Eskom	Standard	Asset Management

Title:	**Earthing and Lightning Protection Standard**	Unique Identifier:	**240-56356396**
		Alternative Reference Number:	**474-085**
		Area of Applicability:	**Engineering**
		Documentation Type:	**Standard**
		Revision:	**2**
		Total Pages:	**64**
		Next Review Date:	**June 2027**
		Disclosure Classification:	**CONTROLLED DISCLOSURE**

APPROVED FOR AUTHORISATION
GENERATION ENGINEERING
DOCUMENT CENTRE ☎ X4962

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Date: 2022/05/27	Date: 2022/05/30	Date: 2022/05/30

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1. INTRODUCTION

The primary goal of earthing systems is to ensure personnel safety and prevent damage to installations. The secondary goal (in systems with sensitive equipment) is to serve as a common voltage reference and mitigate disturbances introduced by lightning activity, electrical short circuits, or plant and equipment's normal operation. The problems associated with earthing and lightning protection are complex. There will always be risks to plants and equipment associated with lightning activity, surges and noise imposed on the power and control systems, and therefore it is of utmost importance to put measures in place to take care of such problems to ensure that the plant is protected at all times.

2. SUPPORTING CLAUSES

2.1 SCOPE

This document defines the design, supply, installation, and testing requirements for Power station earthing and lightning protection, including design guidelines, application information and maintenance, and test plans, which shall apply to electrical and instrumentation systems.

2.1.1 Purpose

The purpose of the document is to specify the requirements for the earthing system and lightning protection.

2.1.2 Applicability

This document shall apply to Eskom Generation.

2.2 NORMATIVE/INFORMATIVE REFERENCES

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

2.2.1 Normative

REFERENCE	DESCRIPTION
0.54/393	EARTHING STANDARDS
240-170000153	Copper Conductors Used for Earthing in Substations
240-84854974	Continuity Measurement of Substation Earth Grid Systems
240-170000349	Copper-Clad Steel Conductors Used for Earthing
240-17000053	Exothermic Weld Connections for Substation Earthing
IEC 61662	Assessment of the risk of damage due to lightning (including amendments)
IEEE 665	IEEE Guide for Generating Station Grounding
IEEE 1050	IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations
NRS 042	Guide for the protection of electronic equipment against damaging transients

REFERENCE	DESCRIPTION
SANS 121	Hot-dip galvanized coatings on fabricated iron and steel articles – specifications and test methods
SANS 804	Unwrought tough pitch coppers: Electrolytic tough pitch high conductivity copper
SANS 1063	Earth rods, couplers and connections
SANS 1195	Busbars
SANS 1213	Mechanical cable glands
SANS 10142-1	The wiring of premises Part 1: Low-voltage installations
SANS 10313	Protection against lightning - Physical damage to structures and life hazard
SANS 10198-12	The selection, handling and installation of electric power cables of rating not exceeding 33 kV Part 12: Installation of earthing system
SANS 10199	The design and installation of earth electrodes
SANS 61000-4-2	Electromagnetic compatibility (EMC) Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test
SANS 61000-4-4	Electromagnetic compatibility (EMC) Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test
SANS 61000-4-5	Electromagnetic compatibility (EMC) Part 4-5: Testing and measurement techniques - Surge immunity test
SANS 61000-5-2	Electromagnetic compatibility (EMC) Part 5: Installation and mitigation guidelines Section 2: Earthing and cabling
SANS 62305-1	Protection of structures against lightning: Part 1: General principles
SANS 62305-2	Protection of structures against lightning: Part 2: Risk Management
SANS 62305-3	Protection of structures against lightning: Part 3: Physical damage to structures and life hazard
SANS 62305-4	Protection of structures against lightning: Part 1: Electrical and electronic systems within structures
SANS 62561-1-7	Lightning protection system components (LPSC) Part 1 – 7
SANS 61643-11	Low-voltage surge protective devices Part 11: Surge protective devices connected to low-voltage power systems - Requirements and test methods
SANS 61643-12	Low-voltage surge protective devices Part 12: Surge protective devices connected to low-voltage power distribution systems - Selection and application principles

2.3 DEFINITIONS

Definition	Description
Armoured Cable	Armoured cable is installed in locations exposed to mechanical damage, such as on the outsides of walls, as an alternative to a conduit. Armoured cable usually has a small metal ribbon to ensure electrical continuity of the safety ground. The armouring material can be Wire Braided Armour, Steel Wire Armour (SWA), Aluminium Wire Armour (AWA), or Steel Tape Armour.
Bonding	Bonding is referred to the connection of exposed conductive parts of apparatus together, systems and installations to ensure that they are at the same potential.
Continuity	The effect one gets when bonding is done between different earth mats or equipment to get a low resistive path between the areas.
Down conductor	A down conductor connects an air terminal to an earth terminal.
Earthing Contractor	An Earthing Contractor is a contractor (the Contractor in terms of the specific contract) appointed to install the earthing conductors on the cable racking and connection of electrical and mechanical equipment (provided by Others) to earth.
Earthing conductor	An Earthing conductor usually is a copper or aluminium conductor that connects the equipment and the earth mat.
Earth mat	Earth mat is used to bring the connection to the earth indoors. It connects through a conductor inserted within the ground port of an earthing strap. It limits the ground potential & protects against the fault current. Earth mats are used where the large fault current is to be experienced.
Earth spike	An earth spike is a conducting rod, usually copper, driven into the soil to get a conducting path for fault currents.
Electromagnetic compatibility	Installations with sensitive (to all types of electromagnetic interference) and interconnected electronic and electrical systems should exhibit electromagnetic compatibility (EMC).
Equipotential bonding	Equipotential bonding is the electrical connection putting various exposed conductive parts at an equal potential.
Indoor lightning protection	It includes the additional (to “outdoor lightning protection”) measures required, such as the shielding of buildings, cable ducts and outdoor cables, including cable laying, grounding of cable trays and cabinets etc. and the handling of cable screens and the reference conductor system.

Definition	Description
Main Station earth mat	The main station earth mat is the main portion of the station earth mat, formed by the Boiler and Turbine earth mat grid.
Outdoor lightning protection	Outdoor lightning protection covers the complete lightning conductor system and equipotential bonding measures for buildings, cable ducts and the entire plant site.
Reference point	A reference point is a specific node in the earthing system used to do measurements for that specific area.
Shielded	A shielded cable is an electrical cable of one or more insulated conductors enclosed by a common conductive layer. The shield may consist of braided strands of copper (or other metal), a non-braided spiral winding of copper tape, or a conducting polymer layer. Usually, this shield is covered with a jacket. The shield acts as a Faraday cage to reduce electrical noise from affecting the signals and reduce electromagnetic radiation that may interfere with other devices. The shield minimizes capacitively coupled noise from other electrical sources.
Step potential	The difference in surface potential experienced by a person bridging a distance of 1 m with his feet without contacting any other grounded object (IEEE Standard 80-1987),
Station earth mat	The station earth mat is formed by interconnecting all earth mats on the Power Station.
Touch voltage	Touch potential is generated when fault currents flow through an electrical system. Note that the touch potential is lower in the earthing system with lower resistance/impedance in the earthing system.
Trench earth	Trench earth is an electrode consisting of a length of bare conductor buried in the earth at a uniform depth.

2.3.1 Classification

a. **Controlled Disclosure:** Controlled Disclosure to External Parties (either enforced by law or discretionary).

2.4 ABBREVIATIONS

Abbreviation	Description
CT	Current Transformer
Cu	Copper
DC	Direct Current
DCS	Distributed Control System
EMC	Electromagnetic Compatibility
EP	Entry Point

Abbreviation	Description
HF	High Frequency
HV	High Voltage
I	Current
I/O	Input/ Output
IDMT	Inverse Definite Minimum Time
IN	Interference Current
L	Inductance
LAN	Local Area Network
LPZ	Lighting Protection Zone
LV	Low Voltage
NEC	Neutral Earthing Compensator
NER	Neutral Earthing Resistor
PLC	Programmable Logic Controller
PM	Preventative Maintenance
PVC	Polyvinyl Chloride
R	Resistance
RF	Radio Frequency
SPD	Surge Protection Device
V	Voltage
VN	Interference Voltage
VT	Voltage Transformer

2.5 ROLES AND RESPONSIBILITIES

Engineering practitioners responsible for designs must comply with the standard and incorporate the requirements within new projects and designs.

Electrical Maintenance needs to maintain the integrity of the earthing systems to meet the intent and requirements of the standard

2.6 PROCESS FOR MONITORING

N/A

2.7 RELATED/SUPPORTING DOCUMENTS

None

3. EARTHING AND LIGHTNING PROTECTION

An earthing or grounding system connects specific parts of the installations, such as the electrical apparatus, building structures, and equipment. Copper and steel bars are usually used to make up the design connected to form an earthing network.

The earthing system is usually installed at the initial stage of the plants' construction or when new plants are added to the existing infrastructures. The aim is for the safety of personnel, equipment and functionality of plants.

Earthing systems in power plants such as Power Stations perform the following essential functions:

- Protection of personnel from electric shock
- Protect equipment from excessive voltages
- Facilitate isolation of faulted systems
- Permit the dissipation of transient currents
- Provide a stable reference point for instrumentations and control circuit measurements

A lightning protection system includes a network of air terminals, bonding conductors, protection devices such as arrestors and ground electrodes designed to provide a low impedance path to the ground for potential strikes. Lightning protection systems prevent or lessen lightning strike damage to structures.

Travelling waves caused by lightning strikes are exceptionally steep fronted (i.e. the voltage rise occurs in nanoseconds). Hence, installing all earth conductors must avoid sharp bends or corners, as fault currents will otherwise not follow the metallic paths provided but will jump across insulation gaps and cause damage at undetermined points.

3.1 SOME OF THE CHALLENGES ASSOCIATED WITH EARTHING SYSTEMS AND LIGHTNING PROTECTION

It is challenging to implement (specify, design and build) an effective indoor and outdoor earthing and lightning protection system due to the complex nature of such a multiple unit power station construction, the lengthy period it takes to build, theft, and inadequate supervision. Therefore, many of the problems experienced during the power station's running are associated with the initial construction phase.

3.1.1 Copper Theft

Due to the high monetary value of copper (used as the main earthing material), theft will remain a reality for the power station's life both during construction and during its operating life. Therefore, alternatives for the initial construction and the replacement of stolen copper for earthing should be reconsidered. Where possible, painting copper metal using a different colour, such as black versus the traditional green or replacing copper with different materials such as silver, aluminium, zinc/brass, steel, etc., is recommended to mitigate against copper theft. That provides good electrical properties should be considered where high copper theft is prevalent.

3.1.2 Excavation Work

Excavation work is a problem that is associated with the construction phase when civil work is undertaken on and off the terrace. The problem associated with excavation work requires as-built drawings indicating pipes, cables, earth conductors, drainage, etc., and route markers. It is essential to have a site regulation in place that controls excavation work by providing information about the pipe, cable and earthing servitudes to the Contractor responsible for the work.

3.1.3 Corrosion

Particular attention should be given to the installation where corrosion of the copper conductors and cable racking in areas where chemicals are present, for example, at the water treatment plant, condensate polishing plant etc.

3.2 DESIGN CRITERIA, PRINCIPLES AND GUIDELINES

Earthing is the equipment connected to the ground of non-current carrying metal parts of an installation. The connections include earthing of metal conduits, metal cable racks, cable armouring, junction boxes, panels, motor frames, transformer tanks, switchgear enclosures, and metal enclosures for motor controllers, frames, metal enclosures for miscellaneous electrical equipment, electrically operated equipment, main support structures, reinforcing, roofs, metal wall cladding, gutters etc. The criteria are listed below:

a. The first objective of effective earthing is to limit the touch and step potentials on structures and equipment and provide a low impedance return path to limit the damage to equipment or danger to human life by fault currents during abnormal system conditions. The estimated maximum earth resistance for the complete earthing system is 10 milli-ohms. The stated value is based on historical results and adopted testing criteria during maintenance cycles and is often achievable due to the earthing conductors running short distances to the closest earth tail. The earth resistance value of 10milli-ohms should be maintained everywhere for all up to but not exceeding a maximum distance of 45m, as detailed in 240-84854974. Where the 10milli-ohms cannot be achieved, 240-84854974 and relevant SANS Standard can be considered as guideline.

b. The second objective is to protect the installation against lightning, surges, spikes and other induced interferences by conducting/directing the energy produced by such events away from the sensitive circuitry via a preferred path to earth.

c. Earthing of cubicles, distribution frames, control boxes, switches etc., for the control and electronic equipment is to be done as detailed in Appendix E. Earthing of a system is done via insulated earth conductors (cables) to one central point where connection to the main station earthing via cables is effected. The central earth point connection box has either a ‘G’ or ‘U’ shaped insulated copper bar.

3.2.1 Earthing and Lightning Protection Principles

a. The different types of interferences that the grounding/earthing mechanism is trying to alleviate that can be experienced by equipment are:

- Common impedance coupling,
- Capacitive coupling,
- Inductive coupling and
- Electromagnetic coupling (EMC).

b. The above must be considered when constructing an earthing network and designing the protection devices to cater to free interference on electronic devices.

c. Grounding aims to facilitate the interference-free operation of electronics by establishing equipotential areas on all structural levels. This method provides that building floors, equipment enclosures and circuit boards are constructed using local ground planes on each level. The ground planes can also be mesh structures.

d. The traditional grounding philosophy is based on the principles of electrical safety. This philosophy is good for maintaining personnel safety and limiting material damages due to electrical faults. However, for interference-free electronics, more profound actions are needed. Digital electronic equipment, whether for communication, computing or control of power semiconductors, consists of high-frequency equipment that is a potential source of high frequency (HF) power and susceptive to interference from other equipment. Therefore, proper HF-grounding methods are needed to maintain electromagnetic compatibility (EMC) and other relevant measures.

e. The best earthing and lightning protection results are achieved by establishing an effective equipotential earthing platform throughout the power station, allowing a well-structured and integrated earthing system. Station earthing is achieved by a subgrade earthing system comprising earth mats, earth spike electrodes, crows' foot earth points, and reinforced concrete foundations and structures. The system also includes the steel structure and roofing of the building, steel machinery, pipe work, cable tray, and ladder systems, all interconnected to form a plant-wide earthing network.

The electrical equipment is connected to the earth network through a short copper conductor or other earthing conductor material such as silver, aluminium, zinc/brass etc., welded or lugged to local steel frames and cables racking, the conductor size and length so arranged as to minimise the earth conductor impedance.

Subsection 3.2.2 discusses the interferences.

3.2.2 Types of Interference

3.2.2.1 Common Impedance Coupling

a. Common impedance coupling appears if interference sources have a common path of current. Usually, this impedance can be found in the grounding or power supply circuit. Current changes in the interfering circuit cause potential changes in the common impedances. The interference voltage is

$$V = RI - L\frac{di}{dt}$$

b. Coupling via the earthing can be reduced by:

- Using one-point grounding can prevent low-frequency coupling.
- It is essential to keep inductance as low as possible for high frequency. The relation between length and width should be less than five to achieve low impedance. In practice, this rule is implemented by multi-point grounding.

3.2.2.2 Capacitive Coupling

a. The capacitive disturbance is caused by a changing electric field that appears in circuits that have stray capacitance with each other. Interference current (I_N) is proportional to frequency (f), voltage level (V_1) of the interfering conductor and stray capacitance between conductors (C_{12}). The interference voltage is

$$V_N = j2\pi f V_1 C_{12} R$$

b. Capacitive coupling can be reduced by:

- Reducing stray capacitance between circuits.
- Reducing the impedance level of the victim circuit.
- Limiting the frequency level of the interfering circuit.
- Limiting the voltage level of the interfering circuit.

c. Stray capacitance can be reduced by:

- Using metal casings for devices.
- Using shielded conductors.
- Increasing distance between conductors.
- Using a ground plane between conductors.

3.2.2.3 Inductive Coupling

a. The inductive disturbance is coupled via a magnetic field. Current in the interfering circuit will generate magnetic flux around the conductor. When a changing magnetic flux cuts a closed-loop circuit, an alternating voltage will be induced to the victim circuit, and an interference current will flow in the closed loop. Interference voltage (V_N) is proportional to frequency (f), current (I_1) of the interfering conductor and mutual inductance of the circuits (M_{12}). Mutual inductance can be calculated by considering the area of the loop perpendicular to the magnetic lines (Acosθ) and the distance between the conductors (r). The interference voltage is

$$V_N = j2\pi f M_{12} I_1$$

where,

$M_{12} = \mu x A cos\theta / 2\pi r$ (Long, straight conductors)

b. Inductive coupling can be reduced by:

- Reducing mutual inductance between circuits,
- Filtering the high-frequency content of the interfering circuit and
- Reducing the current of the interfering circuit.

c. Mutual inductance can be reduced by:

- Using twisted pair signal cables,
- Increasing the distance between conductors,
- Reducing the loop area by galvanic isolation and
- Avoiding parallel conductors and coils.

d. Some extra suppression is achieved by shielding the victim conductor with a high permeability material. High permeability material "short-circuits" the magnetic circuits causing the most flux to flow through this material. This effect is known as the "Faraday Cage effect". Using a metal enclosure or shield reduces high-frequency disturbance. Highly conductive metals such as aluminium and copper are suitable to shield materials.

