Eskom	Concept Design	Nuclear Engineering

Title: Concept Design for Earthing and Lightning Protection on New Nuclear Build Power Stations

Document Identifier:	**240-131750549**
Alternative Reference Number:	**N/A**
Area of Applicability:	**Nuclear Build Engineering**
Functional Area:	**Nuclear Engineering**
Revision:	**1**
Total Pages:	**41**
Next Review Date:	**N/A**
Disclosure Classification:	**Controlled Disclosure**

Compiled by	**Functional Responsibility**	**Authorized by**
KAMaluleke		
K.A Maluleke	**K. L Molele**	**K. M. Msabala**
Senior Technician	**Senior Engineer**	**Senior Manager (Acting)**
Nuclear Engineering	**Nuclear Engineering**	**Nuclear Engineering**
Date: 2017-10-31	Date: 2017-10-31	Date: 2017-10-31.

Nuclear Additional Classification Information

Business Level:	**3**
Working Document:	**4**
Importance Classification:	**No**
NNR Approval:	**No**
Safety Committee Approval:	**No**
ALARA Review:	**No**
Functional Control Area:	**Integrated Plant Design (Fleet)**

CONTENTS

1. LIST OF FIGURES

2. LIST OF TABLES

1. INTRODUCTION

In line with the Integrated Resource Plan 2010 (IRP 2010), Eskom intends to build a fleet of New Nuclear Power stations to expand the South African power generating capability to satisfy future demand. Various sites for this purpose have been identified and are subject to the Environmental Impact Assessment (EIA) process, prior to final selection. The development of the nuclear fleet will be divided into manageable projects cumulating to 9600 MWe. The first of these projects, commonly known as the Nuclear-1 Project, is expected to be constructed at the Thyspunt site (Eastern Cape) with the first unit planned for commissioning in 2023.

Eskom has identified numerous readiness activities to support sustainable development of the proposed power stations. Amongst these activities, is the establishment of an Earthing and Lightning Protection System (ELPS) that safeguards personnel and sensitive equipment from hazardous step and touch potentials. These potentials are normally induced by atmospheric conditions (Lightning stroke, static induction) or from electrical system earth fault currents.

When lightning strikes an object on earth with a natural high impedance, unwanted heat and mechanical damage can occur since the stroke energy isn't efficiently dissipated into ground. The purpose of a LPS is to intercept an incoming flash and provide a low impedance path to ground in order to dissipate the stroke energy safely and quickly, thereby protecting the structure. No LPS is 100% effective and the design of a LPS is related to statistical probabilities and risk management. A system designed in compliance with a specific standard should statistically, mitigate the risk of lightning damage below a defined threshold. In accordance with the Lightning Protection Standards [2][3], induced currents from a lightning flash can enter a structure, through an indirect flash to a service connected to the structure such as Telephone lines, water pipes and so forth.

Electrical System Earthing (ESE) is normally made at the neutral point of the supply equipment, to establish the ground reference of the system. This ensures a low impedance path for electrical fault currents to ground, which enables the circuit protection to detect and trip the faulty circuit in a short time. The magnitude of the earth fault current can be limited by the earthing topology of the neutral point such as solid grounding, resistive grounding or transformer grounding. Electrical system earthing, service earthing as well as other lightning protection systems, will be interconnected to form a station earth mat with a common ground potential as illustrated in Appendix A, Figure 4. However, these earthing systems will function independently and dissipate induced lightning and electrical fault currents safely.

The objective of this document is to prescribe a conceptual design methodology, for an effective Earthing and Lightning Protection System (ELPS).

1.1 SYSTEM IDENTIFICATION

System Codification	N/A
System Name	Earthing and Lightning Protection
Official System Abbreviation	ELPS

2. SUPPORTING CLAUSES

2.1 SCOPE

This document establishes the key concept design principles for an Earthing and Lightning Protection System to be implemented at all New Nuclear Power stations. It serves as the precursor for the site specific basic design. The concept design is in adherence to the code of engineering practices and is aligned to the statutory standards.

2.1.1 Purpose

The purpose of this document is to prescribe a conceptual design methodology and to establish fundamental attributes of an effective Earthing and Lightning Protection System (ELPS).

2.1.2 Applicability

This document is relevant to the following departments:

- Nuclear Client Office – Operations Readiness
- Nuclear Client Office – Project Management
- Nuclear Engineering – Integrated Plant Design (Fleet)
- Nuclear Engineering – System Design Engineering

2.2 REFERENCES

The following references are applicable.

REF NO	DOCUMENT TITLE	DOCUMENT NUMBER	YEAR / REVISION	PROPRIETARY CLASSIFICATION
[1]	The design and installation of earth electrodes	SANS 10199	2010, Ed 2.1	Public Domain
[2]	Protection against lightning - Physical damage to structures and life hazards	SANS 10313	2010, Ed 3.1	Public Domain
[3]	Protection against lightning, Part 1 : General Principles	SANS 62305 Part 1	2007, Ed 1	Public Domain
[4]	Protection against lightning, Part 2 : Risk Management	SANS 62305 Part 2	2007, Ed 1	Public Domain
[5]	Protection against lightning, Part 3 : Physical damage to structures and life hazards	SANS 62305 Part 3	2007, Ed 1	Public Domain
[6]	Protection against lightning, Part 4 : Electric and electronic systems within structures	SANS 62305 Part 4	2007, Ed 1	Public Domain

[7]	Earth rods, couplers and connections	SANS 62305 Part 4	2008, Ed 3	Public Domain
[8]	The control of undesirable static electricity	SANS 10123	2001, Ed 1.1	Public Domain
[9]	Earthing of low-voltage (LV) distribution system	SANS 10292	2001, Ed 1.1	Public Domain
[10]	IEEE Guide for generation station grounding	IEEE std 665	1995	Public Domain
[11]	IEEE Guide for measuring earth resistivity, ground impedance and earth surface potentials of a grounding system	IEEE std 81	1983	Public Domain
[12]	IEEE Guide for AC substation grounding	IEEE std 80	2000	Public Domain
[13]	IEEE recommended practice for grounding of industrial and commercial power systems	IEEE std 142	2007	Public Domain
[14]	IEEE recommended practice for determining electric power station ground potential rise and induced voltage from a power fault	IEEE std 367	1996	Public Domain
[15]	Grootvlei Power Station: requirements for plant and equipment earthing and lightning protection	N/A	Jul 2005, rev c	Public Domain
[16]	Medupi Power Station: Earthing Standard drawings	0.84/3482 Sht 1 to 60	N/A	Public Domain
[17]	Medupi Power Station Project: Earthing and Lightning protection	200-11757	Feb 2010, rev 0	Public Domain
[18]	Dehn & Söhne : Lightning protection guide, 2nd updated edition	ISBN 3-00-015975-4	Sept 2007, 2nd ed	Public Domain
[19]	ERITECH: Lightning protection handbook.	N/A	N/A	Public Domain
[20]	IEEE Standard for qualifying permanent connections used in substation grounding	IEEE std 837	2002	Public Domain
[21]	Wiring of premises Part 1: Low-voltage installation	SANS 10142 Part 1	2009, Ed 1.7	Public Domain
[22]	A definitive guide to earthing and bonding in hazardous areas	TP1121-1	May 1997	Public Domain

2.3 ABBREVIATIONS

ABBREVIATION	DESCRIPTION
A	Ampere
AC	Alternating Current
ATS	Air Termination System
BBBEE	Broad Based Black Economic Empowerment
BCEW	Bare Copper Earth Wire
C&I	Control and Instrumentation
DCS	Down Conductor System
E/Mat	Earth Mat
EB	Earth Bar
ELPS	Earthing and Lightning Protection System
ESE	Electrical System Earthing
ETS	Earth Termination System
GEM	Ground Enhancement Material
GGS	Generation Group Standard
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ITP	Inspection and Test Point
LPS	Lightning Protection System
LV	Low Voltage
NNB	Nuclear New Build
NNR	National Nuclear Regulator
PVC	Polyvinyl Chloride
SANS	South African National Standards
SD&L	Supplier Development & Localisation
SI	International System of units
SPD	Surge Protection Device
SSR	Site Safety Report
URS	User Requirement Specification

2.4 DEFINITIONS

The terms used in this document are generally in accordance with IEC terminology and if applicable, are further defined and described where they are used in the document.

TERM OR PHRASE	DEFINITION
Air Termination System	Part of an external LPS using metallic elements such as rods, mesh conductors or catenary wires intended to intercept lightning flashes.
Butt Joint	Joint type where no overlapping of earthing conductors takes place. (Head to Head).
Continuity	The effect one gets when bonding is done between different earth mats or equipment in order to get a low resistive path between the areas.
Down Conductor System	Part of an external LPS intended to conduct lightning current from the Air-Termination System to the Earth Termination System.
Earth Bar	Terminal bar provided for the connection of protective conductors, including equipotential bonding conductors, and conductors for functional earthing, if any, to the means of earthing.
Earth Resistance	Resistance of the electrode and surrounding earth as measured between the earthing lead and the general mass of the earth.
Earth Rod	A conducting rod, normally copper, driven vertically into the soil. Earth rods differ in length according to applicability.
Earth Termination System	Part of an external LPS which is intended to conduct and disperse lightning current into the earth.
Earthing Conductor	Any conductor, normally copper or aluminium that is the connection between the equipment and the earth mat.
Equipotential Bonding	Connecting exposed conductive parts of apparatus, systems and installations to ensure that they are at the same potential.
Galvanic Corrosion	Enhanced corrosion of a metal owing to its being in electrical contact with a conductor of a more noble metal in electrolyte.
Lap Joint	Joint type where earthing conductors overlaps each other.
Lightning Current	Current flowing at the point of lightning flash.
Lightning Equipotential Bonding	Bonding to LPS of separate metallic parts, by direct conductive connections or via surge protection devices, to reduce potential differences caused by lightning current.
Lightning Flash	Electrical discharge of atmospheric origin between cloud and earth consisting of one or more strokes.

Lightning Stroke	Single Electrical discharge in a lightning flash to earth. The lightning flash may have multiple strokes.
Multiple Stroke	A lightning flash where more than one stroke (Electrical Discharge) occurs.
Off-Terrace	This relates to buildings and structures, not included in the main vendor scope of work.
Point of Stroke	Point where lightning flash strokes Earth/Object.
Soil Resistivity	Resistance between opposite faces of a cube of soil having 1meter length.
Step Potential	Part of the earth electrode potential gradient that could be bridged by a person, from foot to foot (1m), through the body.
Touch Potential	Part of the earth electrode potential gradient that could be bridged by a person from a hand in contact with a structure, through the body to the feet.

