical equipment, in particular cables, are designed so that the most likely fault is a low energy earth fault and not a high energy short circuit fault.

Note: Earth connections in some equipment may only be rated for low values of current and sufficient mechanical integrity; they have been known to fail under conditions where two phases to earth faults have occurred.

There are two main types of earth fault limiters: purely resistive and those termed reactors (which have significant inductance). Earth fault limiters should be constructed in accordance with AS/NZS 2081.5: 2002 *“Electrical equipment for coal and shale mines—Electrical protection devices Part 5: Earth-fault current limiters”*

Where earth fault limiters are iron cored reactors the initial earth fault current can be many times more than the steady state value (analogous to switching in a transformer on no load). It is common knowledge that past tests have revealed that the earth fault inrush current can be 10 – 12 times higher than the steady state value when iron cored reactors are used for earth fault limitation. Therefore with high inrush currents initial touch voltages and arc energy can exceed the steady state values by a significant amount. The touch voltage and arc energy diminish to the steady state value over a period of time (testing has shown that this time can be significant when considering touch voltages and clearance times - up to 300 milliseconds (15 cycles)).

To limit the touch voltage, Clause 2.8, AS/NZS 2081.5: 2002 states:

“The power factor of the earth-fault current limiting impedance, assuming zero cable capacitance, shall be not less than 0.65 lagging.”

Calculations show that with a 5 ampere earth fault limiter with a power factor of 0.65 lagging used on a 1000 volt system the peak inrush current will be less than 11 amperes. Cable and fault resistance will reduce this value further. Older earth fault current limiting impedances with power factors lower than 0.65 lagging have a resistance component that is reduced relative to the inductive reactance and the peak inrush currents increases. When a resistor is used as the earth fault current limiter the inrush current is limited to the steady state value, in this case 5 amperes rms (a peak current of 7 amperes).

Information Note: Refer to AS/NZS 2081 for earth fault limitation levels

Chapter 4 Feedback Form

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