3.2.2.4 Electromagnetic Coupling

a. Electromagnetic energy can propagate in free space as a wave motion. Each conductor carrying a changing current is a potential transmitter antenna of electromagnetic waves.

b. Jointly, all conductors can operate as a receiver antenna. In addition, each conductor, whether part of the active circuit or not, will shape the fields and perhaps amplify the antenna operation. Sometimes a solid insulator may behave in the same way. The antenna efficiency will increase at a high frequency when the antenna dimensions exceed about 1/100 of the wavelength. Therefore, the problem worsens from 10 MHz onwards due to improved antenna function and the suitable dimensions of normal digital electronics and because they operate at those speeds. Also, part of the climatic interference is 10 to 100 MHz, applying to lightning long distances. A lightning strike close to electronic equipment easily stops the system's normal functioning.

c. The coupling will decrease as distance increases.

d. The following general rules can be applied to protect against electromagnetic waves:

- Use ground planes or mesh structures as local ground.
- Shielding of cables.
- Metal enclosures for equipment and leaky doors are problematic.
- Enclosure openings have to be small.

- No unintentional antenna structures.
- Grounding systematically at short, <1/10 wavelength intervals.
- Pay attention to HF (high frequency) grounding, i.e., capacitive grounding of coaxial cables.

e. Due to mutual dependence, these rules apply to both the source and the victim.

3.2.3 Zoning Concept

At the inception of a project or plant upgrade/extension, the plant is to be assessed, and the various areas are to be divided into relevant lightning protection zones. The plant zoning concept allows identifying different plant areas where there are significant changes or differences in the electromagnetic conditions, typically across a definite boundary or EP (Entry Point). The following lists the relevant protection zones for an industrial installation.

The objective of the zoning concept is to be able to define the electromagnetic conditions within specific areas. The lightning protection zones (LPZs) define the boundaries where transient currents can be diverted to earth, and in this way, the interference is prevented from moving from one zone to the other. All conducted surges are clamped to the ground before entering the next zone at the shielding point, also known as the equipotential point.

Electromagnetic shields at the power station can include:

- Building steel/reinforcing,
- Walls of equipment rooms and,
- Equipment cabinets.

If the building walls were perfectly conducting, they would form a Faraday cage, and differential voltages within the building would be limited to extremely low values - even though the building earth (and hence the building) may fluctuate dramatically due to currents in the earth electrode. Achieving this is not often justifiable, so we rather shield separate items or systems of electronic equipment - for example, the electronic equipment and the cabling associated with the part of the process control system (DCS) at a site. The different zones used for shielding are shown in Figure 1.

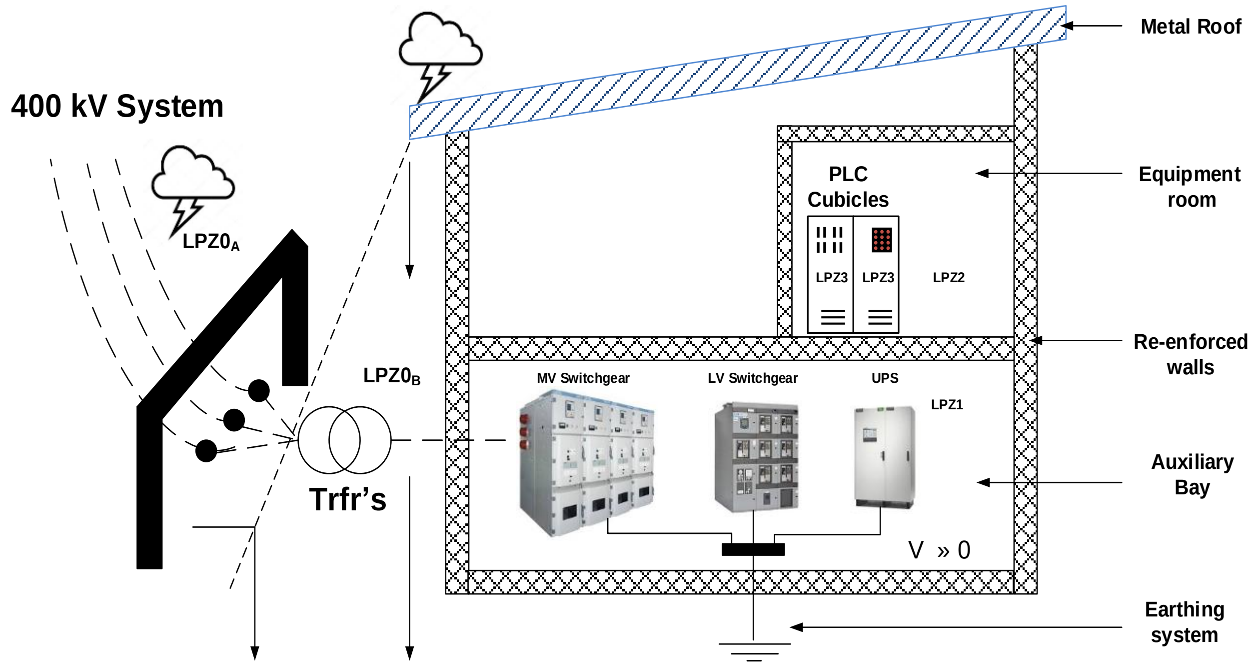

Figure 1: Power Station typical Zone Definition

Zone Identification	Zone Description
LPZ 0A	An outside area, unprotected by building or shelter, where exposure to direct lightning strikes and un-attenuated LEMP is possible. This includes overhead power lines, cables running on gantry racking, and equipment installed on the structure roof.
LPZ 0B	An outside area, with some protection by a building or shelter, where direct lightning strikes are not likely, but still exposed to un-attenuated LEMP. This includes buried cables, HV switchyards (where overhead earth is installed) and plant floor equipment in open process areas.
LPZ 1	Inside a building with no risk of a direct lightning strike, and any LEMP is attenuated by structures and metallic roofing etc.
LPZ 2	An area inside a substation or equipment room or inside isolated equipment cabinets wherein measures have been taken to significantly limit LEMP and unwanted electrical noise, surges and or spikes.
LPZ 3	Inside equipment enclosures within a substation or equipment room where sensitive electronic devices such as PLC, DCS, or computer equipment are housed.

Figure 1 depicts the severity of the $LPZ0_A$ interference experienced in the area during direct lightning activity. $LPZ0_B$ on the other hand, is protected from direct lightning by the shielding of the building, although still experiencing high interferences. One enters the building into LPZ1, that are more shielded from interference. All interference in this area may only enter indirectly via another route (i.e., unprotected power cables). The configuration is maintained until it reaches LPZ3 (i.e., the area inside), e.g., a PLC cabinet, “perfectly” protected from external lightning interference.

Realistically, it is aimed to achieve zones where the exterior of the building is the harshest, and as we move deeper into the building towards more protected zones, the electromagnetic environment becomes more and more harmless. This configuration only applies if one does not violate the shield between the inside and the outside zones.

3.2.4 Conductors

a. The station earth mat shall consist of a 10 mm diameter annealed copper rod in accordance with 240-170000153 (except in the transformer bay where two copper rods run in parallel), laid at a depth of one meter. The rods under the main buildings and the transformer bays shall be arranged to provide a matrix such that the maximum size of each mesh does not exceed 800 m^2.

b. All earth mats shall be connected to the main station earth mat by at least two 50 x 3.15 mm flat copper bar connections. These do not run side by side and, where possible, connect to diagonally opposite portions of the earth mat system.

3.2.4.2 Fault Levels

All earthing shall be designed to allow for the following fault levels:

Table 1: Fault Levels

VOLTAGE LEVEL	MAXIMUM EARTH FAULT (MVA)	EARTH FAULT CURRENT (A, RMS)[1]
275 kV or 400 kV or 765 kV	Dependent of location[2]	
22 kV (generator voltage)	N/A	10
15 kV	500	300
11 kV	500	300
6.6 kV	250	300
3.3 kV	250	300
690 V	57	50 000
400 V (unfused)	35	50 000

3.2.4.3 Design Basis of material and connection types

The sizes of earth conductors have been determined considering their allowable temperature rise and the type of connection used. Table 2 presents the maximum allowable temperature per conductor type and application, as detailed in 240-134369472.

Table 2: Maximum allowable temperature per conductor type and application

CONNECTION TYPE	ALLOWABLE TEMPERATURE RISE	RECOMMENDED APPLICATION
Bolted	250ºC	Gates, fences, and structure to earth tail connections. Regular maintenance is required to maintain intended connection integrity.
Crimped	450ºC	Main earth grid cross connections but is skill and tool dependent to ensure intended connection integrity.
Brazed	650ºC (Only if 3mm Silver Copper Phosphorus Brazing Filler Metal welding rods are used, otherwise 600ºC)	Earth-tails to main grid but is skill and material dependent.
Exothermic Weld	Cu or CCS: 1050ºC All other materials: Material specific	Connections between dissimilar materials, especially earth-tail connections to equipment steelwork. Connection quality is skill and mould condition dependent.

3.2.4.4 Conductor Sizes

a. Whenever a connection is made from an earth bar to the earth mat, it is assumed that the current divides from the connection to both sides of the earth mat. Hence, any connection to the earth may be twice the cross-sectional area of the earth mat conductor or earth bar. Should a greater area be required for the earth connections, two or more connections shall be made to different portions of the earth mat, preferably to diagonally opposite sides of the nearest mesh of the mat.

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[1] These values are not directly calculated from the Maximum Earth Fault MVA, but restricted earth fault current using either Neutral Earthing Transformer (NET) or an earthing resistor. Refer to section 3.9 for further details.
[2] Refer to the latest Eskom Transmission System Annual Fault Level Report published by the **System Operator**. The latest published report is Eskom Transmission System 2021 Annual Fault Level Report REV. 1 (240-118802871).

b. The minimum size of the annealed copper strap shall not be less than 25 mm x 3.15 mm, while other standard sizes are 40 mm x 3.15 mm, 50 mm x 3.15 mm and 50 mm x 6.30 mm. The annealed copper earth rod shall be 10 mm in diameter.

c. In preparation for the tables and drawings, parallel paths may be taken, i.e., earth wires to the high-voltage yard structures, separate oil conservator and cooling systems on transformers, and cable sheaths, wherever applicable.

d. Appendix A gives details of earthing conductors used. The required cross-sectional areas shall be obtained using standard copper sizes or appropriate combinations.

e. The station earth mat conductor shall be a 10 mm diameter annealed copper rod in accordance with 240-170000153.

3.2.4.5 Earthing Tails

Earth tails protruding from reinforcing concrete structures or buried portions of the earth mat shall be 500 mm long to permit the termination of exposed portions of the earthing system onto the earth mat.

3.2.4.6 Connections

a. Interconnections of 10 mm diameter copper rods forming the earth mat utilise brazing or exothermic welding.

b. Flat copper bars for earth tails shall be silver soldered or welded exothermically onto the copper rod or embedded reinforcing bars as per relevant sheets of drawing 0.54/393 where applicable. Refer to 0.54/393 – Sheet 0 for applicable earthing requirements on plant equipment.

c. Where equipment is earthed, connections to earth shall be made by brazed lap joints.

3.2.5 Materials used

a. The materials used for earth mats and conductors depend on the specific application, but the following shall mainly be used:

- Annealed Cu 10 mm diameter for earth mat
- 50 x 3.15 mm copper strap for interconnections and earthing of equipment or
- 2 x 10 mm diameter copper rod can be used where required.

b. Alternative materials and earthing methods are available and can be used, e.g., aluminium conductors can be used in high theft risk areas, e.g. conveyors but with an increased conductor size as per Table 3 below, while ensuring that proper bonding of different materials is observed as detailed below:

- Lugs

Only bi-metallic lugs should be used to connect aluminium conductors/cables to copper bars/tags.

For motors, the use of a bi-metal lug has been identified as problematic for terminating in the existing motors terminal boxes due to its bigger size when compared to the typical copper lug. A combination of copper and aluminium cable will be used to overcome the problem, whereby the aluminium cable will be changed into copper closer to the motor.

- Cable Joints

Normal straight joints of the correct size for the cable to be used for jointing of aluminium and copper cables.

Table 3: Equivalent Cross-Sectional Area (mm^2) of Copper and Aluminium Standard Cables

Copper (Cu)	16	25	35	50	70	95	120	150	185	240
Aluminium (Al)	35	50	70	95	120	150	185	240	300	400

c. In addition, because openly installed copper conductors are subject to theft, hot-dip galvanized steel strap can be considered where low earth faults are required since relatively large steel cross-section size is required to match the performance of a copper material due to poor conductivity of a steel material. In this case, the steel material should be galvanized to SANS 121, and all its cut sites or drilled surfaces must be covered with a cold galvanizing paint within four hours of machining. However, this approach is not recommended due to the relatively low conductivity of steel to copper in the order of 3%-15%to that of copper[3], resulting in large steel straps.

d. Mild steel is used for installations in “ground” comprising fly ash as an alternative to a copper strap. Galvanised steel is not as effective as the zinc coating will deteriorate relatively quickly due to the moisture’s pH value resulting from either spray- or rainwater. Experience shows that plain mild steel is the most compatible material. Therefore, mild steel can be used where earth mats or earth connections have to be installed under these conditions. The joints between mild steel straps shall be welded. Joints between mild steel and copper straps used above ground for earthing purposes should preferably be made indoors. Whenever the joints have to be made outdoors, they must be protected against the joint corrosion by wrapping them with Denso-tape to about 100 mm on either side of the joint. Steel/copper joints are brazed with a silver alloy rod or preferably using an exothermic welding process.

e. Special anti-theft earth conductor is used in high-risk areas where personnel activity is generally low and in remote plants. Due to the high cost of these conductor types, it is not used for long conductor runs but only for connections between equipment and the main earth conductors. Some examples include high mast earth straps (or any metal structure earth connections), construction ring substations, switchboard connections (between the board and rack earth conductor), parallel cable rack inter-connections, and repetitive copper theft areas that take place during construction. The effective copper area specification is used to size this conductor following the application sizing requirements given in Appendix A.

f. Copper-Clad steel conductors in accordance with 240-170000349 can also be used in areas where theft of copper conductors is prone. Joining of cooper-clad conductors should comply to the requirements stipulated in 240-170000535 as well as application drawing 0.54/393 Sheets C5A and C5B.

3.2.6 Boundary Management

At each EP or change in LPZ, a definite measure must be taken to implement boundary management. These measures are intended to ensure:

[3] https://www.bluesea.com/resources/108/Electrical_Conductivity_of_Materials

- Equipotential earth platform in a continuous manner throughout all relevant LPSs.
- Drain any surge, impulse, or noise ground at the boundary points to reduce the risk of conducting such into well earthed or grounded systems within LPZ1 and LPZ2 areas where sensitive equipment is installed.

Where cables, cable racking or conduits enter or exit an LPZ, such are to be provided with a positive connection to the earth. Where stacked or multiple racking or conduit are used, such should be arranged to enter high-risk boundaries at a common or central point. These systems are interconnected and have a local earth bar or grounding point. The connection is of the shortest possible routing using suitably sized green PVC insulated copper conductor or alternative suitable conductor such as silver, aluminium, zinc/brass, steel, on any other material of good electrical properties. The dimension of this conductor is to be determined with the following general guidelines:

- Use ≥ 35mm^2 Cu and green sheathed conductors for multiple cable racking or conduit entry.
- For conduit interconnection, use ≥ 16mm^2 Cu, green sheathed conductors.
- For single conduit entries or single small cable rack entries, use ≥ 16mm^2 Cu, green sheathed conductors.
- Earth conductor length should be as short as possible to ensure effective low impedance ground connection.
- Bare earth conductors should never be installed in a metal conduit to prevent galvanic corrosion relating to different materials and enable colour coding identification, cost and difficulty associated with the verification of hidden conductors.

3.2.6.1 PLC cable entering from LPZ0 to the highly protected zone LPZ3

A galvanically continuous cable with armouring running from outside (LPZ0) to a PLC cabinet deep within a building in LPZ3 is shown in figure 2.