2.5 SYMBOLS

The following symbols are applicable to this document:

SYMBOL	DESCRIPTION
Ø	Diameter
°	Degrees
℃	Degrees Celsius
Ω	Ohm
mΩ	Milliohm

2.6 UNITS

The following units are applicable to this document:

SYMBOL	DESCRIPTION
kA	kilo Ampere
m	meter
mm	millimetre
mm^2	millimetre squared
V	Volt
V_{pn}	Voltage - phase to neutral
V_{pp}	Voltage - phase to phase

3. CONCEPT DESIGN INFORMATION

3.1 SCOPE OF CONCEPT DESIGN

- The scope of the Earthing and Lightning Protection System entails:

- Interception of lightning flashes near structures/buildings to safeguard site personnel, to limit possible thermal and mechanical damages.
- Reduction of hazardous step and touch potentials. Dissipation of earth fault current safely into the earth.
- Minimisation of damage to electrical and electronic systems.

3.2 KEY DESIGN ASSUMPTIONS

The assumptions for this concept design include:

- Pre-construction and operational user requirements (URS) were not available when compiling the conceptual design.
- The ELPS for balance of plant buildings/structures will be installed after civil construction activities have finished. Thus there shall be provision for the ELPS in the civil design.

The exclusion of all earthing requirements and practices for equipment on the power generating unit, that is covered under the main vendor scope

3.3 DESIGN APPROACH

The design of the ELPS shall be in accordance with the provisions outlined in SANS 62305 part 1 to 4 [3][4][5][6]. Figure 1 highlights the key milestones for the design of the ELPS. The design approach for each new nuclear site will incorporate aspects of lessons learned (Operating Experience) from new-build projects and existing power stations.

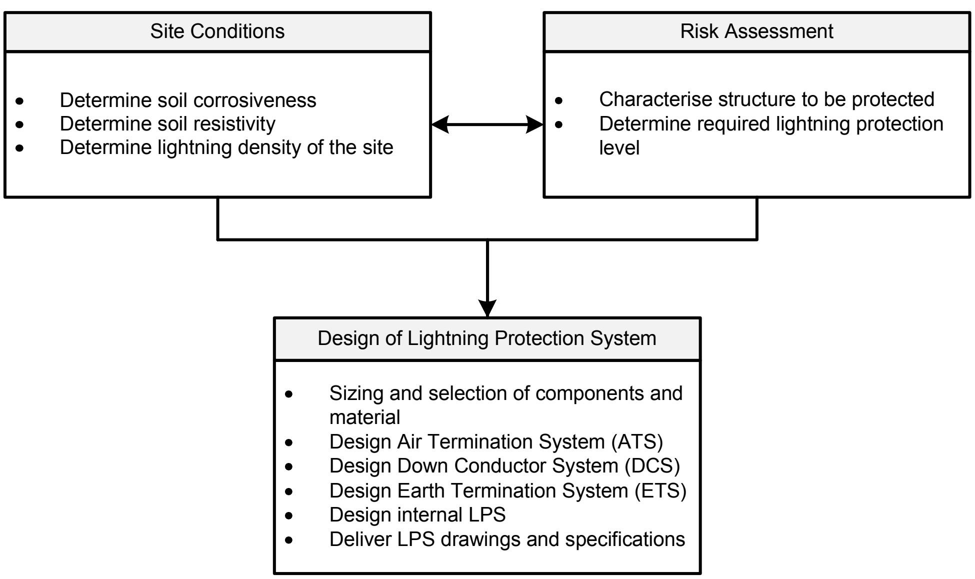

Figure 1: The ELPS Design Approach

3.3.1 Site Conditions

Site conditions generally refer to those parameters which could affect the mechanism of data gathering for the purpose of analysis and material selection for the ELPS. Key aspects, with regard to site conditions, are discussed as follow:

3.3.1.1 Soil Resistivity

Soil resistivity values are used in the design of the Earth Termination System (ETS). The soil resistivity of the site will be determined through the use of the Wenner Array technique, as outlined in section 4 of SANS 10199 [1]. Measurements will be taken at various locations on site, in the vicinity of the area were building/structures are to be constructed. The interval distances (a) according to the Wenner array method [1], will be in multiple steps of 2, with the maximum mandatory distance of 24 meters. Weather and soil conditions must also be recorded when the tests are performed.

3.3.1.2 Soil Corrosiveness

As outlined in section 5 of SANS 10199 [1], soil corrosiveness will be based on the value of soil resistivity. The corrosiveness determines if the ETS will be encased in a conductive mixture to prevent corrosion of the earth conductors.

3.3.1.3 Lightning Density

The lightning density describes the amount of lightning strokes per square kilometre. It is used to determine the required lightning protection level of a building/structure. The lightning data is available from the Counsel for Scientific and Industrial Research (CSIR) as well as the South African National Weather Services.

The Site Safety Report (SSR) makes reference to lightning density, as they are crucial for the design calculations. Lightning densities varies nationally, dependent on the site location. It is expected that there may be variants in the detail design of ELPS between nuclear sites.

3.3.2 Risk Assessment

All buildings and structures intended to have an ELPS, will be subject to a lightning risk assessment as outlined in SANS 62305 Part 2 [4]. The risk assessment will determine the class of the lightning protection system. Revised risk assessments that includes lightning protection devices and equipment, will reduce risks R1 (Loss of Human Life) and R2 (Loss of essential service) below acceptable threshold values [4].

3.4 SYSTEM DESCRIPTION

3.4.1 Process Description

Figure 2 depicts the functional process description of the ELPS.

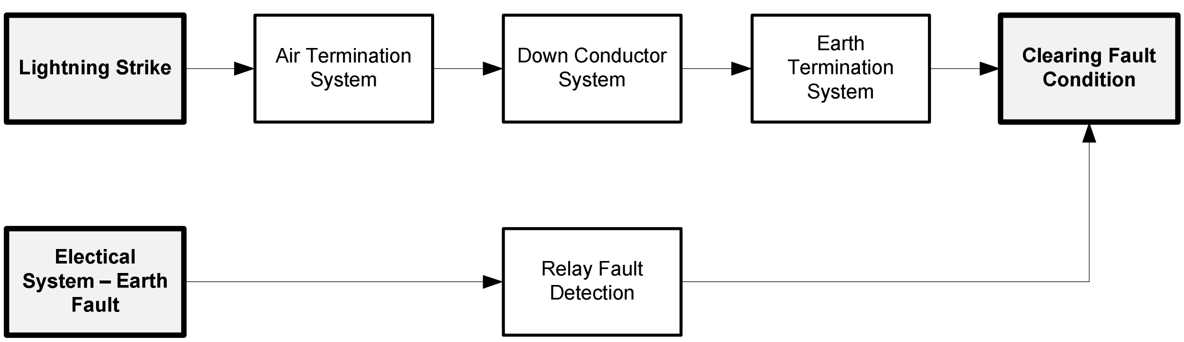

Figure 2: Process Description of the ELPS

3.4.2 System Architecture

The configuration of the ELPS system shall comprise of compact sub-systems such as the Air Termination System (ATS), Down Conductor System (DCS), Earth Termination System (ETS) and Electrical System Earth (ESE). The standard requirements are outlined in the following subsections.

3.4.2.1 Air Termination System

Air Termination System (ATS) refers to devices specifically designed to capture/intercept a lightning flash. Acceptable devices for the ATS can be a combination of the following elements:

- Rods (Including freestanding masts).
- Meshed conductors.

Structures such as antennas, flag masts and high mast lights will not be permitted to form part of the ATS. The positioning of these elements will be determined through the application of the rolling sphere method, for complex building and structures, as prescribed in SANS 62305 [5]. The class level of the LPS as calculated by the lightning risk assessment is used to determine the minimum recommended radius of the rolling sphere method. The Mesh method as described in SANS 62305 [5], is also an acceptable method, which can be used for the design of the ATS. This method is only applicable for flat planer surfaces, where no metallic structures protrude the surface area. Table 1 [5] summarises the maximum radius and mesh sizes for the two protection methods, based upon the class of the LPS that need to be installed. Appendix C (Figures 6 to 9) illustrates the design methods, which can be used for the design of the ATS.

Table 1: Maximum values for rolling sphere and mesh protection methods [5]

Class of LPS	**Protection Methods**	
	Rolling Sphere Radius (m)	Mesh Size (m)
I	20	5 x 5
II	30	10 x 10
III	45	15 x 15
IV	60	20 x 20

The following requirements shall be included in the design of the ATS:

- The components of the ATS shall be interconnected at each structural level.
- The ATS shall be connected to the structure/building down-conductor system at multiple points.
- The ATS design shall incorporate thermal expansion joints where necessary.
- The ATS shall be installed as close as practically possible to roof edges.
- The ATS shall introduce no trip hazards upon roof surfaces.
- The ATS shall be installed in areas free of possible water pooling (e.g. gutters).
- The ATS shall be retrofitted to the structure/building after construction activities have finished.

3.4.2.2 Down Conductor System

The function of the Down Conductor System (DCS) is to safely conduct the intercepted lightning current from the Air Termination Systems (ATS) down to the Earth Termination System (ETS), without causing intolerable temperature rises or damages to structures. Table 2 is an extract from SANS 62305 [5], which recommends the separation distances between down conductors. The DCS of the ELPS will be designed to conform to the indicated distances. A minimum of four down conductors will be installed for each building/structure, irrespective of the lightning protection class.

Table 2: Recommended distances between down conductors [5]

Table 2: Recommended distances between down conductors [5]

Class of LPS	Typical Distances (m)
I	10
II	10
III	15
IV	20

The following additional requirements are included in the design of the DCS:

- Down conductors shall be equally distributed around the perimeter of the structure.
- Natural components such as reinforced steel, gutters, pipes etc. shall be excluded of the DCS
- The DCS shall be vertical, straight and provide within the shortest path between the ATS and ETS.
- No sharp turns will be permitted.
- The DCS shall only make use of approved materials.
- The DCS shall be installed away from windows, doors, exits or areas where people may congregate.
- The DCS shall not be installed in gutters, regardless if the conductor is insulated.
- All down conductors shall be PVC insulated or installed in PVC conduit with a minimum thickness of 3mm, to mitigate the risk of touch potentials.

3.4.2.3 Earth Termination System

The reliability and effectiveness of the ELPS is dependent on the Earth Termination System (ETS). The ETS shall be designed in accordance with SANS 62305 part 3 [5]. The ETS will be installed, after the construction of a building/structure has been completed. The ETS will satisfy the following minimum requirements:

- The ETS shall be a Type B arrangement, with additional vertical electrodes for all buildings/structures as describe by SANS 62305 part 3 [5] (See figure 13 of appendix E).
- The total conductor length for each buildings/structures ETS shall be calculated as prescribed in SANS 62305 part 3 [5]. The earthing length (l1) must meet the minimum requirements according to the class of LPS graph. Figure 12 in Appendix E illustrates this graph.
- The resistance of the ETS relative to ground shall not be higher than 10Ω [5].
- The ETS shall be installed at a minimum distance of 1m away from all buildings/structures.
- The ETS shall be installed at minimum depth of 0.5 m below ground surface.