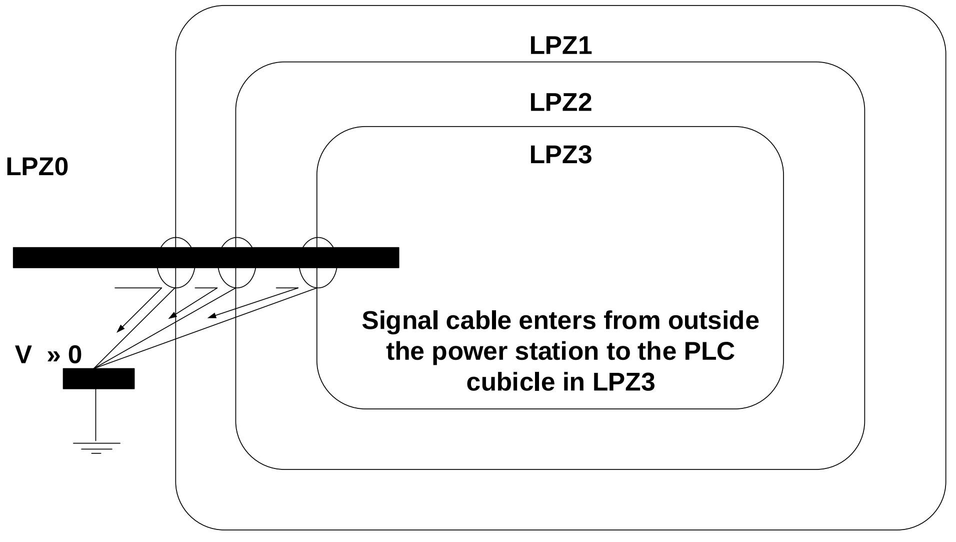

Figure 2: PLC cable entering from LPZ0 to the highly protected zone LPZ3

a. Surge protective devices (SPDs) should be installed to limit voltage levels between the screen and signal lines from the entry point to the next zone. The interference is drained to earth at every zone boundary, and with this method, one prevents it from influencing the sensitive PLC equipment in LPZ3. The harsh external environment is shielded from the deeper zones.

b. It is crucial to maintain shielding integrity. The skin effect is where current flowing within conductors prefers to flow near the surface. This phenomenon becomes significant at higher frequencies. This simple fact should be kept in mind when installing surge protective devices (SPDs), cable screens, or grounding conductors. The frequency of interference is usually high.

3.2.6.2 Minimising of surface current by single entry point of cables

a. A further consideration is to minimise coupling into zones. Surface currents should be minimised. Therefore, a single-entry point panel is recommended. The surface currents are diverted to earth at one point, preventing surface currents through a cubicle housing. The two scenarios are shown in Figure 3. The surface currents in the bad installation can start to flow in screens and cause problems in other plant areas. Using a single-entry point implies that (in most industrial situations) poor quality shielding can be used on the remainder of the shield.

b. In poorly shielded areas, electronic equipment should ideally be in the centre of the building. It should not be near the roof of the building or near corners where high lightning currents are expected in down conductors. Routing of cabling within a screened room is not critical. However, it is recommended to avoid large loop areas between the mains' supply and communications cables by running them adjacent (but not in the same) ducts.

c. In unscreened buildings, cabling and wiring should not be run adjacent to conductors expected to carry high lightning currents (down conductors). Loops in the vertical plane should be avoided to minimise coupling with fields generated by high currents in vertical down conductors.

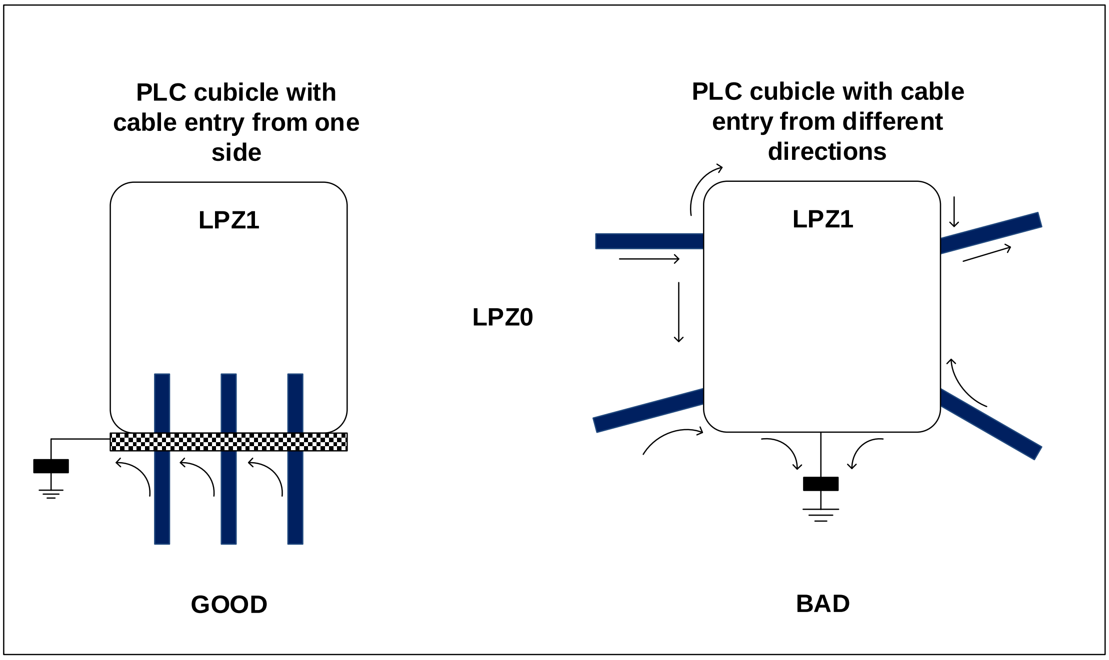

Figure 3: Minimising surface current by single entry point of cables

3.2.7 Requirement for Specifications

It is essential to consider the requirement of the new equipment and systems. The specification of earthing and lightning protection should be included in all the enquiry documents, and the suppliers should provide their specific requirements in their offer in the tender documentation, e.g., interface with the station earth mat, protection against lightning, cable types for control and instrumentation, cubicle details and earthing thereof. The standard earthing drawings 0.54/393 must be considered when designing the earthing system for different plant areas.

3.3 SURGE PROTECTION APPLICATION

The EMC-based Lightning Protection Zones Concept, as discussed in the previous paragraph, has been developed as a complete method of lightning protection. It divides the volume into protection zones formed by shielding the building, rooms and equipment utilising the existing metal components.

3.3.1 Surge protection guidelines

The most obvious source is lightning, but surges can also come from normal utility switching operations or unintentional grounding of electrical conductors (such as when an earth switch is applied to a live cable). Surges may even come from within a building from fax machines, copiers, air conditioners, elevators, motors/pumps, or arc welders, to name a few. The electric circuit is suddenly exposed to a large quantity of energy that can adversely affect the equipment.

Surge protection that is appropriately designed and installed successfully prevents equipment damage, especially for sensitive electronic equipment.

3.3.1.1 Earthing system

A surge protection device (SPD) is designed to divert high-current surges to the ground and bypass the equipment, limiting the voltage that is impressed on the equipment. For this reason, the facility must have a good, low-resistance grounding system, with a single ground reference point to which the grounds of all building systems are connected. There is no way to protect against surges without a proper grounding system.

3.3.1.2 Zones of surge protection

The best means of protecting the electrical equipment from high-energy electrical surges is to install SPDs strategically throughout the building/installation. Considering that surges can originate from internal and external sources, SPDs should be installed to provide maximum protection regardless of the source location. For this reason, a “Zone of Protection” approach is generally employed.
SPDs should have the capability for remotely monitoring where possible. Alternatively, they should be integrated into a routine maintenance inspection program to confirm operational status.

By dividing the protected volume into lightning protection zones, an integrated installation of surge protective devices (SPDs) is made easier even in large communication/signalling systems. Starting from the field side (protection zone 0A of figure 2), a direct lightning flash and un-attenuated lightning electromagnetic fields occur. The protection zones follow a decreasing level of risk relating to line-based disturbances and lightning electromagnetic fields effects.

The lightning protection zones (LPZ), as defined previously in Figure 2, are:

- LPZ 0A: direct lightning flash and high electromagnetic fields.
- LPZ 0B: no direct lightning flash but high electromagnetic fields.

- LPZ 1: projected electrical system, weakened electromagnetic fields (typically 30dB).
- LPZ 2: terminals protected centrally, considerably weakened electromagnetic field.
- LPZ 3: a protected area within the terminal.

The different zones must be protected accordingly using various surge protection devices.

The first level of protection is achieved by installing a SPD on the main power supply (i.e., where the power comes into the building). The installation of a SPD will protect against high-energy surges from the outside, such as lightning or supply transients from the transmission network, distribution network, or the local municipality network. However, the SPD installed at the supply point will not protect against internally generated surges. In addition, not all of the energy from outside surges is dissipated to the ground by the main power supply protection device. For this reason, SPDs should be installed on all distribution panels within a facility that supplies power to critical equipment. Similarly, the third zone of protection is achieved by installing SPDs locally for each piece of the protected equipment, such as computers or computer-controlled devices. Each protection zone contributes to the overall protection of the building/installation as each helps to reduce the surge voltage further.

3.3.1.3 Coordination of SPDs

The SPD on the main power supply provides the first line of protection against electrical transients for a building/installation by diverting high-energy, outside surges to the ground. It also lowers the surge's energy level entering the facility to a level that can be handled by downstream devices closer to the equipment. Therefore, SPDs are properly coordinated to avoid damaging the SPDs installed on the distribution panels or locally at sensitive equipment. If coordination is not achieved, excess energy from propagating surges can cause damage to Zone 2 and Zone 3 SPDs of Figure 2 and destroy the equipment to be protected.

3.3.1.4 SPD selection

Several factors are considered when selecting a SPD for a given application, as discussed in the following paragraphs.

a. Application

   Ensure that the SPD is designed for the zone of protection for which it will be used. For example, a SPD at the power supply point should be designed to handle the more significant surges that result from lightning or network switching.

b. System voltage and configuration

   SPDs are designed for specific voltage levels and circuit configurations. For example, the main supply equipment may be supplied from a three-phase power supply at 400/230 V in a four-wire wye connection, but a local computer is installed on a single-phase (i.e., 230 V supply).

c. Let-through current

   Let-through current is the current magnitude that the SPD will allow the protected equipment to be exposed to before the current flow is interrupted. However, the equipment's potential damage depends on how long the equipment is exposed to this let-through voltage about the equipment design. In other words, equipment is generally designed to withstand a high voltage for a brief period and lower voltage surges for a more extended period.

d. Surge current

SPDs are rated to effectively and safely divert a given quantity of surge current. This rating ranges from a few amps up to 400 kA or more. The average current of a lightning strike is approximately 20 kA, with the highest measured currents being just over 200 kA

Several factors must be considered when deciding what size SPD is appropriate for the application. For example, lightning that strikes a power line will travel in both directions, so only a portion of the current travels toward the installation. Along the way, some of the current may dissipate to the ground through the network equipment. Therefore, the potential current from an average lightning strike at the power supply point is around 10 kA. In addition, certain areas of the country are more prone to lightning strikes than others. Note that it is also essential to consider that an SPD rated at 20 kA may be sufficient to protect against the average lightning strike and most internally generated surges once, but an SPD that is rated 100 kA will be able to handle additional surges without having to replace the arrester or fuses.

e. Data line protection

Electrical transients are not confined to the electrical distribution system. They can enter a facility through phone/fax lines, cable or satellite systems, and local area networks (LAN). Therefore, SPDs should be installed on all systems susceptible to electrical transients to achieve maximum protection from surge damage.

f. Installation

SPDs should be installed as close to the protected equipment for maximum protection. Cable lengths should be as short and straight as possible to minimise the circuit’s resistive path to the ground. A solid connection to the system grounding conductor is essential for the proper operation of the SPDs. The surge protectors should be equipped with indicators that show if the circuit is grounded and operating correctly and the devices installed in locations so that these indicators can be inspected with ease.

3.3.2 Surge protection devices (SPDs)

If a transient is suddenly imposed upon an electrical system, there are different protection methods: (viz. protection by an open circuit or protection by a short circuit).

The main technologies employed are:

- Voltage breakdown devices (spark gaps)
- Voltage limiting devices (metal oxide variable resistors or avalanche diodes)
- Bandwidth suppressors (various filters, inductors, and capacitors)
- Isolation devices (opto-isolators and fibre-optics)

Each type of SPD has certain advantages and disadvantages. Hybrid SPDs incorporate combinations of the above technologies and are more costly but more beneficial in handling different transient waveform components.

3.4 BRAZING OF COPPER

Brazing is a process for joining metallic materials with the aid of an additional molten material (the solder) and a flux, if necessary, and or with inert gases. The solder’s melting temperature is above 450°C, but less than the materials to be joined. Thus, the surfaces of the materials can be made wet without being melted. The advantage of brazing compared to welding is the lower working temperature and the joints' rapid completion.

3.4.1 Filler Metals and Fluxes

a. Filler metals and fluxes are selected according to the application, as well as to match the materials. Fluxes contain aggressive chemicals to produce the desired effect; fluxes clean the joint to be made and prevent access to oxygen from the air.

b. For copper-to-copper joints (brazing), use only the filler metal LAg 40Cd (Hartlot 4003, refer to DIN 8513). Only filler metal LAg 5P (Silfos 15) should be used for steel-to-copper joints. For large cross-sections and low working temperature, use filler metal LAg 40Cd. For smaller cross-sections, or when the remaining flux traces cannot be removed, use filler metal Lag 15P. This filler metal contains phosphorus and therefore needs no extra flux.

3.4.2 Types of Joints

Brazed copper strap joints should be of either the butt or lap type:

a. Butt joints are made by putting the flat copper bars to be joined so that no overlapping occurs. The joints are reliable and easy to make but must be carefully prepared and clamped. Butt joints should be avoided if possible if high mechanical stresses are involved.

b. On the other hand, Lap joints are made by having a copper bar overlapping. They are generally easier to prepare for brazing than butt joints. The brazed area of a lap joint should be at least four to five times the cross-sectional area of the thinnest of the two flat copper bars to be joined.

c. Lap joints are always used on a round copper rod with at least 30 mm overlap.

3.4.3 Preparations for Brazing

a. The brazing surfaces' edges should first be deburred, then brushed down to the bare metal using a steel wire brush (not emery cloth) and degreased when the brazing surfaces have been cleaned (NB. do not touch them with bare hands).

b. Ensure proper support (e.g., firebricks) when the bars are laid flat and allow the joint to project beyond the support so that heat can also be applied from below. If possible, arrange the pieces to be brazed to make horizontal brazing surfaces using sheet filler metal. When brazing with sheet filler metal (approximately 0.2 mm thick), arrange for the upper piece to be movable in the brazing surface direction so that as the filler metal melts, the correct gap can be produced. The correct gap is achieved either by the weight of the piece of material or by applying extra force.

c. For small pieces of lightweight material, use a suitable device to exert extra force on the movable material to produce the prescribed gap. Such devices provide good clamping of the pieces being brazed and, at the same time, prevent the upper piece from floating when the flux and filler metal melt.

d. Do not press on the joint by hand as it is solidifying because the upper piece may be moved, which would spoil the joint. Place the sheet filler metal centrally on the flat copper bar, and it must cover about two-thirds of the brazing area.

e. Vertical gaps should not be brazed with sheet filler metal but strip filler metal, allowing a 0.05 mm to 0.2 mm gap.

3.4.4 Brazing

a. When the standard filler metal Lag 40Cd (Hartlot 4003) is to be used for brazing, first apply Type "h" flux (F-SH1 as per DIN 8511) generously to both brazing surfaces and their surroundings with a brush before heating the joint. Next, heat the joint uniformly and over a large area using a wide flame torch. If regular welding torches are used, move the flame back and forth quickly and evenly over the entire brazing surface. For large joints, use several welding torches or wide-flame torches. Adjust them to a neutral flame of a slightly reducing flame, i.e., with excess gas.

b. If possible, do not use a flame to make steel-to-copper joints as hydrogen embrittlement is dangerous in the copper. If a flame must be used, ensure that the flame does not contact the surfaces to be brazed. Cover the workpiece with graphite plates and clamp the plates using copper sections. Only heat the graphite as the heat will flow from the graphite to the workpiece. The Type "h" flux becomes viscous at approximately 500°C. After further heating, the working temperature of 610°C is reached quickly.

c. When brazing with Lag 15P, the working temperature of approximately 710°C has been reached when the metal is glowing red hot in a slightly darkened room. Strip filler metal should only be applied on one side of the joint with the flame on the opposite side. If the material's temperature is correct, the filler metal will run automatically into the joint gap. Do not use the torch flame to drive the filler metal into the gap or melt off the strip. When the joint gap is full of filler metal, stop heating and avoid shaking or disturbing the joint.

d. Brazing should be completed within approximately three minutes maximum after the beginning of heating. Allow the joint to cool down to 300°C and, if possible, pour warm water onto it so that the flux washes away. Remove any traces of flux with a steel wire brush but do not use tools on the brazing concave fillets. If the brazing is not completed in time, set up the joint again, clean it with a steel wire brush, apply more flux and heat up again using a larger torch. Dark brown flux indicates that the brazing has taken too long. Do not attempt to re-braze a defective joint without first separating the joint and removing all filler metal traces from the brazing surfaces (e.g., filling).

e. If brazed joints' strength is maintained, they should not be exposed to temperatures above 200°C.

3.5 INSTALLATION

This section discusses the plant-specific implementation of the theory and philosophy, as discussed earlier in the document.

3.5.1 Earthing with Cable Racking

a. Earthing conductors shall be installed on all the cable racks at the power station. The cable racks serve as an excellent medium for ensuring continuity in the plant. It is a secondary earth mat (surface equipotential bonding system) connected to the station and local earth mats. Even if copper is not installed on the rack, it links equipment. The metal is conducting and helps lower the resistance between equipment, improving continuity. The cable racks must be bolted together to ensure continuity. The racks shall be connected with copper straps where this is not possible.

b. Special cable racks with an embedded earth conductor are used. This type of rack eliminates the installation of the copper conductor after rack installation and prevents theft of conductors from the racking. Note that not all racks are of the embedded copper type, i.e., several racks are running parallel. Only one of these racks with two embedded copper conductors is required.

c. Avoid parallel running of power cables to signal cables. The process control cables are also laid on the station cable racking system. This system is connected to the power station's equipotential surface earth bonding system. Care is taken to ensure the segregation of the control and instrumentation cables from the low voltage and medium voltage cables. The distance between power and control cables should be at least 1000 mm. If not, the control cables tray should be shielded with a cover. When control cables cross power cables, ensure this is done at an angle as near to 90 degrees as possible. The cable racks support the cables. Therefore, it should be installed in such a way as to limit interference between cables.

3.5.2 Power and Control Cables 600/1000 V

a. Cables are dimensioned following the regulations concerning short-circuit protection, operating voltage, permissible touch voltage appearing under fault conditions, and the cable's current carrying capacity. In addition to safety regulations, the cable type also supports the EMC protection of the installed equipment.

b. Where earth continuity conductors are provided as a separate core in cables, this earth core shall be connected to the earth bar of the switchboard, cubicle, internal earthing point provided in the motor termination box, local control station, etc. For this purpose, the copper conductor is covered with a tightly fitting yellow-green sleeve before a lug is crimped onto it.

3.5.2.1 Supply Cabling

a. At low current (< 300 A), utilising only one cable is sufficient. The supply cable can be either unshielded or shielded symmetrical multi-core type, non-armoured or armoured symmetrical multi-core type. The shield or armouring is connected to the earth at one end, following 240-56227443 (Requirements for Control and Power Cables for Power stations Standard).

b. The supply of high current (>300 A) applications can be either a busbar or a sizeable current cable system. The alternative large current supply is constructed using parallel multi-core or single-core cables. A sizeable current system typically consists of several single-core cables. It is designed to reduce the conductor material because of the better cooling of separate conductors.

c. Where single-core cables are used, the supply cable can be either unshielded or shielded, non-armoured or armoured. For the single-core, the shield or armouring is earthed only at one end to prevent the development of a circulating current. Circulating current occurs in the shield or armouring if the cable is earthed on both ends. The non-magnetic gland plates are used in the installation.

3.5.2.2 Motor Cables

a. For instance, it is essential to use shielded symmetrical cable types of armoured cable to meet the EMC requirements in variable speed drives. The shield conductivity must be at least 1/10 of the phase conductor conductivity to ensure effectiveness at high frequencies. Good effectiveness is easily met with a copper or aluminium shield, but a steel shield's cross-section must be ample. The shield conductivity must be at least 50% for protective conductors.

b. The first alternative is a three-core cable equipped with a concentric protective copper shield. In that case, the wires are at an equal distance from each other and the shield. Hence, the shield can be used as a protective conductor.

c. The alternative with wire armour, where the stranded wire iron armour is connected to earth at both ends, needs a separate high-conductivity earth conductor. The length of an unshielded part of the cable should be as short as possible.

d. Several conductor elements must be parallel when cabling a high-power frequency converter and motor. Always use symmetrical cabling.

e. The field cable of a DC motor is a heavy source of interference because of the abrupt commutation. Therefore, always use a shielded field cable. Single-core cables should not be used for DC drive applications.

f. All armoured cables shall be earthed as shown on the relevant drawings in 0.54/393.

3.5.2.3 Signal Cables

The uniform principle of equipotential grounding is extended to all structural installations in large buildings containing electrical equipment. Examples of levels are floor, equipment cubicle and circuit board level. It is impossible to keep all system levels at the same high-frequency potential, but applying uniform grounding at all levels will ensure electromagnetic compatibility.

3.5.2.4 Interfacing challenges of systems with dissimilar grounding

a. The different installations being supplied by the various manufacturers may utilise other grounding principles, e.g., low-frequency EMC. The latest earthing approaches employ a uniform system where everything is bonded to everything. These systems have to operate together. The dissimilarity may create matching problems, which must be solved for each case. Physically large installations (dimensions, power) usually need a matching method. Matching is done to achieve good compatibility. Sometimes it is reasonable to accept a lower immunity level. However, the legal requirement of emission and immunity must be fulfilled.

b. Usually, matching elements between the systems are transformers, opto-couplers, optical fibre links, galvanic analogue isolation and common mode interference filters and inductors. All these methods can improve signal transmission. Galvanic isolation of control signals improves interference immunity and is recommended, especially for long distances. Isolation prevents interference caused by common impedance-coupling (ground loop) and suppresses inductive coupling interference. Weak signals are isolated and amplified precisely at the source; normal signals can also be isolated at the receiving end. Isolation transformers are used for power supplies.

c. In particular cases with high emission levels, common mode inductors can be used in signal cables to avoid interfacing problems between different systems. Wiring signal conductors could suppress common mode disturbances through the common mode inductor ferrite core. The ferrite core increases conductors' inductance and mutual inductance, so common mode disturbance signals above a specific frequency are suppressed. An ideal common mode inductor does not suppress a differential mode signal.

d. The interfacing practice will not be discussed in detail, but it is essential to be aware of interfacing problem areas before implementation.

3.5.3 Control Cable Shielding

Using the correct cable types to meet the EMC compatibility essential since incorrect cable types can cause severe interference problems. A shielded control cable will reduce disturbances and should always be used primarily with the increased use of portable communication equipment.

3.5.3.1 Analogue and Low Voltage Digital I/O Signals

a. Twisting the signal wire with its return wire reduces disturbances caused by inductive coupling. Pairs should be twisted as close to terminals as possible. A double-shielded twisted pair cable must be used for analogue signals. Use one individually shielded pair for each signal, and be careful when using a common return for different analogue signals.

b. A double-shielded cable is the best alternative for low-voltage digital signals, but a single shielded, multi-pair cable can also be used. Never use 24 V DC and 230 V AC signals in the same cable.

3.5.3.2 Serial Communication

Use double-shielded or coaxial cables in sensitive equipment like variable speed drives in internal communication. The serial communication can also be implemented with optical cables. A communication system may also have its cable specification matching the double-shielded and coaxial cable.

3.5.3.3 Shield Connection

a. Standard practice is to earth the screen at the cable source to earthing terminals and insulate the drain wire with the screen at the remote cable end to avoid creating earth loops (More details are provided in Appendix E: Earthing and Lightning Protection Guidelines for the Design and Installation of Process Control & Instrumentation Equipment/Systems). The unshielded part of the cable shall be minimised. The ground connection of the shield shall be kept as short as possible.

b. One end grounded shield does not suppress electromagnetic field or inductive disturbance. Grounding the shield of the signal cable at both ends will improve suppression above a specific frequency, but grounding at both ends forms a closed ground loop, and if the ends of the cable screen are at different potentials, as in a short circuit situation of high-power equipment, a low-frequency current will flow through the screen. Therefore, the other shield's other end can be grounded via a capacitor if HF grounding is needed.

c. Where the signal is of such magnitude that radio frequency (RF) interference is possible, double-shielded type cables with braided screens shall be used. The outer screen is usually earthed at a suitable earth point at both ends of the cable, and the inner shield is connected to the circuit earth point.

3.6 CABLE JUNCTION BOXES

Cable junction boxes are not earthed provided that at least two earth paths exist through cable sheaths and armouring. Metal junction boxes shall be provided and earthed as shown on the relevant sheets of drawing 0.54/393, where it is impossible to provide a minimum of two earth paths. Moulded plastic junction boxes of thermoplastic material do not have to be earthed but must be fitted with an internal earth bar or connection point to provide earth continuity of either cable armouring or separate earth core.

3.6.1 Computer and Computer Room Earthing

According to the supplier's computer and ancillary equipment requirements, details of the earth grid in a computer room and its bonding to the main station earth mat shall be carried out.

The un-insulated earthing circuit looping within the computer room shall be connected directly via the shortest route with only one connection to the main station earth mat to prevent loops. Usually, the un-insulated earthing circuits for bonding the computer flooring, frames, and cabinet earth are separated from the insulated electronic earth. The electronic earth is brought to a common insulated bar or junction box and shall be bonded to the earth mat only through an insulated earth (cable).

3.6.2 Earth Mats under foundations and floors

The minimal corrosion effect between copper and reinforcing bars where the earth mat passes under concrete foundations or floors, resulting in the lowest earthing resistance, is achieved if the 10 mm diameter copper rod is placed directly on top of the blinding cast concrete by the foundation or floor.

3.6.3 Structural Steelwork

a. The steelwork structures in the transformer bays shall be connected to the earth mat following the relevant sheets of drawing 0.54/393.

b. The main building of the boiler and turbine house columns shall be connected to the earth mat as shown on the relevant drawings. The main structural steelwork of all ancillary buildings shall be connected to their relevant earth mats.

c. Steel columns supporting equipment such as the bag filter houses, inclined conveyors, etc., are connected to the station earth mat with at least one 50 x 3.15 mm earth strap or a 2 x 10 mm diameter copper rod.

3.6.4 Reinforcing Steel in Concrete Columns

a. Reinforcing steel in concrete shall be earthed as indicated on the relevant sheet of drawing 0.54/393. This approach ensures an excellent earthing method, providing significantly low continuity resistance values.

b. A continuous reinforced concrete structure protects its occupants and contents against lightning, owing to the continuous steel reinforcement forming a metal cage. The steel that is bonded together in numerous places ensures low resistance contacts in splice joints and provides an adequate number of parallel paths that enable the lightning discharge current to flow safely to the general mass of the earth without ill effects on the occupants, contents or the strength and durability of the structure.

c. Note that building regulations generally exclude reinforcing steel for the conduction of current. Such exclusion is aimed explicitly at using reinforcement for the conduction of power frequency currents, either during normal operation of the electrical system or under fault conditions, but does not relate to the effects of natural phenomena such as lightning.

d. For internal down conductors, use the reinforcing steel of the vertical columns, particularly those on outer corners, provided that the reinforcement is electrically continuous. Alternatively, use conductors cast in concrete, vertical metal columns, stormwater drain pipes, external metal staircases, fire escapes or other metal structures.

3.6.5 Metal Roofs and Cladding

a. Metal roofs or steel trusses not directly connected with building steelwork shall be connected to the earth mat at opposite building points (e.g., diagonally).

b. Structures with metal roofs do not require earth terminals but must be earthed by conductors. Metal sheets separated by insulating strips or epoxy or plastic coatings may provide a continuous metal roof.

c. Un-insulated cladding not in direct contact with building steelwork is bonded to the building steelwork shown on the relevant sheet of drawing 0.54/393. Where cladding is fully insulated (e.g., sheets covered with a bitumastic compound and fully insulated from one another), the sheets do not require earthing.

3.6.6 Fire Protection

a. The fire protection piping shall be earthed in the region of the transformers to reduce the touch potential. The piping shall also be earthed at various points. Care must be taken to install fire protection and detection equipment because the equipment is applied in harsh environments in terms of interference, i.e., Generator Transformer yard, HV Yard, Generator etc. Suitable earthing and EMC filtering should be added to prevent false operations.

b. Herewith are some general requirements concerning the fire protection system:

- Earth the Unistrut or cable trunking that contains the control cables to the deluge valves.
- Earth the deluge valves (use copper braid).
- Earth the conduit containing the signal wires between the sensors (if installed) and the control cabinet.
- Bond the conduit to the cable trays and cable trunking.
- Use screened, twisted-pair cables for the signal cables.

3.6.7 Ancillary Buildings

a. These buildings include, e.g., the electrical substations, water treatment plant, auxiliary cooling system, workshop and stores, station services building, hydrogen plant, coal silos, fuel oil plant, administration buildings, etc.

b. Each building shall be provided with a dedicated earth mat. The building earthing system shall be connected to the main station earth to ensure continuity. All major apparatus in the building shall be connected to the main earth strap that runs in a cable tunnel or trench and shall be connected to the earth mat.

c. The individual building or area earth mats on the terrace shall be bonded to the main station earth mat by at least two 10 mm diameter copper rod connections, linking each into separate meshes of the main station earth mat. Individual earth mats for buildings or areas outside the terrace must be large enough to provide resistance to earth of not more than 0.2 ohms, which is achieved by either putting a 10 mm diameter earth rod into cable trenches dug for cables laid directly in the ground or by driving earth rods according to SANS 1063 into the ground.

3.7 ELECTRICAL PROTECTION EQUIPMENT

It is essential to ensure that electrical protection schemes are immune to interference since they detect and initiate the clearing of faults to prevent plant damage and injury to personnel. Hence, the schemes should be appropriately installed and clear of any interference to ensure their reliability. The following standards listed below detail the technical and functional requirements for the installation of the protection scheme devices:

- Generation Auxiliary Plant Medium Voltage Protection Standard (240-143485806)
- Generating Unit Electrical Protection Standard – Coal Fired (240-132533107)
- Generating Unit Electrical Protection Standard for Pumped Storage Schemes (240-151976059)
- Generating Unit Electrical Protection Standard for Hydro Schemes (240-151976059)
- Generator Synchronising and Network Synchronism Check Standard (240-56357419)
- Generation Stand-alone Disturbance and Fault Recorder Standard (240-56356566)
- MV and LV Protection Standard (240-563356548) – Applicable to the LV switchgear protection systems.

3.8 EARTHING AND LIGHTNING PROTECTION GUIDELINES FOR THE DESIGN AND INSTALLATION OF PROCESS CONTROL & INSTRUMENTATION EQUIPMENT/SYSTEMS

Comprehensive requirements relating to the earthing and lightning protection for the design and installation of process control and instrumentation equipment are presented in Appendix E.

3.9 NEUTRAL AND RESISTANCE EARTHING

As discussed in this paragraph, the transformer star neutral points (except 400 V and 690 V neutrals) are earthed directly or via earthing transformers and resistors. Eskom deviates from the SANS 10198 code of practice on all 400 V neutrals. The transformer is not earthed directly at the transformer but only via a removable link in the incomer panel of the low voltage switchboard. The neutral is earthed in only one place on the switchboard.

3.9.1 The Main Electrical Systems are earthed as per Table 4.

Table 4: Neutral and Resistance Earthing

ELECTRICAL SYSTEM	TYPE OF EARTHING
22/420 kV Generator Transformer:	Solid earth on star connected 400 kV side
20/420 kV Generator Transformer:	Solid earth on star connected 400 kV side
16.5/420 kV Generator Transformer:	Solid earth on star connected 400 kV side
20/300 kV Generator Transformer:	Solid earth on star connected 275 kV side
Unit Transformer (Various sizes)	Earthing transformer and resistor on star connected generator output (HV) side and earthing resistor on the LV star connected sides of the transformer
11/6.9 kV Service Transformer	Neutral earthing resistor on 6.9 kV side of the transformer
11/3.3 kV Service Transformer	Neutral earthing resistor on 3.3 kV side of the transformer
132/11 kV Station Transformer	NEC/NER
Other 11/6.9 kV transformers	Solid earth
11 kV/420 V Dry-type transformers	Solid earth (once in switchboard)
11 kV/690 V Dry-type transformers	Solid earth (once in switchboard)

ELECTRICAL SYSTEM	TYPE OF EARTHING
11 kV/420 V Oil type transformers	Solid earth (once in switchboard)
Other 11/6.6 kV transformers	Solid earth
Other 11/3.3 kV transformers	Solid earth
6.6 kV/420 V Dry-type transformers	Solid earth (once in switchboard)
6.6 kV/420 V Oil type transformers	Solid earth (once in switchboard)
3.3 kV/420 V Dry-type transformers	Solid earth (once in switchboard)
3.3 kV/420 V Oil type transformers	Solid earth (once in switchboard)

The details and integration of each resistance earthing system are discussed in the following subsections.

3.9.2 Generator Earthing

It is common practice to ground generators via external impedance to facilitate the stator winding protection. This protection limits the magnitude of the earth fault current and subsequent core damage by the arc that burns the core and welds the laminations together (that leads to overheating due to excessive eddy currents). This high impedance protection method also allows the detection of ground faults within the generator.

Figure 4 depicts a simple single line diagram of the generator earthing system. It utilizes three single-phase earthing transformers with the primaries connected to the generator terminals in a star configuration and with the generator load side connected in a broken delta configuration across a resistor. The primary voltage rating of these transformers is equal to the line to neutral voltage of the generator (for example,22 kV/√3), and the secondary voltage is 230 V in some cases. Thus, there is a slight variation in the magnitude of the secondary voltage. The low secondary voltage means that the resistor has a low resistance value and, therefore, rugged construction but still provides a high equivalent resistance value in the generator circuit.