- Vertical electrodes shall be buried at a minimum depth of 0.5m below ground surface.
- A minimum of 1 vertical electrode (minimum length of 1.2m) shall be installed at the point where each down conductor terminates on the ring earth electrode (Type B arrangement).
- The ETS of each buildings/structure shall be interconnected with a minimum of two 70mm² BCEW as outlined in of SANS 62305 [5], section E.5.4.3.6
- Appendix E (Figure 14) illustrates a type B earthing arrangement with additional vertical rods.
- The ETS shall be installed with Ground Enhancement Material (GEM) as illustrated in Figure 15 and 16, when it is determined from the soil resistivity survey, that the virgin soil is highly corrosive. SANS 10199 [1] describes the relationship between soil corrosiveness and resistivity and should be installed accordingly.

3.4.2.4 Electrical System Earthing

Electrical System Earthing (ESE) will conform to the requirements and recommendations outlined in standards [9][10][11][12][13][14] and [21]. Each ESE will be designed differently based on prospective fault currents from the system. Appendix F serves as an informative section regarding ESE. The following minimum requirements shall be met for the ELPS:

- Power cable installations with conductor sizes greater than 16mm² will have an additional – visible 70mm², single core, PVC insulated copper conductor, which will serve as an equipment earth.
- All material as outlined in section 3.4.2.6 will only be accepted for ESE. In cases where prospective fault currents are higher than material limits as specified (Appendix D), double conductors will be installed to meet the requirements.
- Earthing layouts for electrical equipment (Generators, transformers) will be specifically designed in the systems applicable conceptual or detail design documentation.

3.4.2.5 Equipotential Bonding

All metallic installations, internal systems and external conductive services connected to a building/structure shall be bonded to the ETS. This prevents static induction, overvoltage on internal systems and sparking which could cause explosions. The ELPS minimum requirements for equipotential bonding are listed as follow:

- All metallic enclosures on equipment and exposed noncurrent-carrying conductive materials capable of becoming energized due to either insulation failure, inadvertent contact with an energized conductor, or building up of a static or induced voltage should be grounded.
- Equipotential bonding shall be done by means of direct connection to ETS, Surge Protection Devices (SPD) and insulation mediums (Air, concrete or PVC) as prescribe in standards [5][6].
- On ground level/basement of a structure/building, an earth bar (EB) is required to be installed. The EB will be located as close as possible to all external services entering the building/structure. Numerous earth bars may be needed, depending on the amount of services entering the building/structure (See Figure 22 of Appendix G). These earth bars should be interconnected via the ETS or a dedicated internal ring. The following metallic – conductive services requires earth bonding (See Figure 20 and 21 of Appendix G):
    - Metallic piping systems (Water, Air, Gas, Heating, Waste, Fire Protection etc.)
    - Metallic Tanks
    - Telecommunication lines and IT systems
    - Power lines
    - Antennas
    - Cable trays
    - Ventilation ducts

- Structural steelworks (Rebar) will be bonded to the ETS and the ATS in order to prevent possible potential differences between metallic structures. Each individual platform, floor and pillar of a structure/building will be bonded to the ETS (See Appendix H). All steel work encased by concrete shall be earthed by means of a PVC insulated copper conductor.
- Metal roofs, gutters and steel trusses will be bonded to the ETS.

3.4.2.6 ELPS Materials

The material specifications are outlined in Tables 6 and 7 of SANS 62305 [5] for the construction of an ELPS. In addition, the material selection will be consistent with Eskom Earthing and Lightning Protection standards [16][17][20]. The ELPS will be constructed out of copper material with provisions made for tin plated copper to reduce bimetallic bonding where necessary. Table 3 lists the recommended materials for the ELPS. Appendix D provides information as to how these materials were selected.

Table 3: ELPS recommended materials

Material	Configuration	Minimum Cross Sectional Area (mm^2)	Comments
Copper / Tin Plated Copper	Solid - Round	70	9.5mmØ Bare Copper Earth Wire
	Stranded - Round	70	PVC Insulated Earth Wire (Green/Yellow)
	Tape - Rectangular	150	50mm x 3mm
	Solid - Round	200	16mmØ Solid Air Terminal/Ground Rod

- **Galvanic Corrosion**

Galvanic corrosion occurs when two dissimilar materials are in contact with each other in the presence of an electrolyte. The natural potential difference between the two materials promotes this phenomenon. The recommended practice is that the potential difference should be limited to 0.35V to avoid excessive corrosion [19]. The electrochemical voltage series as shown in Figure 5 and Table 4 of Appendix B, indicates that a steel and copper connection will yield a potential difference of 0.53V. To reduce this effect only tin plated copper connections to structural and reinforced steel will be permitted. Any currents induced in the reinforced steel shall be demonstrated as not to increase the susceptibility of the reinforcement to corrosion. Approved bimetallic connectors will also be permitted.

3.4.2.8 CADWELDS

CADWELDS refers to an exothermic welding process where a permanent, molecular bond is formed between conductors/materials which cannot be loosen or corrode. This connection method exceeds the requirements as outlined in the qualifying permanent connection standard [20]. CADWELDS shall be used for copper to copper and copper to steel (rebar) connections for the construction of the ELPS.

3.4.2.9 Earth Tails

Earth tails connected to the ETS will protrude the structural concrete, in the vicinity where electrical and electronic equipment will be installed as shown in Figure 19 of Appendix F. The earth tails will be $70mm^2$, Polyvinyl Chloride (PVC) insulated copper conductors and will serve as a safety earth connection in terms of ESE. During installation the tail must protrude a minimum distance of 500mm to permit the termination of the earth tail to equipment.

3.4.2.10 Test Points

During the detail design phase, certain Earth Bars (EB) and earthing connections shall be identified as test points and labelled by green numbered triangles, which correspond to the relevant earthing drawings. The test points will be used to confirm the integrity of the ELPS. Appendix I is an example of numbered test points on an auxiliary plant.

3.4.3 External Interfaces

The ELPS will be provided with the key external interfaces as shown in Figure 3.

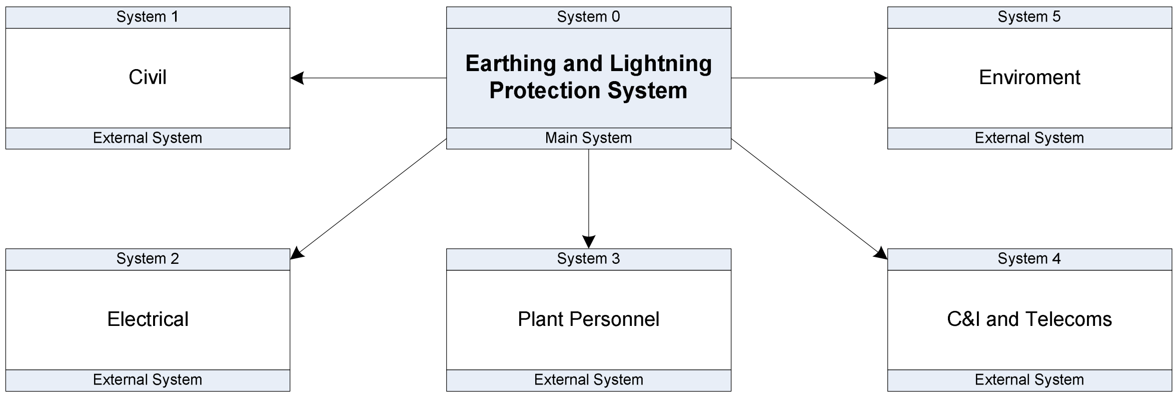

Figure 3: ELPS External Interfaces

3.4.3.1 System 1 – Civil

The civil design of building/structures will incorporate elements of the ELPS, in order to avoid future integration problems. The building/structures must embed conduits, cable ducts, earth tails and rebar connections etc. The civil and ELPS will be an integrated detailed design. This will facilitate the installation process of the ELPS, as well as reduce the visual impact of the system on the building/structure. The rebar used in each column and floor shall be earthed as discussed in section 3.4.2. Copper conductors shall be cad welded to the concrete enchased rebar, whilst earth tails exit the sides of the building/structures, to be connected to the ETS (Figure 9). Final levelling around building/structure will only be done after the ETS is installed**.**

3.4.3.2 System 2 – Electrical

The earth conductor/bar of each electrical cabinet will be bonded with the ETS of each building/structure. The functional interface will primarily exist to ensure coordination with respect to electrical earth fault protection and to create a global station earth mat. See Figure 23 of Appendix G.

3.4.3.3 System 3 – Plant Personnel

The plant personnel interface will be designed to facilitate sound interactions for safe maintenance operations of the ELPS. In addition, the interface will ensure unhindered movement of plant personnel on site. The layout of the ELPS will be such that it imposes no undue restrictions to plant personnel in the performance of their duties.

3.4.3.4 System 4 – C&I and Telecoms

All C&I and Telecommunications equipment will have its own 0V "clean" EB for operations as illustrated in Figure 23 of Appendix G. This EB will be grounded by means of a single, insulated grounding cable to the ETS. The cabinets that house the equipment will be earthed through safety earths or the electrical supply earth. All C&I and telecommunications equipment must have surge protection devices in their design according to SANS 62305 part 4 [6]. No independent grounding arrangement for the C&I and Telecommunications system shall be permitted.

3.4.3.5 System 5 – Environment

The interactions between the ELPS and the meteorological conditions will be designed out to mitigate the effect of external conditions. The environmental interface will be setup such that it discourages fauna attraction to the ELPS system.

3.4.4 Maintenance Concept

Maintenance programs shall be compiled according to section 7 of SANS 62305 part 3 [5]. The condition of the ELPS is reliant on a maintenance program that focuses on routine visual inspections, tests and measurements. Appendix J recommends the minimum activities for an effective maintenance program.

3.4.5 Operating Concept

The operations of the ELPS is inherently passive. The system shall form an integral component of the site equipment and personnel safety, whilst imposing no undue influence to the environment. It shall conform to all applicable statutory earthing and lightning protection requirements.

3.4.6 Safety Concept

The safety of the ELPS shall be consolidated and demonstrated through the submission of the following design documentation:

- Type Test Certificates
- Design Calculations
- Material Selection
- Design Drawings
- Inspection and Routine Test Sheets

3.5 SITING

The ELPS as outlined in this concept design shall be applicable to all nuclear sites. The ELPS will become structure/building specific during the basic design stage.

3.6 DESIGN CONFORMANCE ASSESSMENTS

3.6.1 Environmental

The ELPS will be designed within the parameters and recommendations of the site specific environmental impact assessment.