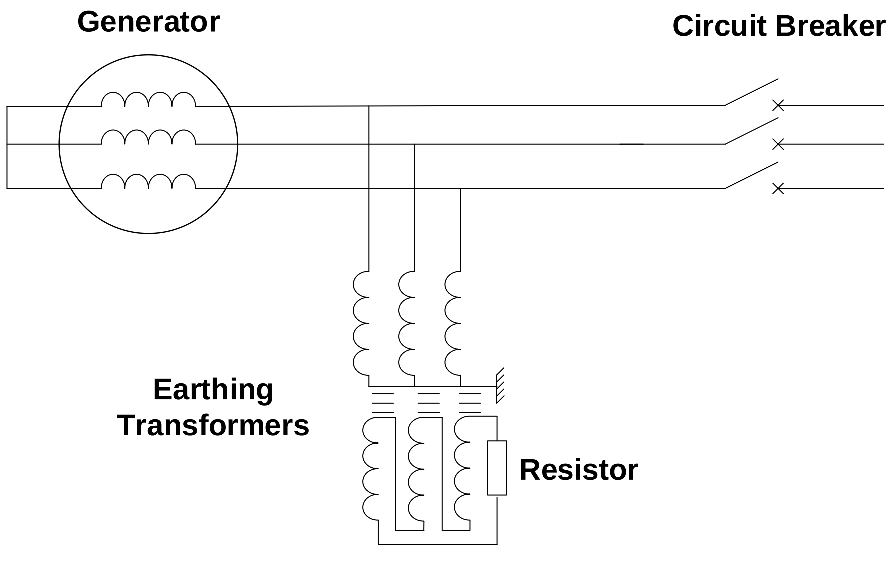

Figure 4: Generator Earthing

The resistor prevents the creation of high transient over-voltages in the event of an arcing earth fault. This configuration is achieved by discharging the bound charge in the circuit capacitance. The size of the earthing resistor is related to the capacitance current to earth of the generator stator winding, the generator cables and the low voltage winding of the generator transformer. The practical aim is to make the earthing transformer's primary current equal to the capacitance fault current, usually from 4 A to 15 A. The phase to earth fault current limit for the power station is calculated as 10 A.

The advantages of the earthing transformer on the terminal side instead of on the neutral side of the generator are that the detection of inter-turn faults is possible, and a path for the in-phase harmonic currents generated by the generator does not exist.

3.9.2.1 Small Generator Earthing (e.g. Kendal Black Start Gas Turbine)

The generator star side/point shall be earthed through a Neutral Earth Transformer (NET). Where multiple generators are installed, an appropriately rated contactor shall be integrated on the earthing conductor to ensure that only one of the generators is earthed at a given point to prevent multiple earthing points by interlocking the contactors. This arrangement isolates the neutral generator to avoid circulating current through the neutral conductor while generators work parallel.

3.9.3 Generator Transformer Earthing

The configuration of Generator Transformers is in a star connection on the high voltage side with the neutral solidly earthed, as shown in Figure 5.

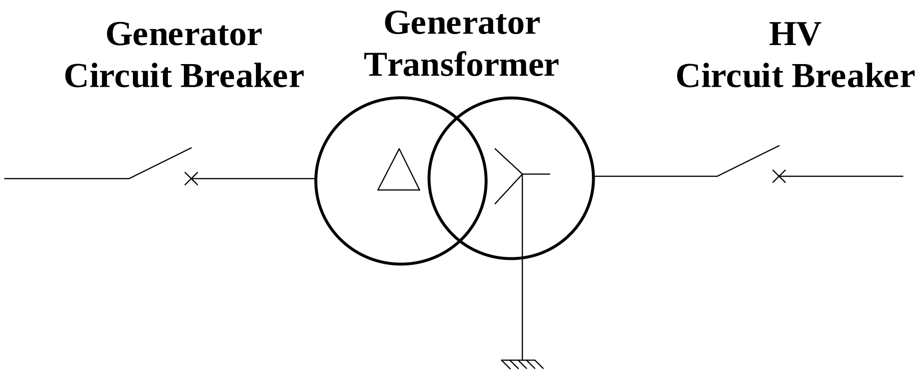

Figure 5: Generator Transformer Earthing

The advantages of solidly earthing the neutral are as follows:

a. Earth fault protection is simple; as the fault, currents are usually high.

b. Arcing ground faults cannot occur, as the short circuit current is much larger than the capacitive charging developed between the line connection, transformer windings and ground, which is even greater when the system is resistively earthed, thus eliminating its influence. This charge is developed due to the capacitance reactance of the windings and the line connection with reference to the ground. If the system was resistively earthed, the capacitance charge due to the line connection and the transformer windings during such a fault creates large overvoltage spikes on the healthy phases, which is not desirable.

c. Over voltages during earth faults are the lowest, i.e. less than 0.8 times phase-to-phase voltages, since, with solid earthing, the voltage on the healthy phases will only increase towards the phase-to-neutral magnitude, whereas with resistive earthing, the voltage here tends towards the phase-to-phase magnitude.

d. The only disadvantage that could be encountered is that the fault current is inherently high, which can cause plant damage.

e. As mentioned, the fault currents here are high and vary with the distance to the fault from the neutral end of the winding. The fault currents, in this case, are controlled mainly by the leakage reactance of the winding.

3.9.4 Generator Export System Earthing (busbars, breaker and earth switch)

a. All metallic parts of the export system must be earthed to avoid any potential rise for safety purposes. The busbar enclosure sections are electrically connected and form a continuous body, insulated from the supporting structures. The enclosures of the busbar connections to the Unit Transformers are insulated by rubber bellows. The busbar enclosures are shorted out at the generator, and Generator Transformer ends and earthed (with 10 mm diameter copper conductors to the earth mat tails at 0 m level) at the Generator Transformer side only to avoid creating loops.

b. The breaker enclosure should also be insulated from the support structure. The busbar enclosure ends are connected with flexibles to the breaker enclosure to ensure continuity of the busbar enclosure.

c. The busbar and enclosure resultant magnetic field under normal and abnormal current flow conditions are shortly discussed:

d. The phase conductors and enclosures are comparable to a short-circuited transformer's primary and secondary turns. The magnetic field produced by the primary conductor induces a current in the opposite direction in the secondary turn. The primary and secondary current components are practically equal with the conducting enclosure, and the resulting magnetic field outside the enclosures is almost nil under stable conditions.

e. When a multiple-phase short circuit occurs on circuits connected to the busbars, the conductors' and enclosures' alternating current components are very similar (due to the transformer effect). However, the direct current components of these currents have different values at a given time of the short circuit. These initially identical components are reduced by different time constants respectively for the conductor (time constant of the circuit connected to the conductor) and the enclosure (time constant of the circuit formed by the enclosure). Therefore, the magnetic field outside the enclosures is essentially due to the difference between the direct current components of the currents in both the conductors and the enclosures.

3.9.5 Unit Transformer Earthing

Once the Generator Circuit Breaker is closed, the earthing transformers on the generator busbars are sufficient for protecting the complete busbar system, incorporating the LV side of the Unit Transformers. The Generator Transformer will often be back energized when the generator is not synchronized to the network. It is then necessary to earth the generator 22 kV side of the transformers, as shown in figure 6.

On the 11 kV side of the Unit Transformers, an earthing resistor is implemented to limit any resulting phase to earth fault current to a maximum of approximately 300 A. The high resistive earthing on the

22 kV side of the transformer will not prevent high fault currents on the 11 kV side when a fault occurs on the 11 kV side of the transformer. In this instance, the zero-sequence impedance of the Unit Transformer will still be low enough to allow the high phase to earth fault currents on the 11 kV side, thus necessitating using the earthing resistor on the 11 kV side neutral.

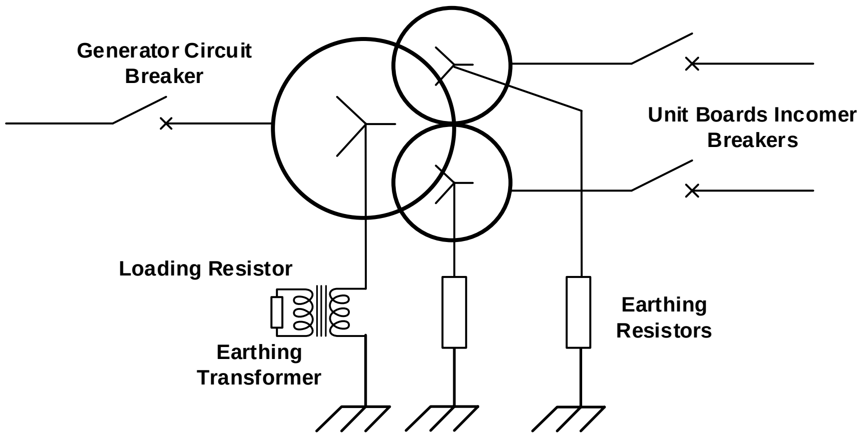

Figure 6: Unit Transformer Earthing

3.9.6 Service Transformer Earthing

On the 6.6 kV Service Transformers side, an earthing resistor is implemented (connected to the neutral, similar to the Unit Transformers) to limit any resulting phase to earth fault current to approximately 300 A.

3.9.7 Station Transformer Earthing

a. The star-delta winding configuration used for the Station Transformers means earth fault currents can circulate in the secondary delta winding. This phenomenon is eliminated by using a neutral earthing compensator (NEC) and resistor (NER) arrangement, as shown in figure 7. The NEC and NER are connected in series and limit the earth fault current to approximately 300 A.

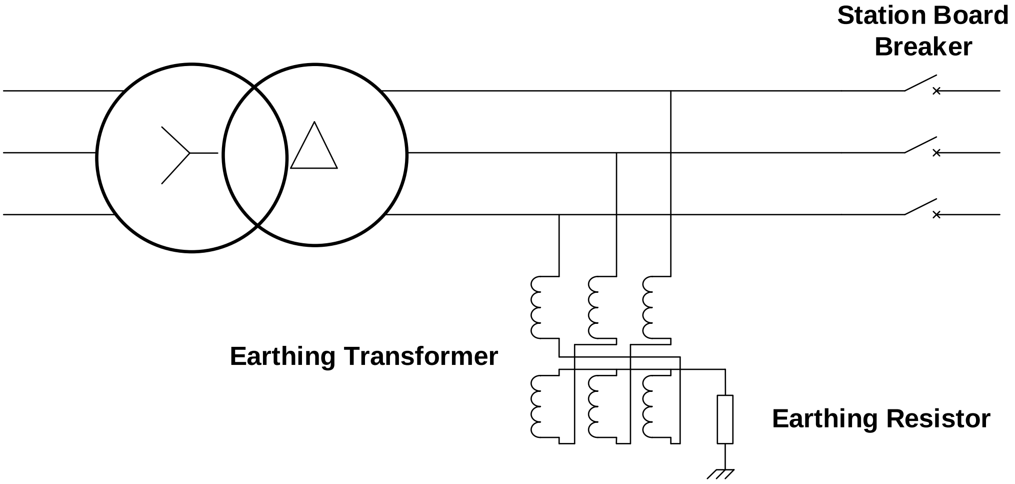

Figure 7: Station Transformer Earthing Arrangement

b. Two types of protection are used on the low voltage side of the transformer, namely sensitive earth fault protection and inverse definite minimum time (IDMT) earth fault protection.

3.9.8 Other Transformer Earthing Requirements

Earthing requirements for other transformer arrangements (e.g., 11/6.63 kV or 11/3.3kV wet type) used in the common plant area are discussed in Section 3.9 and presented in section 3.9.1, Table 4.

3.10 FAULT CURRENT RATINGS

The requirements for the respective equipment fault current ratings are provided in this section. The earth fault requirements are dictated by the earthing philosophy, as discussed in the previous section.

3.10.1 Generator Phase Isolated Busbars

The phase-isolated busbars are designed and rated following 240-56357295 (High Current Phase Isolated Generator Busbars at Thermal Power Generating Plant Standard). A phase side earthing transformer and resistor configuration is provided to limit the generator phase-to-earth current to approximately 10 A. This high impedance system prevents the development of high transient over voltages in the event of an arcing earth fault. A means for detecting ground faults within the generator is also provided.

3.10.2 Generator Circuit Breaker

a. The generator circuit breaker is phase segregated and can carry the phase-to-phase fault current of the busbar system.

b. Detailed technical requirements of a generator circuit breaker are presented in 240-56227522 (High Current Phase Isolated Generator Circuit-Breakers, Disconnectors and Generator Earthing Switches at Power Stations). The peak short circuit phase-to-phase current when the earth switch closes is 10kA. The phase-to-ground fault current is limited to approximately 10 A by the busbar earthing transformer and resistor system.

3.10.3 Generator Transformer

The Generator Transformer neutral is solidly earthed. The high fault current is a disadvantage, but this earthing method has several advantages, namely:

- Earth fault protection is easy because the fault currents are high,
- Arcing ground faults cannot occur because the short circuit current is much larger than the capacitive charging current developed between the line connection, transformer windings and ground.
- The maximum overvoltage during a fault condition is the phase-to-neutral voltage lower than the maximum for resistive earthing, which is the phase-to-phase voltage.

3.10.4 Unit Transformers

On the LV side of the Unit Transformers, an earthing resistor is implemented to limit any resulting phase to earth fault current to a maximum of approximately 300 A. The high resistive earthing on the HV kV side of the transformer will not prevent high fault currents on the LV side when a fault occurs on the LV side of the transformer. In this instance, the zero-sequence impedance of the Unit Transformer will still be low enough to allow the high phase to earth fault currents on the LV side, thus necessitating using the earthing resistor on the 11 kV side neutral.

3.10.5 Service Transformers

An earthing resistor is used on the Service Transformers' LV side (3.3 or 6.6 kV) to limit any resulting phase-to-earth fault current to approximately 300 A.

3.10.6 Station Transformer

The neutral earthing compensator (NEC) and resistor (NER) are connected in series and limit the earth fault current to approximately 300 A.

3.11 GENERATOR AND UNIT TRANSFORMERS

a. All equipment support steelwork shall be earthed with at least two connections. Where detailed instructions are not given in reference drawings, the two connections made from such steelwork preferably link to two diagonally opposite sides of the nearest mesh of the earth mat. Where the equipment is provided with an insulated earthing terminal such as lightning arresters, one of the support structure earthing straps shall run up the structure and be bolted to the equipment earth terminal.

b. All overhead earth wires are terminated using reverse pistol strain clamps onto U-bolts provided on the supporting structures. Earthing contact is achieved using a U-bolt and strain clamp, and no additional earth connections are required.

3.12 GENERATOR EXPORT SYSTEM (BUSBARS, EARTH SWITCH AND CIRCUIT BREAKER)

a. The generator shall be earthed from two points to the main station earth mat via tails on the 0 m turbine house level. Note that the generator neutral star point connection is floating.

b. The phase insulated busbars shall be earthed on one end only to the main station earth mat. This earth connection is at the busbar enclosure shorting plate, connecting the three bus ducts at the generator side. To prevent circulating currents, any equipment connected to the busbars, e.g., cubicles, excitation transformer etc.) shall be isolated with non-conducting bellows and separately earthed to the main station earth mat.

c. Secondary VT and CT connections from the breaker to the junction boxes shall be run as unarmoured cables without an earth continuity conductor. Armoured cables must be avoided because they can be the origin of large circulating currents in the armouring. VT and CT secondary terminals are earthed as per the respective drawings to the earth studs in the junction boxes to the nearest earth mat tail.

3.13 TRANSFORMERS

Each transformer tank shall be earthed following the relevant drawings referring both to the earth mat layout drawing for the point of installation of the transformer as well as the manufacturer’s drawing indicating the position of earth terminals on the transformer tank following: 240-56065080 (Large Power Transformers Standard).

3.14 MV AND LV SWITCHBOARDS, CONTROL PANELS AND CUBICLES

a. When equipment is assembled into cabinets, panels or any enclosure, it is grounded to prevent dangerous voltages that may result under any circumstances. When assembled into the cabinets using mounting brackets or plates and fixing screws, it must be kept in mind that the connection to the ground through fixing screws and the cabinet chassis is not good enough.

b. Low impedance high-frequency grounding is necessary to create a uniform potential for all electronic devices installed inside the enclosure. Therefore, bonding shall be done with a separate copper strip(s) or bar(s) to the enclosure chassis.

c. Switchboards, control panels and cubicles have an earth bar running over the length of the board. The earthing contractor shall connect this earth bar to the earth mat once for single panels and at least on each end for larger boards. Switchboards exceeding 15 m in length shall be bonded to the earth mat in three positions minimum.

d. The neutral of the main 400 V low voltage switchboard with direct transformer feeds shall be earthed inside the board at only one point. The star point neutral is earthed onto the board earth bar via a removable link. The neutral shall not be earthed again in secondary LV switchboards fed from the main 400V board to avoid circulating currents.