3.6.2 Reliability

The ELPS will be highly reliable over the entire life expectancy of the plant. Reliability will be demonstrated through calculation, simulation and material selection.

3.6.3 Maintainability

The maintainability of the ELPS shall be based on corrective and preventive maintenance approaches. The mean time for repairs shall not be more than 12-hours.

3.6.4 Availability

The ELPS will operate continuously with a 100% availability factor per annum. Due to the high monetary value of copper conductors, theft will remain a risk during construction and operational phases. Visual inspection of the ELPS form part of maintenance routines and thereby copper theft can easily be identified and rectified.

3.6.5 Constructability

The ELPS design will be such that it promotes constructability. The earthing and lightning protection sub-system designs will be subject to assessment by the applicable Eskom engineering disciplines.

3.6.6 Procureability

The design of the ELPS will incorporate proven and modern components. Critical spares for the system will be kept on site to reduce down time.

3.6.7 Expandability

The ELPS will be designed with the provision for future expansion.

3.6.8 Supplier Development and Localisation

SD&L for the ELPS is addressed in Appendix L.

3.7 TEST AND COMMISIONING

3.7.1 Visual Inspections

Visual inspection will be carried out on all earthed equipment. Inspections form part of maintenance and commissioning process. An inspection report must be produced before any test or commissioning commences by the responsible person. The following will be covered by the report:

- 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.
- Signs that the earthing copper may have been stolen.

3.7.2 Continuity Tests

The continuity test gives an indication of how good a connection is between two earthing points. When there is good continuity between different ETS, the total system voltage rises during a surge, thereby dramatically reducing the risk of damage. The continuity tests are done from the reference points identified on the continuity earth drawings (see Appendix I for illustration). These tests must be done with micro-ohm meter (low resistance ducter tester). The measured resistance depends on the distance between the two chosen structures/earth tails. Distances between two test points should not exceed 100m and measured continuity resistance should be less than 30mΩ [17]. Continuity tests are carried out on all systems/services that have an earth connection to it.

3.7.3 Earth Resistance Tests

The earth resistance test is used to verify the integrity and physical contact of the underground earth termination system (ETS) with virgin soil. It's an indication of system resistance relative to the earth resistivity. Earth resistance recordings will be compared over the years to establish if the earthing system is stable and safe enough to dissipate fault currents safely. Test results will also provide information on the corrosion rate of the ETS. If the ETS is corroding away the earth resistance results will increase. Earth resistance tests should be carried out at least every second year, preferable before the rain season starts, when the soil is dry and ground resistance is high (this is the worst case).

Due to the heterogeneous layout of the ETS only the Tagg method as described in section 9.2.3 of SANS 10199 [1] will be accepted. Once the installation of an earthing system for an individual building/structure has been done the earth resistance test will then be completed, before interconnecting to adjacent earthing systems. This will be established if the grounding system for that specific building/structure is adequate enough. When interconnecting is done the earth resistance will drop due to additional parallel paths created. Once all earthing systems are constructed and completed, certain earth tails will be identified (Generator transformer etc.) for year to year testing. Earth resistance test results less than 10Ω [5] for an individual ETS, without interconnections will be accepted.

3.7.4 Commissioning

Appendix K outlines a high level commissioning process for the ELPS. Stages 1 and 2 refer to the commissioning process at an individual structure/building. Stage 3 outlines the process for the interconnected earth mat.

4. AUTHORISATION

This document has been seen and accepted by:

Name	Designation
Lester Thomas	Manager (Acting) - User Specifications
Johann Breytenbach	Middle Manager - Nuclear Project Management
Derek Lee	Consultant – Civil Engineering

5. REVISION INFORMATION

Date	Rev.	Compiler	Remarks
June 2013	0,Draft A	J.Rudolph	First Draft.
August 2013	0,Draft B	J.Rudolph	Updated with internal review comments.
October 2013	0,Draft C	J.Rudolph	Updated with external review comments.
October 2013	0,Draft D	J.Rudolph	Updated with additional review comments
November 2013	0	J.Rudolph	First Revision

6. DEVELOPMENT TEAM

The following people were involved in the development of this document:

Name	Designation
Mark Gordon	Senior Engineer - Integrated Plant Design (Fleet)
Anthonie Cilliers	Senior Engineer - Integrated Plant Design (Fleet)
Lawrence Molele	Senior Engineer - Integrated Plant Design (Fleet)
Tasneem Vawda	Engineer - Integrated Plant Design (Fleet)
Ndumiso Nxumalo	Technician - Integrated Plant Design (Fleet)
Albert Maluleke	Technician - Integrated Plant Design (Fleet)

APPENDIX A: STATION EARTH MAT - CONCEPT

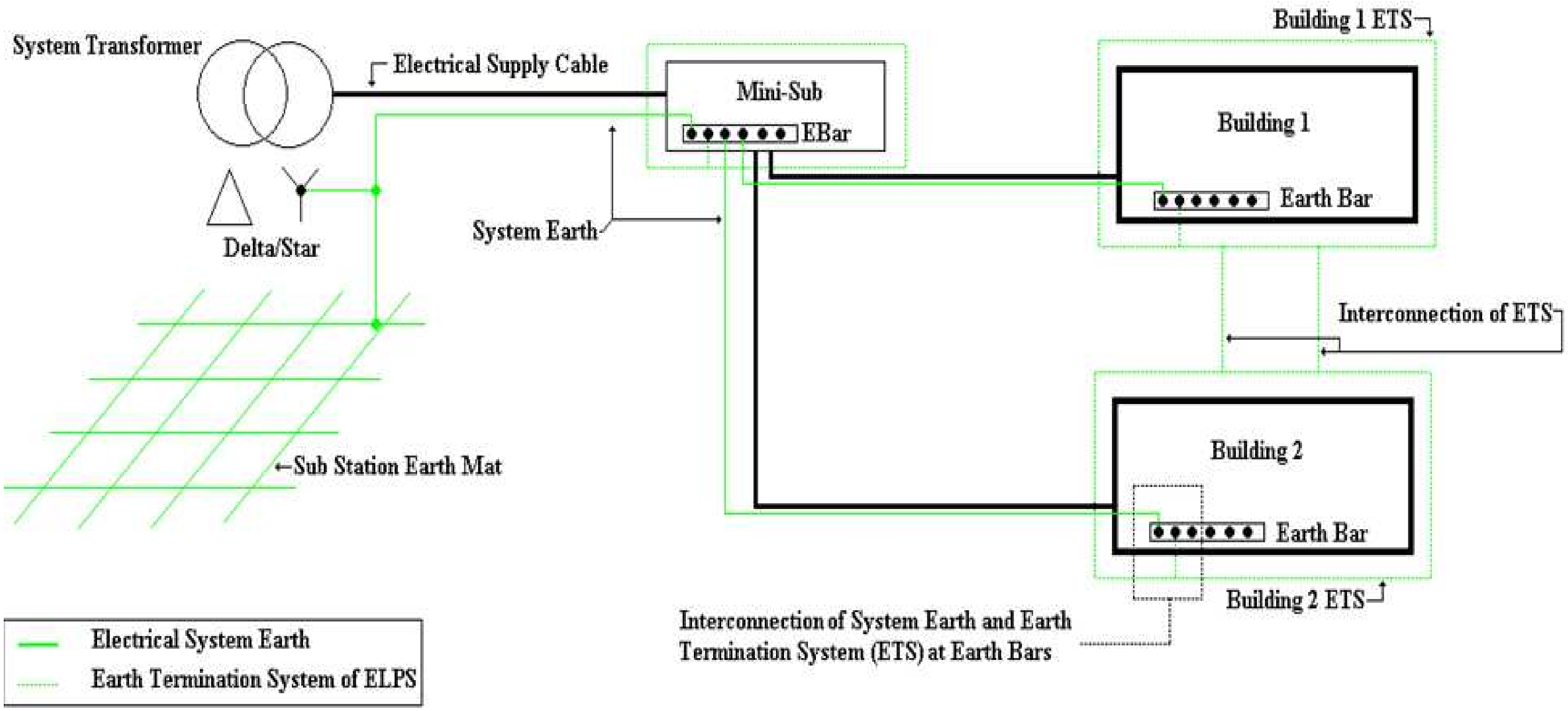

Figure 4: Illustration of an interconnected – equipotential station earth mat

APPENDIX B: DISSIMALR METAL BONDING (INFORMATION)

Table 4: Electrochemical Series Voltage [19]

		Anodic (-)																						
		Silver	Nickel	Monel metal	Cupro-nickel (70-30)	Copper	Silver solder	Bronzes	Gunmetal	Brasses	Stainless steels	Tin	Tin-lead solder	Silver-lead solder	Lead	Grey cast iron	Steels (not stainless)	Aluminum alloys	Aluminum	Cadmium	Galv. iron or steel	Zinc base alloys	Zinc	Magnesium alloys
Cathodic (+)	Silver	0	0.15	0.17	0.19	0.19	0.21	0.23	0.25	0.26	0.33	0.47	0.48	0.51	0.56	0.71	0.72	0.77	0.77	0.79	1.09	1.10	1.11	1.59
	Nickel		0	0.02	0.04	0.04	0.06	0.08	0.1	0.11	0.16	0.32	0.33	0.36	0.41	0.53	0.57	0.62	0.62	0.64	0.94	0.95	0.96	1.44
	Monel metal			0	0.02	0.02	0.04	0.06	0.08	0.09	0.16	0.3	0.31	0.34	0.39	0.54	0.55	0.60	0.60	0.62	0.92	0.93	0.94	1.42
	Cupro-nickel (70-30)				0	0	0.02	0.04	0.06	0.07	0.14	0.28	0.29	0.32	0.37	0.52	0.53	0.58	0.58	0.60	0.90	0.91	0.92	1.40
	Copper					0	0.02	0.04	0.06	0.07	0.14	0.28	0.29	0.32	0.37	0.52	0.53	0.58	0.58	0.60	0.90	0.91	0.92	1.40
	Silver solder						0	0.02	0.04	0.05	0.12	0.26	0.27	0.3	0.35	0.50	0.51	0.56	0.56	0.58	0.88	0.89	0.90	1.38
	Bronzes							0	0.02	0.03	0.1	0.24	0.25	0.28	0.33	0.48	0.49	0.54	0.54	0.56	0.86	0.87	0.88	1.36
	Gunmetal (red bronze)								0	0.01	0.08	0.22	0.23	0.26	0.31	0.46	0.47	0.52	0.52	0.54	0.84	0.85	0.86	1.34
	Brasses									0	0.07	0.21	0.22	0.25	0.3	0.45	0.46	0.51	0.51	0.53	0.83	0.84	0.85	1.33
	Stainless steel										0	0.14	0.15	0.18	0.23	0.38	0.39	0.44	0.44	0.46	0.76	0.77	0.78	1.26
	Tin											0	0.01	0.04	0.09	0.24	0.25	0.3	0.3	0.32	0.62	0.63	0.64	1.12
	Tin-lead solder												0	0.03	0.08	0.23	0.24	0.29	0.29	0.31	0.61	0.62	0.63	1.11
	Silver-lead solder													0	0.05	0.2	0.21	0.26	0.26	0.28	0.58	0.59	0.60	1.08
	Lead														0	0.15	0.16	0.21	0.21	0.23	0.53	0.54	0.55	1.03
	Grey cast iron															0	0.01	0.06	0.06	0.08	0.38	0.39	0.4	0.88
	Steels (not stainless)																0	0.05	0.05	0.07	0.37	0.38	0.39	0.87
	Aluminum alloys																	0	0	0.02	0.32	0.33	0.34	0.82
	Aluminum																		0	0.02	0.32	0.33	0.34	0.82
	Cadmium																			0	0.3	0.31	0.32	0.80
	Galv. iron or steel																				0	0.01	0.02	0.50
	Zinc base alloys																					0	0.01	0.49
	Zinc base alloys																						0	0.45
	Magnesium alloys																							0