3.15 ELECTRIC MOTORS AND LOCAL CONTROL STATIONS

a. The earthing contractor shall earth electric motors, local control stations, and starters following the relevant drawing sheets 0.54/393.

b. According to SANS 10142-1, only one earth connection is required for a motor. For LV motors, earthing may be provided by the fourth cable core (up to 4 x 16 mm^2). A 10 mm diameter round conductor bonding to the nearest earth bar, i.e. earth conductor on cable rack or earth mat tail, shall be used for larger motors.

3.15.1 Boiler Feed Water Pumps

The boiler feed pump system and the associated control and protection equipment shall be earthed following the manufacturer’s recommendations that shall be provided to the earthing contractor.

3.15.2 Air Cooled Condensers

Earth connections are required between the Air-Cooled Condenser steelwork and the earth mat following the ACC earthing drawing.

3.15.3 Other Motors

Earthing motors shall comply with the latest revision of the Earthing Standards drawing 0.54/393 as detailed in Table 5.

Table 5: Applicable Earthing Drawing Standard

APPLICATION	0.54/393 DRAWING SHEET NUMBER
Motors fed by XLPE or Thermoplastic Insulated cables	P2
Motors fed by MICC, Conduit or PILC Steel Wire Armoured (SWA) Cables Mounted on Earthed Material	P3
Motors fed by MICC, Conduit or PILC Steel Wire Armoured (SWA) Cables Mounted on Unearthed Material	P4
Control Equipment & Motor Starters (Connected by Armoured or Unarmoured Thermoplastic Insulated Cables).	P5

APPLICATION	0.54/393 DRAWING SHEET NUMBER
Control Equipment and Motor Starters (Connected By MICC, Conduit or PILC SWA Cables)	P6
Motor Starters Irrespective of Mounting	P6

3.16 AUXILIARY BAY CABLE TUNNELS

a. A main earth conductor comprising a 2 x 10 mm diameter copper rod shall be installed on all the cable racks in the auxiliary bay for the whole length of the station. These shall be connected to the main station earth mat at every second row of columns via an earthling tail.

b. Equipment on the basement floor level shall be connected directly to the turbine and boiler house earth mats via the earth tails (where available in close vicinity).

c. Two copper rods shall also run along with the cable racks from the main cable tunnels in the auxiliary bay to the gas cleaning plant, transformer bays, air-cooled condenser substations etc.

d. Bonding of the cable tray earthling to the main station earth mat shall be performed at the points where earth tails are provided from the meshes of the earth mat.

3.17 HIGH MASTS FOR AREA LIGHTING

Earth connections of 10 mm diameter copper rod from these masts shall be run along the concrete trenches or other trenches for the supply cables to the nearest intersection with the station earth mat, where they shall be bonded to the mat by brazing or exothermic welding.

3.18 MINI-SUBSTATIONS FOR PERIMETER FENCE LIGHTING AND FENCE EARTHING

Mini substations located at various points on the terrace shall be earthed following relevant drawing sheets 0.54/393. Where necessary, and depending on the distance from the main station earth mat, tie-back to this mat shall be done using a 10 mm diameter copper rod running in cable trenches to the nearest portion of the main station mat.

Earthing of the inner perimeter fence shall be done following the relevant sheets of drawing 0.54/393. The earthing rod is buried 600 mm outside the perimeter fence and forms part of the station earth mat.

3.19 CONSTRUCTION RING

The earthling systems of the construction power supply shall be connected to the station earth mat. The mini-substations shall be earthed with earth rods in remote locations following the specification of 0.54/393.

3.20 STATION AND UNIT DIESEL GENERATORS

a. The base frames of standby diesel generators shall be earthed by the earthing contractor with two earth conductors, each comprising 2 x 10 mm diameter copper rods, allowing for possible vibration stresses, to diagonally opposite sides of the nearest earth mat mesh.

b. It is ensured that equipment mounted on the frame is adequately bonded to it.

c. The diesel generator star point shall be earthed through a Neutral Earth Transformer (NET). Where a diesel generator is connected to an earthed transformer, an appropriately rated contactor shall be integrated on the earthing conductors of the diesel generator and transformer to ensure that only one of the generators or transformers is earthed at any point in time to prevent multiple earthing points. This requirement is achieved by interlocking the contactors such that one contactor is closed at any given point in time.

3.21 CHIMNEYS

a. Chimneys shall be provided with an earthing and lightning protection system by the chimney civil contractor.

b. According to the chimney earthing drawing, the system shall comprise an air terminal, down conductors, and an earthing mat. Air terminal components shall be bonded to the chimney down conductors at intervals of 15 m maximum.

c. Chimney down conductors shall be spaced at intervals of 15 m maximum and securely bonded to the reinforcement steel at 15 m maximum. The down conductors shall be cast into the concrete. The combined rated area of the chimney down conductors shall not be less than 700 mm^2.

d. The earth mat electrode of a 10 mm diameter copper rod surrounds the chimney with inspection pits located at intervals as indicated on the relevant drawings. The aircraft warning lights shall be connected to the earthing system.

3.22 FLUE DUCTS AND SUPPORT STRUCTURES

a. The flue gas ducts shall be provided with an earthing system as per this paragraph by the earthing contractor.

b. Earth rods shall be buried along both sides of the support structures for the flue ducts. These rods shall be connected to the earth mat surrounding the chimneys and to the earth mat of the gas cleaning plant. All steel structures supporting the flue ducts shall be connected to these earth rods.

c. Wherever Teflon or other insulating “slide bearings” are installed between supports and ductwork, these are bridged by the earthing contractor with flexible copper connections (either braided tinned copper or yellow/green insulated wire of 70 mm^2).

3.23 ALL VESSELS

The earthing contractor shall bond all storage tanks to the earth mat.

For tanks with diameters less than 5000 mm, one connection is acceptable. Two connections shall be required on opposite sides to separate meshes in the earth mat for all larger tanks.

3.24 CONVEYORS

a. Mechanical interconnections of structural steel and sheet steel cladding are adequate for earthing and lightning protection purposes. The combined footing resistance of all concrete bases along the conveyors will ensure a low ohmic resistance for earthing purposes.

b. Fixed conveyor structures shall be bonded to the earthing system at each end using two separate 2 x 10 mm diameter copper rods. The connection shall be made either to the main station earth mat or transfer houses at the one end and coal stockyard or the ash dump substation earth mat at the other. Connections shall be made by brazing or exothermic welding for rod-to-rod connections or by copper clamp for copper to galvanized steel structures.

c. The shiftable conveyor structures shall be bonded at the head and tail sides with two flexible connections (alternatively 10 mm diameter copper rod can be used) of at least 70 mm^2 to the head station and the feeding conveyor.

3.25 EARTHING OF RAILS

This paragraph discusses the earthing and lightning protection requirements for equipment moving on rails, i.e. coal stackers/reclaimers and ash stackers.

3.25.1 Longitudinal Bonding

a. At all rail joints, electrical bonds are required in addition to the mechanical connection by fishplates. The electrical bonds shall be braided or laminated copper with a minimum cross-sectional area of 70 mm^2 fixed by bolting or exothermic welding on either side of the joint. An alternative is the exothermic welding of galvanized steel wire across the joint. The cross bond may also consist of 70 mm^2 stranded copper conductors with green/yellow PVC insulation with crimped-on lugs.

b. The rails must be bonded to the earthing system of transfer houses and head or tail stations by two 10 mm diameter copper rods at the head and tail end. These shall not be run side by side and, where possible, shall connect to different portions of the earthing system.

3.25.2 Cross Bonding

Cross connections between the two rails shall be established at 50 m maximum by a suitable flat copper bar or PVC insulated conductors with at least 70 mm^2 cross-sectional area. Again, a hot-dip galvanized steel strap of not less than 50 x 4 mm may be used.

3.25.3 Connections to Earth

a. It is essential to reduce the lengths of fault current paths to earth to an acceptable minimum level economically, particularly along conveyors/rails where process control cables (typically for sequence control and interlocking) are laid along the lengths of the steel structure. Only this way can the induction of disturbance signals into the process control systems be minimized. The rails are usually run on concrete sleepers on fixed installations, which have a poor transition resistance to earth. It is thus necessary to install earth spikes at distances of ± 50 m along the rails on alternative sides, i.e., the distance between two earth spikes on the same side to be 100 m. These distances may have to be decreased at installations with severe lightning activity or in areas with high soil resistivity to reduce the resistance to earth.

b. Where rails are continuously welded, electrical bonding shall be required to connect to the earth mats of transfer houses at the ends.

c. The rails are usually installed on steel sleepers with a much lower transition resistance to earth on shiftable conveyors. It is thus adequate to install earth spikes as above only about every 100 m. Once shiftable conveyors are moved, new earth spikes must be installed at the head station and other points where distance or difference in height makes it impractical to run 10 mm diameter copper rods to the established earth spikes.

d. At each earth spike position, spikes are to be driven deep enough into the ground, or multiple spikes must be installed (minimal distance equals the length of spike) to achieve resistance to a true-earth value of less than 500Ω. The resistance is to be measured after each extension or shift of the system.

3.25.4 Earthing of Land Junction Boxes

a. The armouring of fixed power supply cables shall be earthed as per standard instructions for the type of cable installed through the incoming cable gland or via a separate clamp and braided earth lead or solid earth strap. Core screens are earthed via braided earth leads from the heat shrink terminations to the earth stud or rail provided in the land junction box.

b. Single or multiple earth conductors and screens in the trailing cable must likewise be connected to the earth stud or rail inside the box. From the external earth stud of the box, an earth lead of at least 70 mm^2 shall be connected to both rails. Independent of the fact that the land junction box is a fixed or a moving installation (on shifting conveyors), an earth spike is installed at this point.

c. The armouring (if any) of fixed process control cables shall be earthed similar to above at the signal land junction box. Screens or screen drain wires of incoming cables must be terminated like cable cores but not earthed. They are to be earthed at the feeding end of the cable(s) only.

d. The cables must connect the screens or screen drain wires of outgoing flexible reeling cables to an insulated terminal block or earth bar connected to the junction box's internal earthing stud. A single 70 mm^2 earth lead is to be connected to the earth spike at the power cable junction box.

3.25.5 Earthing of Shiftable (ash) Conveyor Modules

a. At least one earth conductor shall be installed along the length of the conveyor with sufficient slack to allow for shifting of the conveyor modules. This conductor must be of 95 mm^2 bare stranded copper. Two 70 mm^2 conductors are preferred where power and control cables run on opposite modules' sides. The conductor(s) shall be connected to the earth systems at either conveyor end.

b. Each module shall be connected by one (or two diagonally placed) earth tails of 70 mm^2 with a crimped-on cable lug for connection to the module and a line clamp to the main earth conductor. The line clamp permits repositioning of the tail on the longitudinal main earth conductor if modules are unevenly spaced after shifting.

c. Through connections (i.e., short copper lengths fitted between two adjacent module faces only) are not permissible as one break can invalidate the entire earthing chain.

3.25.6 Earthing of Stacker/Reclaimer, Tripper Cars and Stackers to Rails

a. Wherever structures are not permanently joined by welding or bolting but have a swivel or other joints, e.g., bogies, earth bonds of not less than 70 mm^2 shall be fitted across such joints. At least one earth shoe located as centrally as possible relative to the entire structure shall be provided. The protection against lightning or electrical fault induced fault currents is improved by installing a shoe for each rail. The shoes must be spring-loaded to maintain good contact with the rails. Fault or imbalance/leakage currents should not flow through any of the multiple wheel bearings (pitting); hence, the importance of adequately sized, placed and maintained earth shoes onto the rails.

b. Earth bonds must allow some movement (of bogies) but may not be pigtailed and should have smooth contours and no sharp bends or kinks.

3.25.7 Earthing of on-board Equipment

On each unit, such as a stacker or link conveyor, a separate earth bus shall be installed with a copper bar of at least 50 x 3.15 mm, preferably 50 x 6.3 mm. All non-current carrying metal parts of the individual on-board installation must be connected once to this earth bus. No loops (e.g., through earth bars of switchgear) shall be established to prevent circulating currents in an earth fault situation.

3.25.8 Cross Bonding of Ash Stackers and Link Conveyors to Tripper Cars

The stacker, conveyor and tripper car are mechanically linked. Flexible earth continuity conductors of not less than 70 mm^2 shall be installed along the cable routes between the three elements forming the integrated earthing of the complete unit.

3.25.9 HV YARD

a. HV yard equipment shall be installed following the relevant drawings – 0.84/1753 sheet 1 and 0.84/1754 sheet 2.

b. The yard shall be connected to the power station earth mat by 2 x 10 mm diameter copper rods at each unit. Due to the high probability of lightning in the yard, this connection must be tested as part of the routine earthing continuity tests. Note that the current Transmission maintenance plan requires that this be tested yearly.

3.26 TESTING AND MAINTENANCE

This section prescribes how to perform maintenance on the earthing system installed at the Power Station. A good set of as-built drawings showing the earth mat layout is required to perform proper maintenance. Inspections can only be done once the drawings are in place. Two things are required to determine the condition of the earthing arrangement:

- Visual inspections, and
- Testing and measurements.

A detailed guideline is presented in 240-56356668 (Maintenance of Power Station Earthing and Earth Mats Guideline). The risk of plant damage due to lightning and electrical faults are minimised by repairing the defects and addressing the issues highlighted by these actions. Earthing and lightning protection integrity is dependent on a sound philosophy associated with a proper installation.

a. Prevention Techniques

The power station must implement maintenance measures and strategies to detect problems resulting in plant trips (loss of production) and major damages. Such techniques include a well-developed maintenance plan that is effectively implemented and continuously updated to identify shortcomings when a new plant is added. Another important aspect of prevention is carefully analysing all trips that may have been caused by interference or any other disturbance.

b. Routine Maintenance

The maintenance plan shown in the appendices is a guideline and should be considered the minimum requirement. The checks are not easy to perform (difficult to detect problems) and take a considerable time due to the diversity and widespread nature of the power station plant. The expense thereof should be seen in the context of the goals of an earthing system and the nature of the consequential damages that may be incurred.

3.26.2 Visual Inspections

a. Visual inspections shall be carried out on all the earthed equipment, and a report is produced in which the following is mentioned:

- Signs of corrosion on all metal structures, particularly fences, at ground level,
- Evidence of loose or otherwise faulty connections,
- Unnecessary bending of earth rods (sharp curves ≤ 90°),
- Unearthed electrical equipment,
- Unearthed structures and
- Any signs that the earthing copper may have been stolen.

b. A complete inspection should be performed every eighteen months, although regular plant checks (every six months) are recommended. The recommended maintenance schedule shown in Appendix D shall be used to ensure that a complete inspection is performed. It is essential to document all inspections.

c. Herewith are the minimum requirements when performing inspections on the earthing installation:

- All earth tails must be checked for corrosion. At substations where the corrosion index stipulates, this check shall be carried out more frequently. These earth tails are either copper or galvanized steel.
- In the HV yard, where the layer of crushed stone at the copper tail can be removed and, at minimum, the top 100 mm of soil, the copper is checked for pitting (only spot checks are required).
- The soil must be excavated below the galvanized steel-copper joint where the tail is galvanized steel. The galvanized steel and copper must be checked for pitting.
- Where a section is badly pitted, this section must be replaced. To do this, first bond the new section of copper to either side of the pitted section. The pitted section can then be cut away, and the section must be sent away for analysis. A soil sample must be taken and sent for analysis.
- Complete the substation Earthing System Checklist.

3.26.3 Earthing Triangles

a. The earth tail reference point shall be used to enable the repeating of the continuity tests. The reference points are the earth mat tails (and major plant, e.g., generator, chimney, etc.), marked in the plant with green triangles, with numbers corresponding to the number on the drawing. The earthing contractor shall install these triangles.

b. The continuity measurements are then performed between the triangles and between the equipment and the triangles. This procedure can be repeated for routine tests. The procedure is a straightforward but effective method. The green triangles can also be used for measurements from equipment during problem-solving with a high level of trust.

3.26.4 Test and Measurements

a. Periodical measurements of continuity and resistivity to true-earth must be recorded in a log sheet or book to recognise changes and counter-measures if values deteriorate. Only an effectively maintained earthing system would provide personnel and equipment's designed/required safety against the consequences of fault conditions resulting from lightning activity or electrical faults.

b. It is vital to check measurements immediately after installation and record the results in a particular log at regular intervals. Tests should be conducted after any major electrical fault. It is vital to ensure that the earth mat of any new installation is correctly bonded to the existing earth mat. All earth connections are essential, but special attention should be given to:

- Earth connections of generator transformer star points, surge arresters, CTs, VTs, NECs or earthing resistors and,
- The effectiveness of bonding between the VTs and CTs' secondary circuit star points (usually earthed at different locations) must be verified.

c. Besides comparing the new and the old test results, comparisons can also be made between the resistances between similar parts on different Units. Interpretation of these continuity measurements and resistance to true-earth indicate the earthing installation's quality and expected life.

d. These tests are performed to verify that the plant is adequately earthed. The record-keeping of the tests is essential. The maintenance (PM) feedback should reflect the measurement, and inspection report numbers should be reflected in the maintenance (PM) feedback.