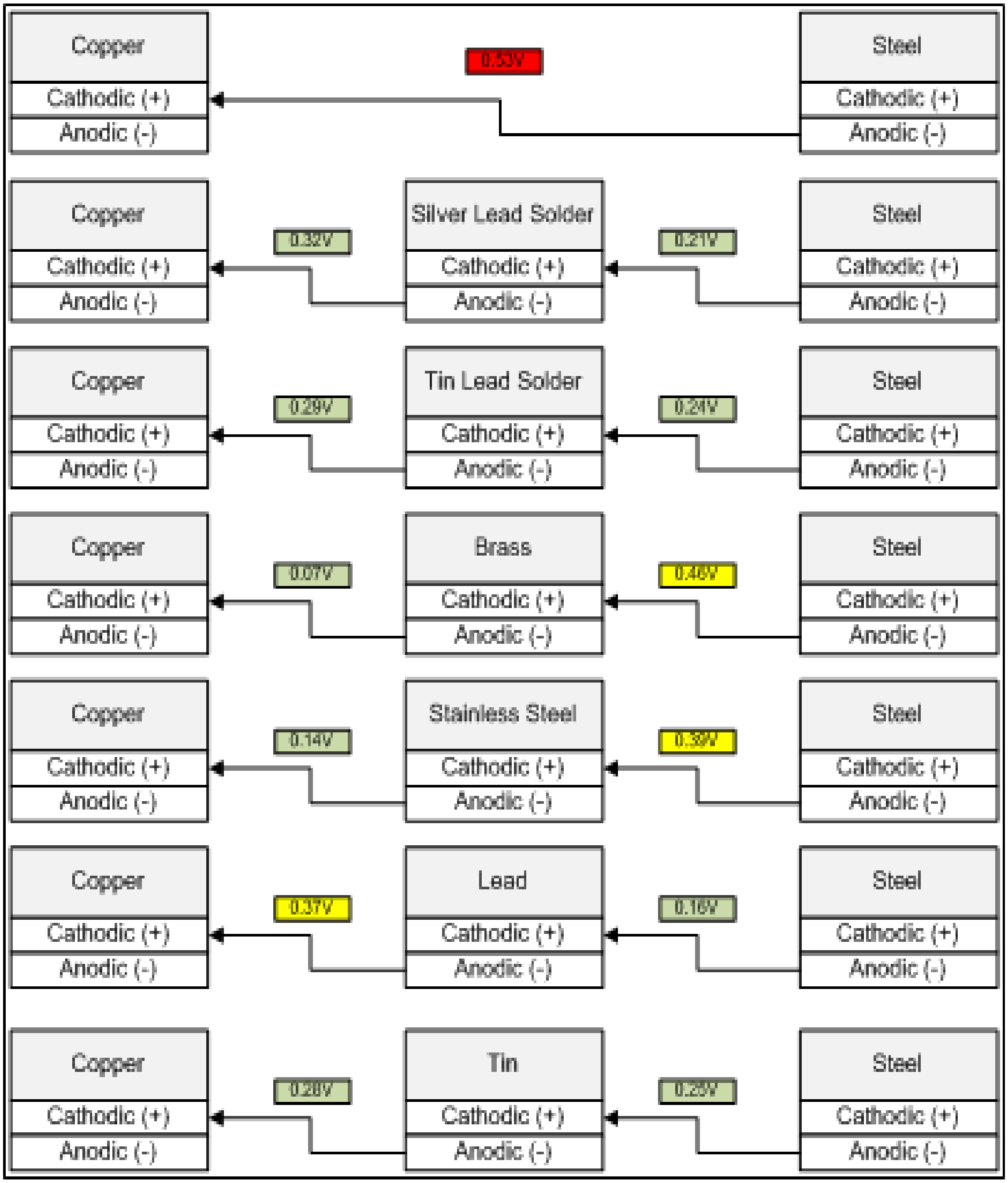

Figure 5: Potential differences between bimetallic connections

APPENDIX C: LIGHTNING PROTECTION METHODS (INFORMATION)

C.1 Rolling Sphere Method

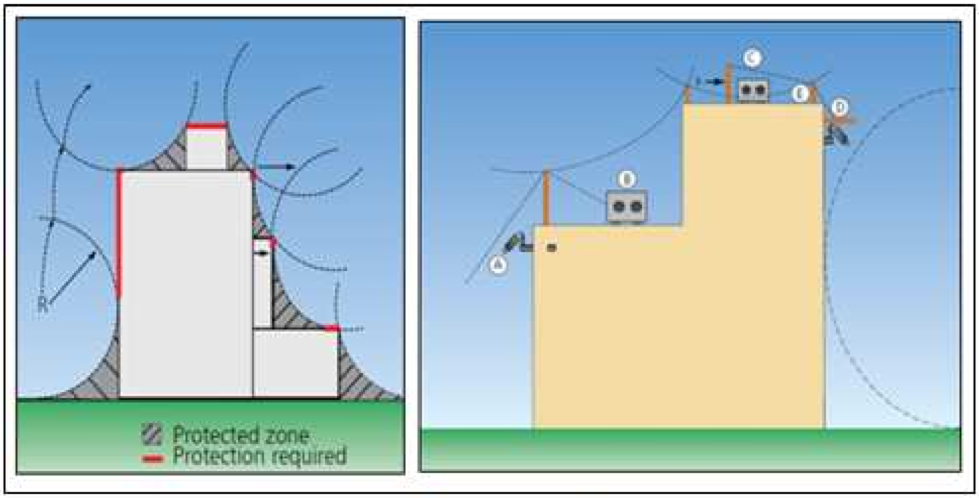

Figure 6: Side view of rolling sphere method to establish the protection zones of the ATS [19]

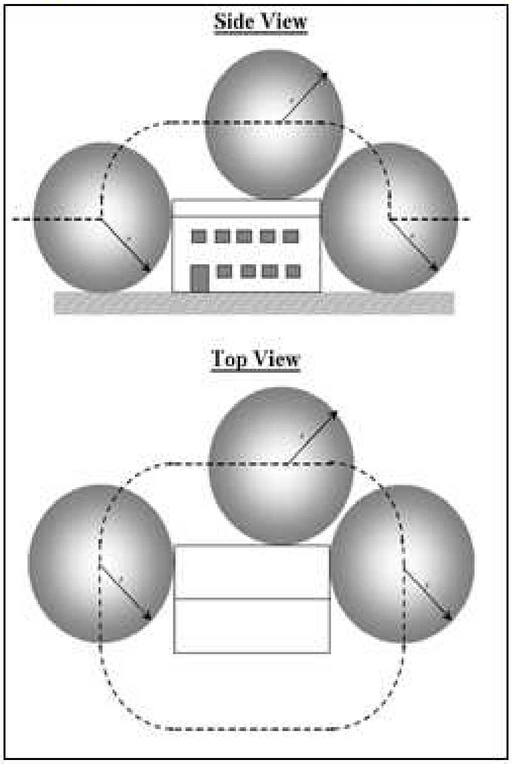

Figure 7: side and top view Illustration of the rolling sphere method [5]

Figure 8: Illustration of the rolling sphere method [18]

C.2 Mesh Method

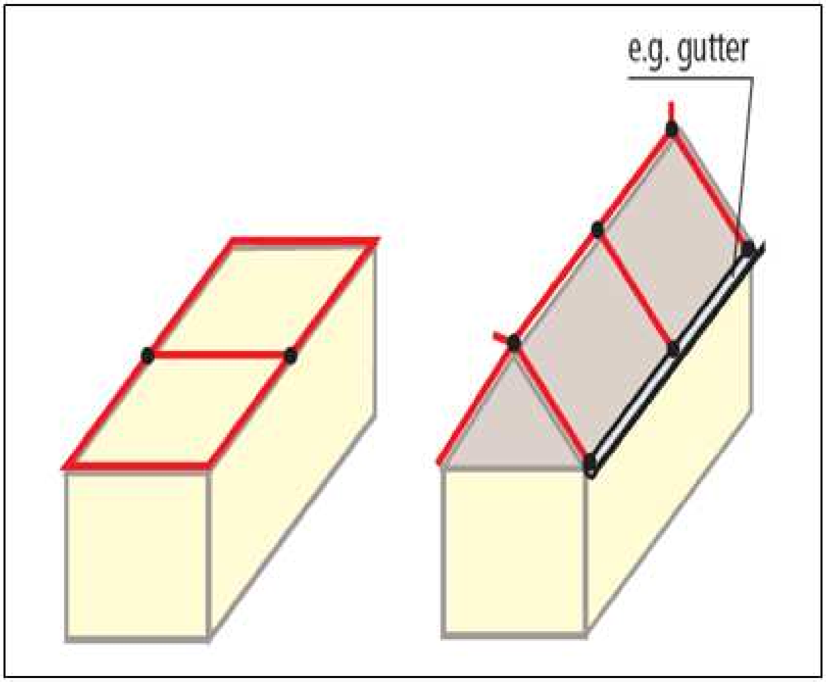

Figure 9: Mesh Method used to establish the ATS [18]

APPENDIX D: Material Sizing (information)

The material size selection for the ELPS is based on the following parameters:

- Lightning stroke duration
- Lightning current
- Standardisation
- Conductor geometry

D.1 Lightning Stroke Duration

The wave shape of lightning current differs from each stroke. Research has shown that a statistical distribution can be determined for the occurrence of a given wave shape. Figure 10 shows this statistical distribution. From this distribution it is concluded that the maximum current, per stroke will be reached after 10µs, while after 350µs the current would have halved. It is therefore recommended that the ELPS material be able to withstand thermal stresses induced by the rated lightning current for more than 1ms.

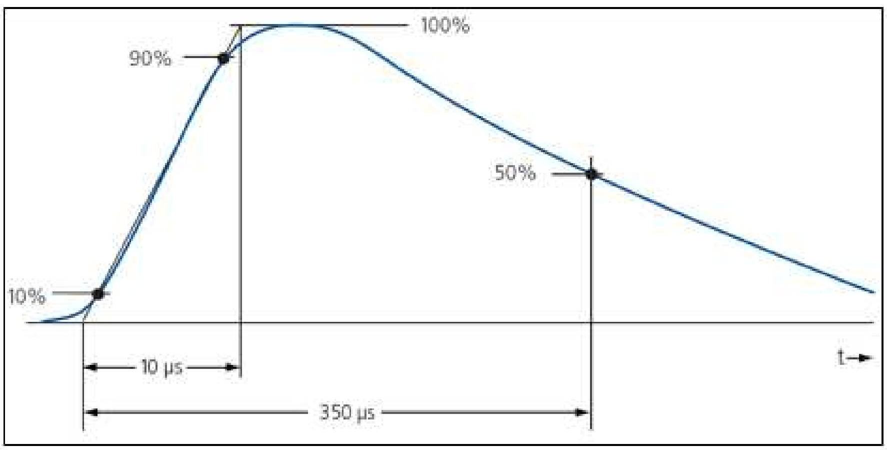

Figure 10: Statistical distribution of lightning strokes [18].

D.2 Lightning Current

Once an ionised path has been formed between the earth and a cloud, lightning current rapidly increases with average peak currents around 30kA. Table is an extract from SANS 62305 [4] and it describes the maximum lightning current for each lightning protection level. The ELPS is designed according to the lightning protection classification of a structure/building based on the risk assessment. For example the material selection of the ELPS, with a LPL I must be able to handle/withstand a maximum current of 200kA. The material and size selection for the ELPS shall be able to withstand the maximum peak current of 200kA for the time duration as recommended in section D.1

Table 5: Maximum current for lightning protection levels [4]

	LPL I	LPL II	LPL III	LPL IV
Maximum Peak Current (kA 10/350µS)	200	150	100	100
Probability of current being greater than peak (%)	1	2	3	3

D.3 Standardisation

Standardisation of system materials, simplifies the maintenance process. Trends and lessons learned from Eskom's new build projects which includes power stations and substations will be taken into consideration when selecting the material and the size of it.

D.4 Conductor Geometry

Different material geometries are selected for different applications. For example Bare Copper Earth Wire (BCEW) will be used to construct the Earth Termination System. PVC insulated conductors cannot be used for the ETS as there will be no physical contact with the ground, however it can be used for the down conductor system. As such different geometries are used for different applications.

D.5 Material Sizes

The material and sizes selected for the ELPS, which was evaluated are summarised in Table 6. Equation 1 was used to determine maximum current the material can handle for a certain time period as prescribed in SANS 10199 [1]. The current density (k) as specified in IEEE 665 [10] is temperature dependant. The initial conductor temperature was taken at 40℃ which repre sents a much worse condition than taking an ambient temperature of 20℃ into consideration. The recomme nded final temperatures for bare and insulated copper conductors are also specified. The current density, initial and final temperatures used for the evaluation is summarised in Table .

Table 6: Material size selection

	Geometry	Dimensions	Area
Copper	Solid	9.5 mm Ø	70 mm²
	Solid	16 mm Ø	201 mm²
	Stranded	9.5 mm Ø	70 mm²
	Tape	50 x 3 mm	150 mm²

$$I = \frac{S \times k}{\left(\sqrt{t}\right)} \quad \text{...} \quad (1)$$

I : Fault Current (A)

k : Current Density

S : Cross-sectional Area (mm²)

t : Fault Current Duration (s)

Table 7: Temperature and current density coefficients [10]

	Initial Temperature	**Final Temperature**	**k - Factor**
PVC Insulated	40	150	131
BCEW (In vicinity of heat sensitive material)	40	200	152
BCEW (Not In vicinity of heat sensitive material)	40	500	223

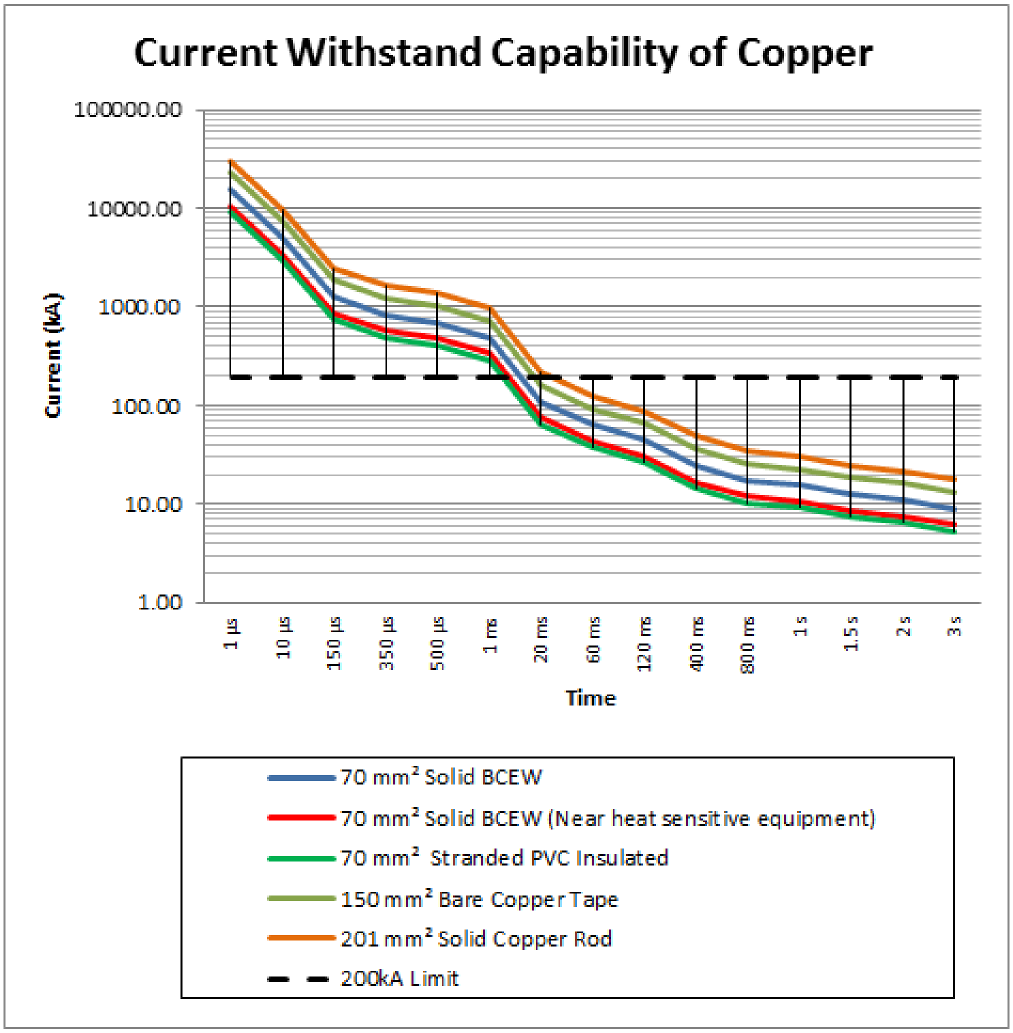

Figure 11: Current withstand capability of copper

Figure 11 illustrates the current withstand capability of the different size copper materials for random time period's. From the graph it is clear that all specified material is capable of handling the 200kA threshold limit for 1ms. A consideration to take note of is the multiple parallel paths created with the installation of the ELPS, which reduces the system resistance, thereby increases the overall system current handling capability. This justifies the minimum material selection as specified in section 3.4.2.6.

In addition IEEE 80 [12] recommends worst case, high speed fault clearing times for protection relays as 400ms (20 – 50 Hz wave cycles). These materials are also well capable of handling high fault currents for electrical system faults. sults for the two time periods.

Table summarises these results for the two time periods.

Table 8: Current withstand values for different copper conductors

	kA @ 1ms	**kA @ 400ms**
70 mm² Solid BCEW	493.63	24.68
70 mm² Solid BCEW (Near heat sensitive equipment)	336.47	16.82
70 mm² Stranded PVC Insulated	289.98	14.50
150 mm² Bare Copper Tape	721.00	36.05
201 mm² Solid Copper Rod	966.14	48.31

APPENDIX E: EARTH TERMINATION SYSTEM

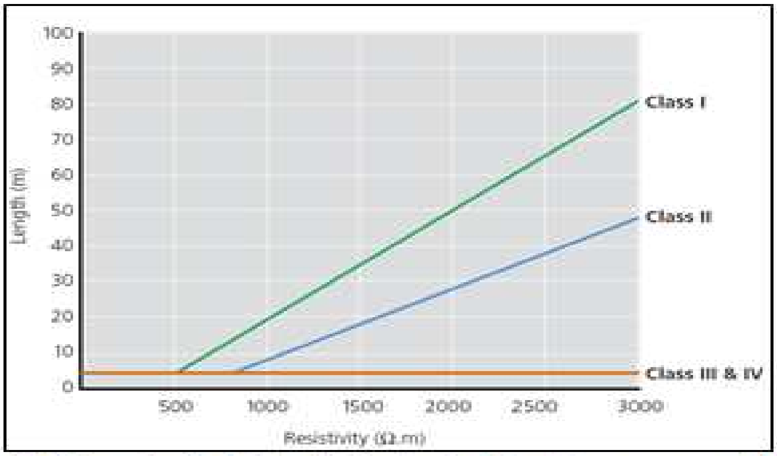

Figure 12: Minimum length of electrodes for a type A and B earthing arrangements [18]

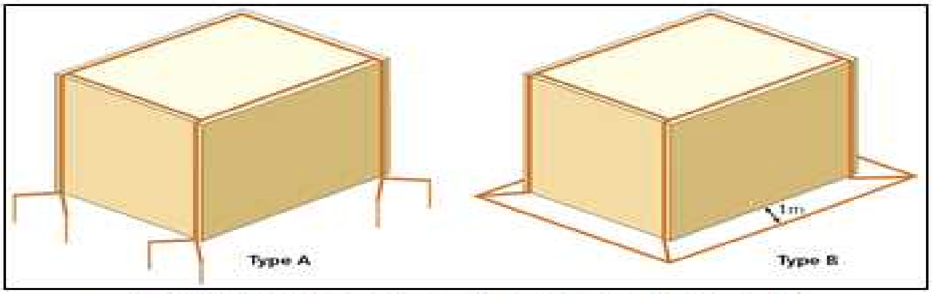

Figure 13: Illustration of a type A and B earth termination system [18]