3.26.5 Earth Resistance Measurements

a. The Earth resistance test indicates the resistance to earth, which is important where personnel can have simultaneous contact with structures and earth, such as fences, conveyors, HV Yard, transformer yards, etc.

b. Earth resistance tests should be carried out at least every second year, preferably before the rain season starts when the soil is dry and has high ground resistance (the worst case).

c. The resistance test is performed with respect to the most critical reference points of the earth mat tail. The reference points are earth tails in the power station marked and numbered with green triangles and a number inside the triangle. The drawings indicate the reference points as they are identified and marked on site.

d. The earth tails are fixed points with recorded earth resistance readings. The readings can be compared over the years to indicate if the resistance to earth stays stable. It is important to record environmental information concerning the time of the year and the rainfall pattern during measurements because this will influence readings. The resistance readings should be smaller than 0.14 Ω to keep the touch-potential smaller or equal to 165 V.

3.26.6 Continuity Measurements

a. This test indicates how good the connection between any two earthing points is. Continuity tests are carried out every eighteen months on all the major earthed equipment on the power station. This test should be performed more frequently when any busbar fault or internal substation fault occurs or direct lightning hits in any area.

b. The continuity test is important because the risk of damage is dramatically decreased when the whole system rises in voltage during a surge. Plant damage is minimised or avoided when there is good continuity between equipment. The continuity test is done from the reference points, and the resistance tests prove these points.

c. While the measured resistance depends on the distance between the two chosen structures, a rough guide for separations of less than 100 m is that 30 mΩ or less would indicate proper copper bonding. However, should the reading be 100 mΩ or more, then the connection is via a stray path through steel. If steel droppers down to a buried copper earth mat are used, about 10 mΩ should be added to the above figures.

d. Continuity tests are carried out on selected metal structures inside the power station and outside in the associated transfer houses, substations, and other buildings to ensure continuity between them by the buried copper earth mat. Continuity tests use a megger or micro-ohm meter. The continuity reading should be smaller than 12 mΩ.

3.27 DOCUMENTATION AND RECORDS

It is challenging to maintain earthing and lightning protection due to its nature and widespread layout. Therefore, additional measures must be implemented to ensure an effective system. The earthing documentation plays a vital role in ensuring that the risks associated with earthing and lightning protection are minimised. Documents should be in place and accessible to personnel, kept updated and only changed as per the applicable change/modification procedure.

3.27.1 Design Standard

A well-documented design standard can be used as a training tool for new personnel, a reference tool for the project engineer, system engineer and maintenance personnel, and it can also be used as part of the technical specification for modifications and additions to the plant.

3.27.2 Drawings

As mentioned in the previous section, the drawings are a maintenance check reference and should reflect the as-built status of the installed plant. The drawings should be easily accessible to personnel, wherein updates and changes are managed by the change/modification procedure.

3.27.3 Maintenance Plan and PMs (planned maintenance activities)

The maintenance plan and check sheets in appendices C, D and E should be used to generate the PMs used by the maintenance personnel to perform the inspections and tests.

3.27.4 Test reports

The test reports are used as a reference to determine plant defects. Their format should be standardised to ensure that the latest test results can be compared with the old test reports. The reports should also be registered and referenced correctly in the PM to enable retrieval later.

3.27.5 Visual Check Reports

Visual checks are one of the most difficult routine maintenance tasks to perform due to the diversity of the plant, and inaccessible areas of the earthing installation, among other challenges. The person performing the visual checks is familiar with the plant and the associated earthing and lightning protection installation to identify defects. The area of responsibility should not be too wide because that will make the task too large and discourage the individual from performing the task effectively.

3.27.6 Copper Theft Reports

Copper theft incidents should be documented on the defect system when detected. The incident should be appropriately investigated (power station occurrence procedure), and the quantity and possible origin should be determined. The history would enable the system engineer to detect any trends concerning copper theft, and it would also give some feeling of where to look for missing copper when plant visual inspections are performed.

3.28 DRAWINGS AND SPECIFICATIONS

Table 6: Drawings

NUMBER	DESCRIPTION
0.54/393 General and as applicable to Generation[4]	Eskom earthing standards
As may be applicable at a specific site	Key plan earth mat layout
As may be applicable at a specific site	Unit 1 to 6 earth mat layout
As may be applicable at a specific site	Typical Unit earth layout
As may be applicable at a specific site	Units 1 to 6 generator transformer yard earth mat layout
As may be applicable at a specific site	Units 1 to 6 air-cooled condensers earth mat layout
As may be applicable at a specific site	132 kV station transformer yard earth mat layout
As may be applicable at a specific site	Station services building
As may be applicable at a specific site	LP services earth mat layout
As may be applicable at a specific site	Water treatment plant earth mat layout
As may be applicable at a specific site	Units 1 to 6 coal silo earth mat layout
As may be applicable at a specific site	Auxiliary Cooler system earth mat layout
As may be applicable at a specific site	Boiler blowdown recovery water sump earth mat layout
As may be applicable at a specific site	Auxiliary bay Unit 1 equipment room earth mat layout
As may be applicable at a specific site	Auxiliary boiler earth mat layout
As may be applicable at a specific site	HV yard foundation earth mat and trench layout

[4] https://hyperwave.eskom.co.za/Eskom/Technology%20and%20Commercial/Group%20Technology/Engineering/Power%20Delivery%20Engineering/PDEDepartments/Substation%20Engineering/Standard%20Designs/Earthing

4. AUTHORISATION

This document has been seen and accepted by:

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5. REVISIONS

Date	Rev.	Compiler	Remarks
November 2012	0	T Joni	Draft Document for review created from 474-085
June 2013	1	T Joni	Final Document for Publication
January 2019	1.1	W Sinema	Draft document with comments for further deliberation by Work Group members
May 2021	1.2	V Mathebula	Draft document issued for formal review by Work Group members, Revision includes detailing of requirements and alignment with related standards and systems, including additional C&I requirements in Appendix E.
May 2021	1.3	V Mathebula	Draft document issued for formal review by external stakeholders comprising Station System Engineers and Generation Protection Care Group.
April 2022	1.4	V Mathebula	Draft document with consolidated comments. Updated Sections: Responsibilities: Clauses 2.5 Design Criteria, Principles and Guidelines: Fault Levels in Table 1: Clause 3.2.4.2, Connections: Clause 3.2.4.6 Surge Protection Application: Zones of surge protection: Clause 3.3.1.2 Installation: Supply cable earthing requirements: 3.5.2.2, Table 3: Neutral and Resistance Earthing: Clause 3.9 Table 3: Clause 3.9.1 Generator Earthing: Clause 3.9.2, Small Generators: Clause 3.9.2.1 Unit Transformer Earthing: Clause 3.9.5, Station Transformer Earthing: Clause 3.9.7 Fault Current Ratings: Generator Phase Isolated Busbars: Clause 3.10.1, Generator Circuit Breaker: Clause 3.10.2, Unit Transformers: Clause 3.10.4, Service Transformers: Clause 3.10.5. Electrical Motors and Local Control Stations: Clause 3.15 Station and Unit Diesel Generators: Clause 3.20 Tasting and Maintenance: Clause 3.26
May 2022	1.5	V Mathebula	Draft document with consolidated comments. Updated Sections: Design Criteria, Principles and Guidelines: Clause 3.2(a) Conductors: Clause 3.2.4, Fault Levels in Table 1: Clause 3.2.4.2, Conductor sizes: Clause 3.2.4.4, Materials used: 3.2.5 Brazing of Copper: Types of Joints: 3.4.2 Conductor sizes updated where application in the Standard to align with SANS 1195. Appendix A: Schedule of Earthing Conductor Sizes: Conductor sizes updated.
May 2022	2	V Mathebula	Final Rev 2Document for Authorisation and Publication

6. DEVELOPMENT TEAM

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7. ACKNOWLEDGEMENTS

Great appreciation goes to all who originally drafted the standard, Thandie Joni for revising the document into the latest format, Winston Seima for initiating the review discussions of the latest revision and all reviewers for their invaluable input.

8. APPENDICES

APPENDIX A:
- Schedule of Earthing Conductor Sizes

APPENDIX B:
- Earthing Audit Check Sheet

APPENDIX C:
- Continuity Measurements Check Sheet

APPENDIX D:
- Scheduled Maintenance Activities

APPENDIX E:
- Earthing and Lightning Protection Guidelines for the Design and Installation of Process Control & Instrumentation Equipment/Systems

APPENDIX A: Schedule of Earthing Conductor Sizes

REF. CLAUSE	DESCRIPTION OF PLANT	DESCRIPTION OF EARTHING	RATED AREA OF COPPER (mm^2)	NUMBER OF CONNECTIONS	CONDUCTORS PER CONNECTION	ALTERNATIVE CONDUCTOR SIZES (mm)
	Generator and Unit Transformers	- Connection straps - Earth rods	600	2	2	- 50 x 3.15 mm - 2 x 10 mm ø
	Generator, 22 kV Phase Isolated Busbars (IPB), Earth Switch and Circuit Breaker	- Connecting straps - Earth rods	600	2	2	- 50 x 3.15 mm - 2 x 10 mm ø
	Generator VT or CT cores, surge arrestors and earthing transformers	- Connection straps - Earth rods	150	1 each	1	- 50 x 3.15 mm - 2 x 10 mm ø
	Transformers	- Connecting straps - Round earth conductor - Insulated earth conductor	600 70	2	2	- 50 x 3.15 mm - 2 x 10 mm ø - Cable
	Trefoil cable bonds	- Connecting straps - Earth rods	75	1	1	- 25 x 3.15 mm - 1 x 10 mm ø
	Lead sheaths of MV cables	- Connection straps - Round earth conductor	75	1	1	- 25 x 3.15 mm - 1 x 10 mm ø
	Cable Junction Boxes	- Connecting straps - Earth rods	75	1	1	- 25 x 3.15 mm - 1 x 10 mm ø
	MV switchgear	- Connecting straps - Round earth conductor	600	2	2	- 50 x 3.15 mm - 2 x 10 mm ø
	690 V & 400 V switchgear (Unfused supply)	- Connection straps - Round earth conductor	600	2	2	- 50 x 3.15 mm - 2 x 10 mm ø
	690 V & 400 V switchgear (Fused supply)	- Connection straps - Round earth conductor	150	2	1	- 50 x 3.15 mm - 1 x 10 mm ø

REF. CLAUSE	**DESCRIPTION OF PLANT**	**DESCRIPTION OF EARTHING**	**RATED AREA OF COPPER (mm^2)**	**NUMBER OF CONNECTIONS**	**CONDUCTORS PER CONNECTION**	**ALTERNATIVE CONDUCTOR SIZES (mm)**
	Control stations starters etc.	- Connecting straps - Round earth conductor	75	1	1	- 50 x 3.15 mm - 1 x 10 mm ø
	MV motors	- Connection straps - Round earth conductor	150	1	1	- 50 x 3.15 mm - 2 x 10 mm ø
	LV motors: 400 V, 690 V and 220 V DC (above 30 kW)	- Connection straps - Round earth conductor - Insulated earth conductor	75 70 or 16	1	1	- 25 x 3.15 mm - 1 x 10 mm ø - Cable
	LV motors: 400 V, 690 V and 220 V DC (below 30 kW)	Earth continuity conductor in the supply cable	1.5 to 16	1	1	- Cable
	Air Cooled Condensers	- Earth mat - Earth bar - Steelwork/earth mat connection	- 75 - 150 - 600	-- 1 2	-- 1 2	- 10 mm ø - 50 x 3.15 mm - 2 x 10 mm ø - 50 x 3.15 mm - 2 x 10 mm ø
	Computer and Computer Room Earthing	Floor grid/earth mat connecting straps	75	1	1	- 25 x 3.15 mm
	Water treatment plant	- Earth mat - Earth bar - Earth bar/earth mat connection	- 75 - 150 - 75	-- - 1 - 1 (min)	-- - 1 - 1	- 10 mm ø - 50 x 3.15 mm - 2 x 10 mm ø - 25 x 3.15 mm - 1 x 10 mm ø
	Workshops and stores	- Earth mat - Earth bar	- 75 - 300	-- - 2	-- - 2	- 10 mm ø - 50 x 3.15 mm - 2 x 10 mm ø

REF. CLAUSE	DESCRIPTION OF PLANT	DESCRIPTION OF EARTHING	RATED AREA OF COPPER (mm^2)	NUMBER OF CONNECTIONS	CONDUCTORS PER CONNECTION	ALTERNATIVE CONDUCTOR SIZES (mm)
	Fuel oil plant	Earth bar/earth mat connection	150	2 (min)	1	- 25 x 3.15 mm - 1 x 10 mm ø
	Boiler and turbine house steelwork	- Earth mat - Main earth bar - Earth bar/earth mat connection - Subsidiary earth bars	- 75 - 300 - 120 - 230	-- - 1 - Every 2 columns - 2	-- - 1 - 1 - 1	- 10 mm ø - 50 x 6.3 mm - 2 x 2 x 10 mm ø - 40 x 3.15 mm - 1 x 10 mm ø - 40 x 3.15 mm - 1 x 10 mm ø

APPENDIX B: Earthing Audit Check sheet

The following information should be recorded and kept on-site so that recently obtained test results can be compared with the corresponding previous results to see if there has been any deterioration (an increase of resistance) in the earth mat.

B.1 Continuity Measurements

- Date of earth continuity test.
- Reason for a test, i.e. annual, fault or extension.
- If after a fault, please give details of the fault.
- The result of the test gives the location tested and the milli-ohms measured.
- Details of instrument used for testing.
- Name of the person who did the test in print and signature.

B.2 Inspections

- Date of inspections.
- A copy of the “Station Earthing System Check List” is duly completed.
- Extent, if any, of the pitting found per individual tail.
- Any section of a tail, which has been replaced.
- The date the replaced section and soil sample was sent to the laboratory.
- Date and results of any tests carried out.
- Follow-up actions that were taken as per the test recommendations.
- Name of persons performing inspection and follow-up.

B.3 Earthing System Checklist

Are all equipment items in the HV yard visibly earthed by flat copper straps, 10 mm diameter conductor or galvanized steel?	YES	NO
RESULT – REMARKS		
Is there electrical continuity between all items of earthed equipment?	YES	NO
RESULT – REMARKS		
Has the electrical continuity been checked with a milli-ohm meter? Date: _	YES	NO
RESULT – REMARKS		
Are all earthing connections to the HV yard fence visible?	YES	NO
RESULT – REMARKS		
Is there at least a 100 mm depth of crusher stone cover in the yard?	YES	NO

RESULT – REMARKS		
Are there any signs of weed encroachment in the HV yard?	YES	NO
RESULT – REMARKS		
Has any external fence been constructed which joins the HV yard fence?	YES	NO
RESULT – REMARKS		
Have any of the existing railway lines been electrified since the last inspection?	YES	NO
RESULT – REMARKS		
If yes, have Engineering adjusted the earthing design to compensate for this?	YES	NO
RESULT – REMARKS		
Are the earth wires of incoming power lines insulated at the terminal towers?	YES	NO
RESULT – REMARKS		
Are there any signs of copper corrosion of earthing connections, e.g. green deposits?	YES	NO
RESULT – REMARKS		
A typical connection nearest to railway traction (if applicable) should be uncovered below the crusher stone and below virgin soil, levels to a depth of at least 100 mm, and be inspected for copper corrosion		
RESULT – REMARKS		
Where galvanized steel has been used to connect equipment to the copper earth mat, a typical connection shall be exposed to the connection to the copper grid and inspected for corrosion and pitting		
RESULT – REMARKS		
What type of soil is in the HV Yard substation, e.g. dry red sand, moist black sand, lime, clay, marsh etc.?		
DESCRIPTION		
What is the soil resistivity?		
AREA	**OHMS METERS**	

B.4 Soil Sample Procedure

- A minimum of 1 kg of soil is required.
- The sample must be taken from the same depth where the earthing is buried. The minimum distance should be 1 meter from the affected section of the earth. If the backfill is different from the area's natural soil, ensure that the sample is taken from the backfill.
- The soil sample must be placed in a clean, sealed plastic container.
- The soil sample must be sent to the laboratory together with the following information:
  - Power station’s name
  - The place from where the sample was taken
  - Reference (if any)
  - Contact person’s name and telephone or email number

APPENDIX C: Continuity Measurements Check sheet

Note that the earthing drawings are used as measurement check sheets. This check sheet summarises the measurements for easy checking and future reference.