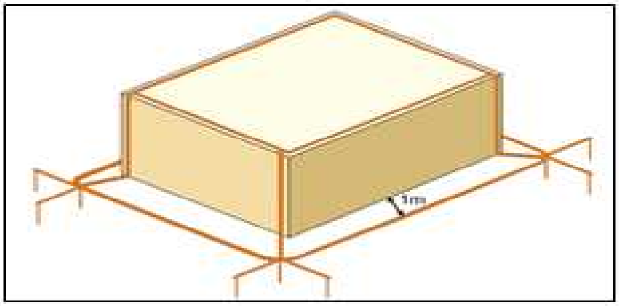

Figure 14: Combination of a Type A and B earth terminating system [18]

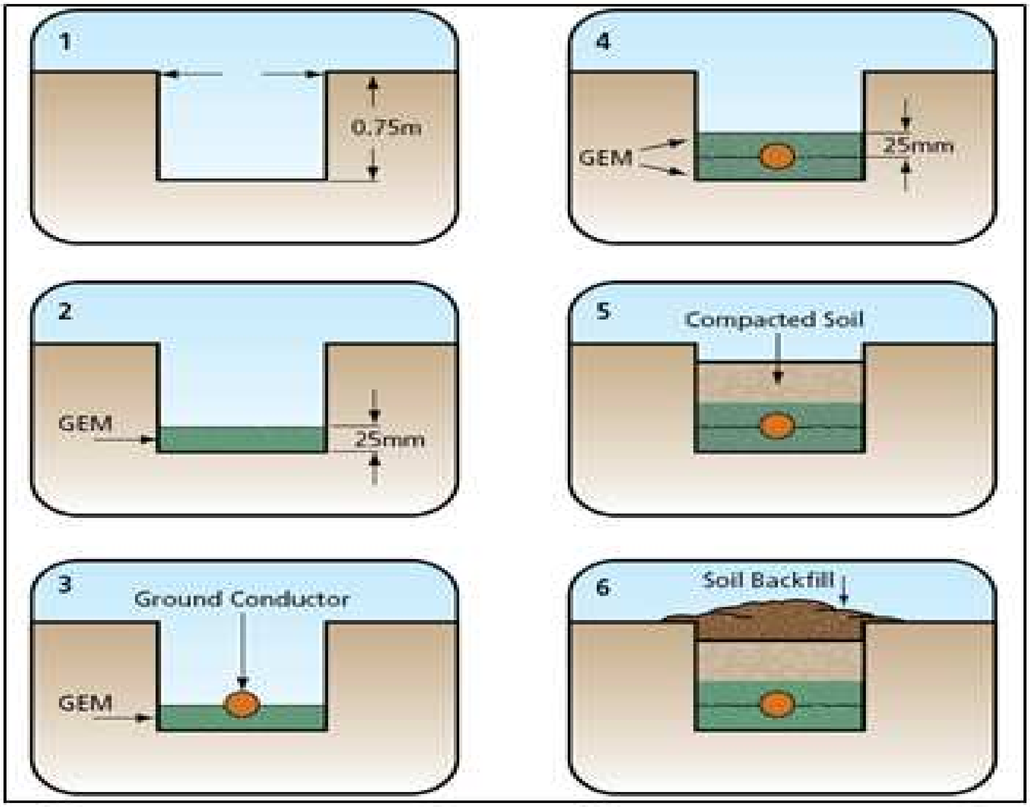

Figure 15: Installation of horizontal conductors with ground enhancement [19].

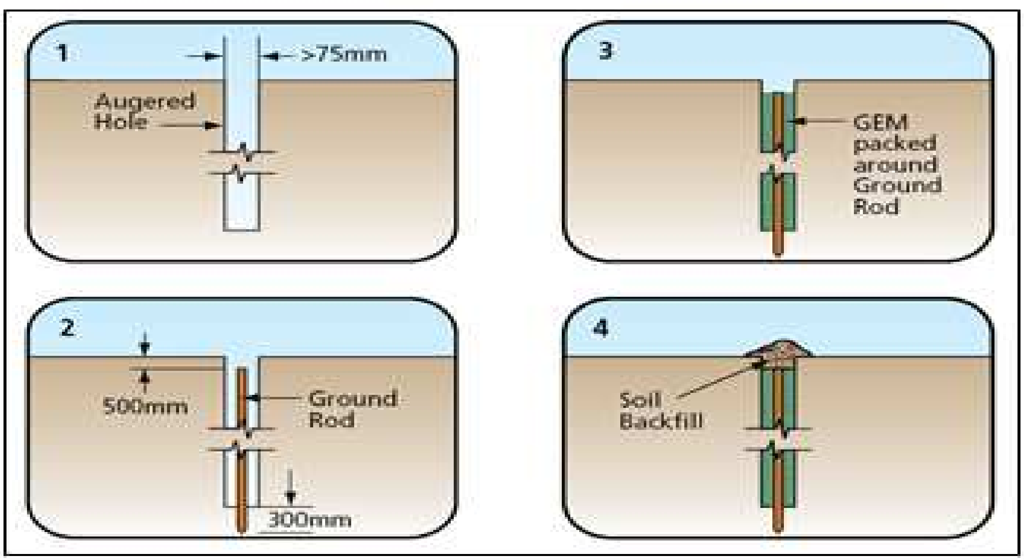

Figure 16: Installation of vertical earth rods with ground enhancement [19].

APPENDIX F: ELECTRICAL SYSTEM EARTHING (INFORMATION)

Electrical system earthing (ESE) refers to grounding practices and techniques used to:

- Ensure the safety of personal and to prevent damages to property.
- Create a system reference to detect and disconnect a circuit with a phase to ground fault, limiting dangerous step and touch potentials.

Figure 17 is an extract from IEEE665 [10] and illustrates the principles of electrical system earthing. Neutral, equipment and safety ground are defined as follow:

Neutral Ground

Neutral ground refers to the technique used to establish the ground reference of the electrical system (Solid grounding, resistance grounding etc.). The neutral ground connection is usually made at the neutral point of supply equipment (Transformers, Generators). The intention of this ground connection is to provide a path for earth fault currents to return to the supply point, thereby allowing protection relays to detect the fault and disconnect the circuit.

Equipment Ground

Equipment ground establishes a dedicated, low impedance path for system earth fault between a live conductor and the enclosure. By installing this earth ground conductor it ensures that the protection relay would pick up and clear an earth fault much faster.

Safety Ground

Safety grounds are additional earth connections made to parts of equipment, which may become live under abnormal conditions. These safety ground connections are installed on equipment where prospective earth fault currents are very high.

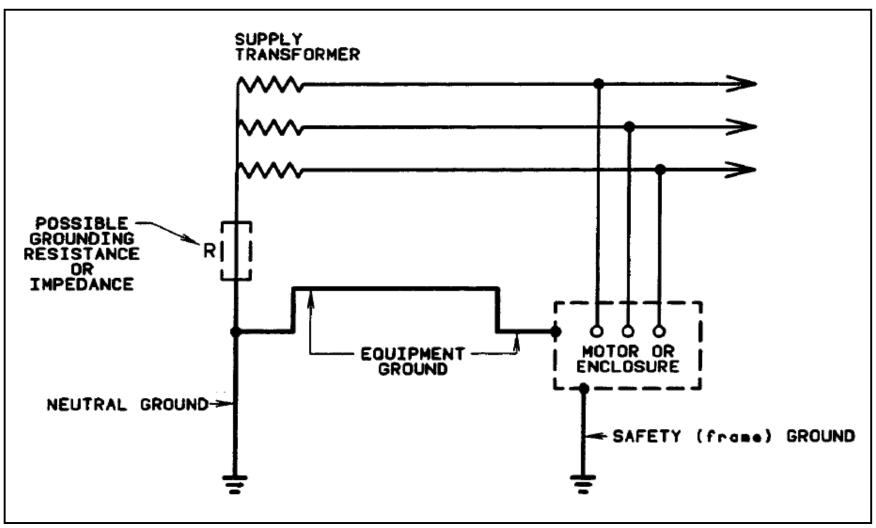

Figure 17: Illustration of neutral, equipment and safety earthing arrangements [10]

Additional earthing is achieved by means of the power cable armouring, which serves as an earthing conductor, when the armouring is connected between the supply switchgear and the equipment enclosure. Within Eskom for cable installations above 16mm² an additional 70mm², single core, PVC insulated/BCEW copper conductor will be installed along with the power cable [17]. The safety earth as shown in figure 18 will form part of the ETS of the specific building /structure. The recommended earthing practice for electrical equipment is illustrated in figure 18 [10].

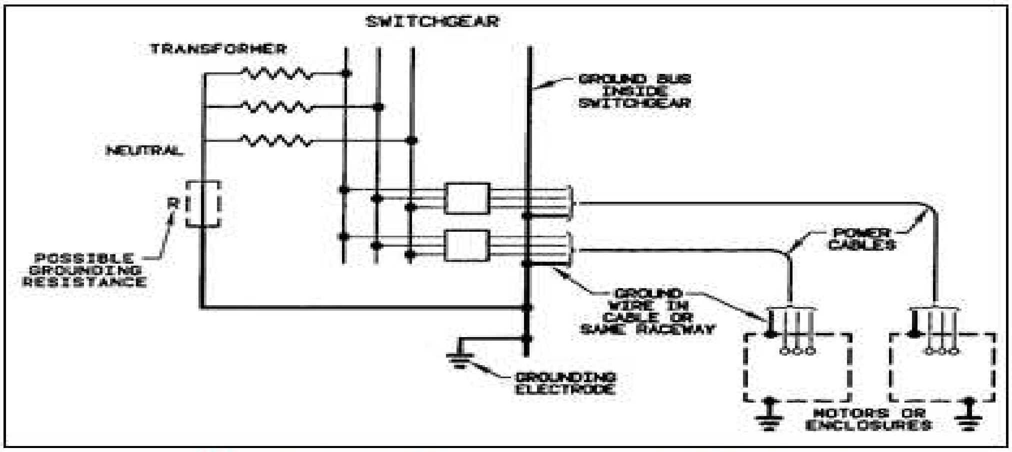

Figure 18: Electrical system earthing arrangement [10]