From: ref. point (no.)	To: ref. point (no.)	Reading (mΩ) Date 1	Reading (mΩ) Date 2	Reading (mΩ) Date 3	Reading (mΩ) Date 4

APPENDIX D: Scheduled Maintenance Activities

Description of action	Reason for action	Frequency	Duration	Unit outage	Comments
Inspect air terminations	Provide a path for lightning current	6 months	2 d	No	
Inspect down conductors	Provide a path for lightning current	6 months	4 d	No	
Inspect bonding of air terminations to down conductors	Ensure a proper path for lightning current	6 months	1 w	No	
Inspect continuity of external lightning protection	Ensure a proper path for lightning current	6 months	1 w	No	
Tight bolted joints of external lightning protection	Ensure a proper path for lightning current	6 months	1 w	No	
Inspect bonding of down conductors/steel structures to earth tails	Improve continuity and provide safety (bring touch potential down)	6 months	1 w	No	
Tighten bolted joints to earth tails	Ensure good connection when current flow	6 months	5 d	No	
Inspect galvanic continuity of cable support systems (cable racks, conduit) - take care at 90° bends	Interference to control cables is undesirable (the most significant cause by magnetic coupling)	6 months	1 w	No	
Ensure earthing is properly fixed	Significant forces when high currents flow	6 months	5 d	No	
Tighten the joints between earth rods and equipment, like motors, switchgear cubicles, etc.	Ensure a proper connection and low touch potential when current flows	6 months	5 d	No	
Inspect and ensure proper bonding of the joints between earth rods and equipment, like motors, switchgear cubicles, etc.	Ensure a proper connection and low touch potential when current flows	6 months	5 d	No	
Test continuity of external lightning protection	Without continuity is a risk of damage high during surges (keep the resistance $\leq$ 12 mΩ)	1 year	2 w	No	

Description of action	Reason for action	Frequency	Duration	Unit outage	Comments
Test galvanic continuity of cable support systems (cable racks, conduit) - take care at 90° bends	Interference to control cables is undesirable (most significant cause by magnetic coupling – keep the resistance ≤ 12 mΩ)	2 year	2 w	No	
Test the resistance to earth of all the reference points	Ensure there is a proper connection down to earth (keep the resistances to earth ≤ 0.14 Ω)	5 years	1 w	No	Don't invest too much money to improve this reading. There are other factors to consider for surges.

APPENDIX E: Earthing and Lightning Protection Guidelines for the Design and Installation of Process Control & Instrumentation Equipment/Systems

E.1 Introduction

This APPENDIX intends to document the earthing and lightning protection requirements for the design and installation of process control & instrumentation systems/equipment at Eskom Power Stations.

E.2 Scope

This APPENDIX documents the earthing and lightning protection requirements for the design and installation of process control & instrumentation systems/equipment. The requirements for testing, maintenance, documentation and records are covered in the main document (240-56356396 Earthing and Lightning Protection Standard).

Figure E.1 below shows a typical cabling concept and is provided to define the earthing scope.

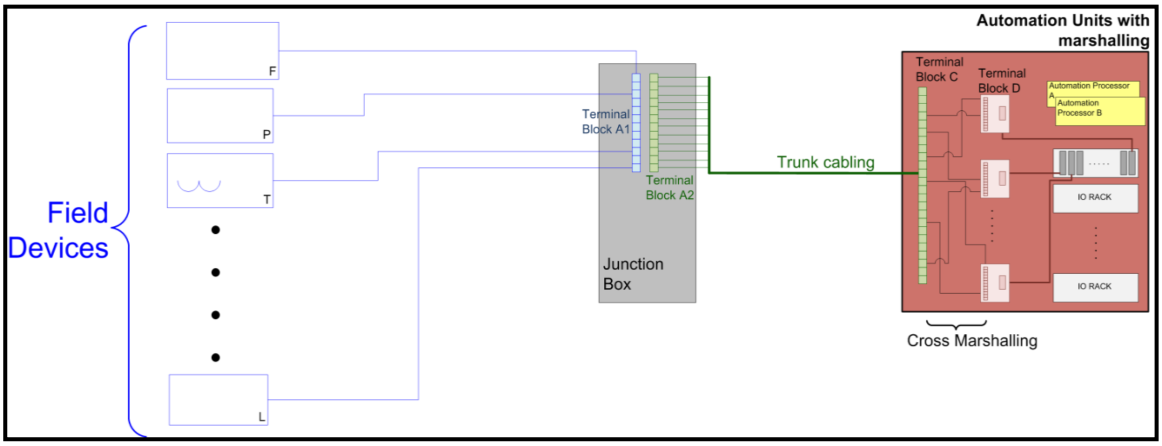

Figure E.1: Process Control & Instrumentation Typical Cabling Concept.

The Earthing Scope, as Indicated In Figure E.1, Includes:

- Enclosures (Junction box and Automation Units Cabinets)
- Cabling (Cabling between field devices and Junction Box and between Junction Box and Automation Unit Cabinets)

The detailed earthing signal grounding of the DCS/PLC network and electronic equipment such as I/O cards, processor cards, network switches, etc., is not specified in this APPENDIX. The OEM shall provide a detailed philosophy and design with installation and testing instructions during the project execution for such equipment.

E.3 Enclosure Design and Installation

E.3.1 Junction Box Earthing

Earth straps shall be bolted to earth studs. Each stud shall be welded or bolted to the junction box. An inside and outside earth stud shall be formed from the same bar, or separate (inner and outer) studs shall be located adjacently inside and outside the enclosure. A bolt and nut arrangement may also be used. Flat washers shall be used as the final mating surface where studs are not welded to the plate.

Cable shields/armouring shall be 360º bonded to the outside of the enclosure. All earth connections shall follow the shortest path, and no 'pigtails' are allowed. Cable entries to the enclosure shall be on the same side as the earthing stud/connection (or vice versa).

Doors shall be bonded to the enclosure, and doors greater than 0,5 m in length shall be bonded in two different locations. Long doors shall be bonded every 0,5 m. Bonds shall be made using braided copper strapping not less than 10 mm wide and has a width to thickness ratio of not less than 5:1. Doors of enclosures used outside buildings shall have a minimum of two straps.

Junction boxes shall be connected to the earth mat by the shortest possible low induction path. The earthing interface for metal enclosures can be via the racking structure if the racking provides adequate equipotential earth bonding on more than a single point. Else dedicated earthing conductors will be provided between the junction box and the closest station earth reference point. Note that the station earthing reference point refers to the protective earth network distributed throughout the plant.

The junction box earth is isolated from the cable screens (discussed in section E4) and connected to an insulated floating screen busbar in the junction box.

E.3.2 Automation (Control System) Unit Cabinets Earthing

The earthing concept applied to the C&I system forms an integrated design within the marshalling and control system cabinets and considers the field interface for I/O as well as cabling. The concept applied by Eskom for C&I control systems provides for an isolated earth reference from the C&I cabinets to the station earth reference. The station earth reference is the common earth busbar nearest the station earth point.

The internal racking within cabinets is bonded to the cabinet enclosure. In addition, earthing connectors can be provided if the bonding is impacted by painting or mounting concepts, reducing bonding efficiency.

All internal cabinet earthing provide a separate signal earth busbar and a protection earth busbar. A supplier provides sufficient design information and motivation if a supplier's design provides for a common cabinet earth reference at the cabinet level, allowing for the connection of the signal earth and protective earth. Other aspects that can also influence the common busbar principle are cabinets that provide high voltage switching components.

The control system cabinet's enclosures are mechanically bonded to adjacent cabinets. Care must be taken to ensure proper equipotential. In addition, the cabinet protective earth busbar per cabinet is connected to adjacent cabinets. The same concept is applied to the signal earth busbar. The connection between the cabinet protection earth busbar and the C&I room protection earth busbar needs to be installed using the appropriate size earthing connectors that support the connection distance. The cabinet earthing busbar and the C&I room busbar must be connected to several cabinets, preferably every second cabinet. The signal earth busbar has the same requirement. This approach ensures effective earthing and mitigates the loss of earthing references due to cable theft.

The C&I room common protection and signal busbar must only provide for the associated C&I equipment earthing of the room. If the supplier designs effectively support a single cabinet earth reference for the protection and signal earth, only a single room earthing busbar will be required. Common practice due to cable theft has resulted in utilising suitable non-copper conductors for the earthing. Other non-C&I equipment installed in the same room must be provided with a separate earthing room busbar.

The C&I room earth busbar is connected to the station earth reference busbar directly connected to the station earth reference. Potential differences may be introduced when using more than one conductor between the C&I room busbar and the station reference busbar must be considered in the earthing design and resolved. This busbar must form the lowest or closest reference to the station earth reference. The C&I control earth reference must not be connected to the protection earth of the general plant between the C&I room and the station earth reference.

The correct station earthing principle is critical to the correct operation of the C&I system and the vulnerability of the over C&I system to potential surges.

E.4 Cable Design and Installation

The process control & instrumentation cables include standard multi-core, unarmoured and screened cables and special cables such as coaxial, compensating and other cables (i.e. cables for PA systems). These cables are not armoured but have braided screens or taped screens with screen drain wires to prevent the coupling of interference voltages. The type of screening depends on the interference frequency. The braided type screens are more efficient against the higher frequencies (i.e. handheld radios > 500 MHz).

E.4.1 Cabling Support Structure and Segregation

The cables are laid on the station cable racking system dedicated to process control & instrumentation cables. This system is connected to the main document's power station equipotential surface earth bonding system following the requirements specified in Section 3.5.1 (Earthing with Cable Racking).

Care should be taken to ensure segregation of the process control and instrumentation cables from the low voltage and medium voltage power cables. Figure E.2 below summarises the minimum required spacing between cable classes when run over a single parallel earth conductor (PEC).

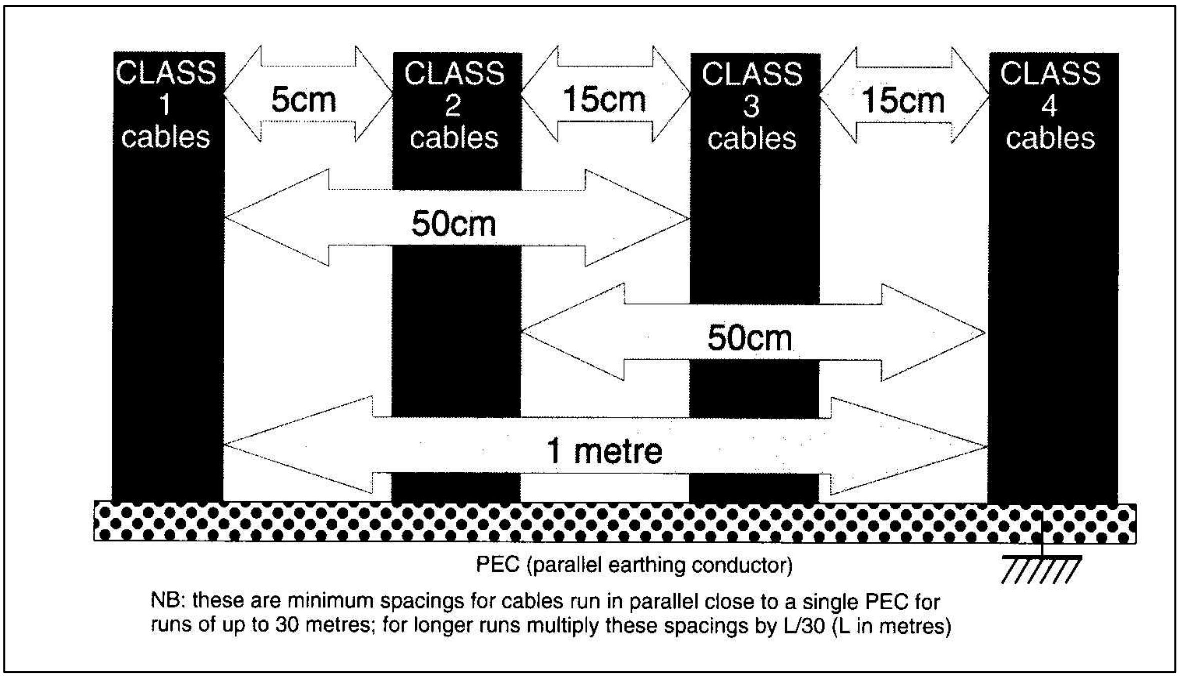

Figure E.2: Summary of the Required Cable Segregation.

The cables classes as specified in the standard [to include a reference standard] are:

- **Class 1** Very sensitive cables
- **Class 2** Slightly sensitive cables
- **Class 3** Slightly interfering cables
- **Class 4** Strongly interfering cables
- **Class 5 & 6** Medium Voltage (MV) and High Voltage (HV) cables

The Eskom minimum spacing requirement between process control and instrumentation cable racks and power cable racks is 1000 mm.

E.4.2 Earthing and handling of Screens

E.4.2.1 Trunk and field cabling

The signal wires for trunk and field cabling should be shielded. Although the shields (screens) can be earthed at both ends, the Eskom approach is earthing the shield wires only at the system end (i.e. at the Automation Unit cabinet) to limit ground loops.

The automation unit cabinet shall have a shield busbar, in which all the shield wires are terminated and connected to the clean earth. If marshalling cabinets are used in the same room as the automation cabinets, the shields from the shielded cables must be connected to the marshalling shield busbar and the clean earth.

The shield wires from the trunk and the field cables are connected to the junction box screen bar to form a loop at the junction box.

The shield wire should not be connected to the earth at the field device end. The shield wire is to be isolated from the other wires and insulated with the heat shrink sleeve to ensure it does not touch the device's body.

E.4.2.2 Special Cabling (Coaxial Cables)

Coaxial cables are shielded cables where the shielding is used as the return path for the signal. The general rule appropriate for the active circuit should apply, and the shield should be earthed at only one end. However, coaxial cables are usually used for transmitting HF or VHF signals where, due to skin effect, a natural decoupling occurs between the currents flowing on the inner surface of the shield (signals) and those flowing on the outer surface of the shield (disturbances). Due to this phenomenon dealing with transfer impedance, the shield of coaxial cables can, in most cases, be earthed at both ends. This requirement assumes that the disturbances are at high frequency or, if they are not, that the signals are high-pass filtered. For long-distance connections and particularly for connections involving different earth networks, it remains advisable not to ground the shield at both ends or put an Earthed Conductor in Parallel (ECP).

E.4.2.3 Cabling for special measurement signals (e.g. Vibration, intrinsic safety applications)

Special measurement signals, such as vibration and speed measurements, must be handled according to the OEM guidelines regarding the shielding concepts (e.g. to mention a few: minimise lengths, no loops, etc.). The detailed design needs to review special applications of field equipment for the earth and non-earth devices.

E.4.2.4 Bonding of cable shield to the cabinet walls

To prevent interference from common-mode currents, proper 360° bonding of cable shields (screens) shall be done on both ends of each cable to the cabinet walls as indicated in Figure 2. Bonding of cable shields this way will allow unwanted, common mode current to be directed back to its source, away from sensitive control equipment.

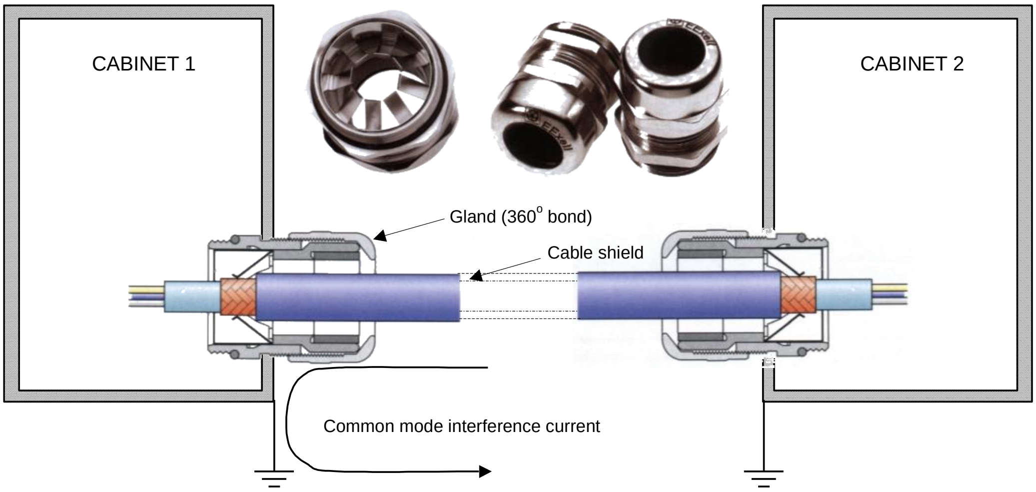

Figure E.1: 360° Bonding of Cable Shield to the Cabinet Walls (Both Sides)

E.4.2.5 Earthing and handling of Screens in Cabinets

The screen shall be connected in connection cables between cabinets on both ends. The screen shall be connected on one end for external marshalling outside the earthing area connections. For cables running from the cabinets to other plant components, the screen shall be earthed in the cabinet only. Note that there are special requirements for the connection of the screens of the different types of cables

E.5 Surge Protection Requirements

Surge protection shall be provided for unitised and outside plant applications exposed instrumentation. More technical detail requirements are stated in section 3.3 of this standard. The surge protection devices must be maintained according to a maintenance strategy supported by the OEM recommendations and provide for annual inspections of the condition of the surge protection device.