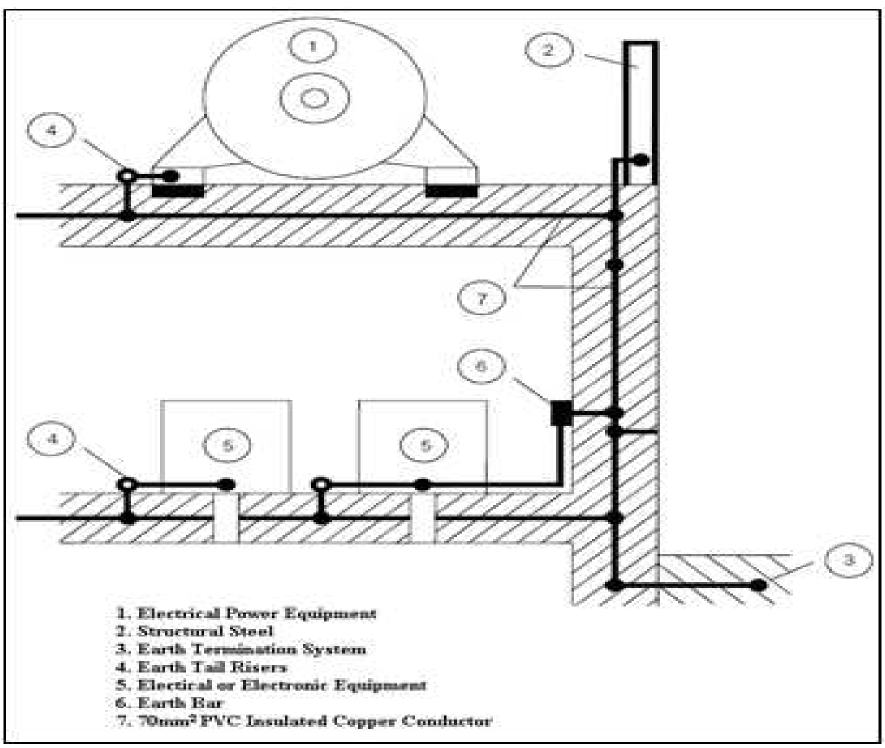

Figure 19: Illustration of concrete embedded earth conductors and tails [6]

APPENDIX G: EQUIPOTENTIAL BONDING

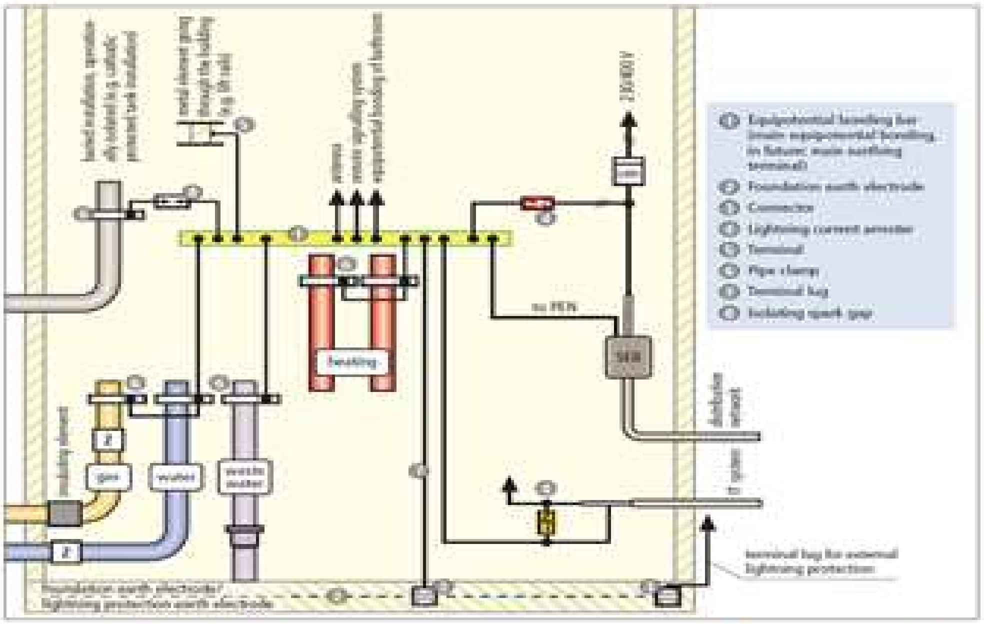

Figure 20: Illustration of equipotential bonding of services entering a structure/building [18]

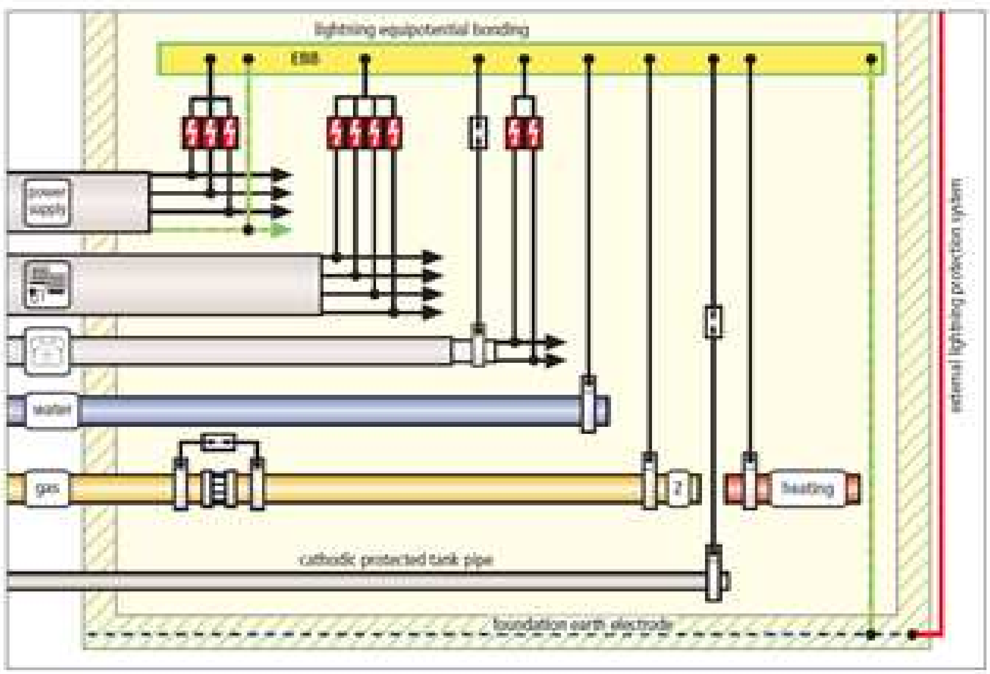

Figure 21: Equipotential bonding of services [18]

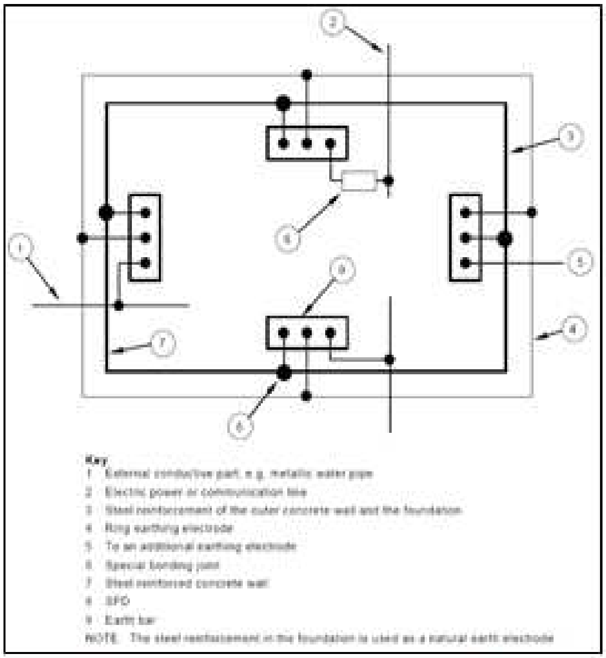

Figure 22: Illustration of equipotential bonding with multiple earth bars [5]

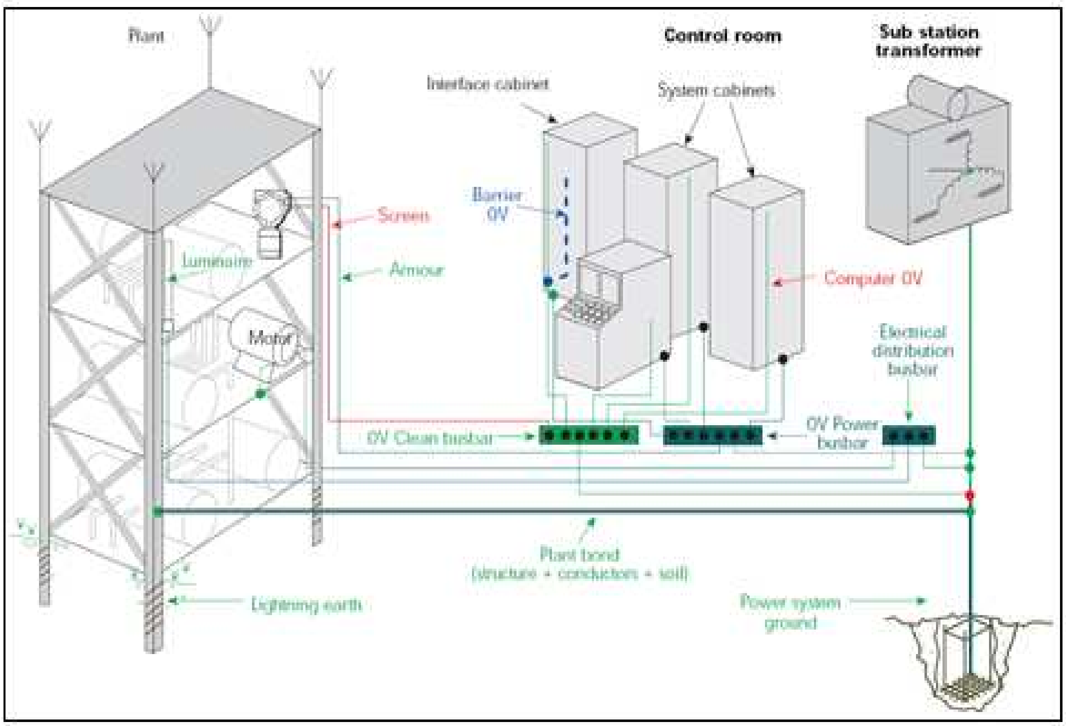

Figure 23: Summarised illustration of equipotential bonding between different earthing systems [22]

APPENDIX H: STRUCTURAL STEEL

By earthing structural steel, is a very good way to create a faraday cage, which reduces step and touch potential hazards. By bonding structural steel and foundation reinforcing to the ETS, reduces the probability of magnetic induction and creates additional multiple parallel paths to ground for fault currents. However the continuity of structural steel cannot be guaranteed and as such justifies the need for a dedicated DCS. Structural material such as metallic roof trusses, foundation rebar's and metallic beams and pillars etc. must be bonded to the ETS. Structural steel in pillars/columns will be bonded to the ETS and ATS. Figure 24 is an example of foundation bonding to a local EB.

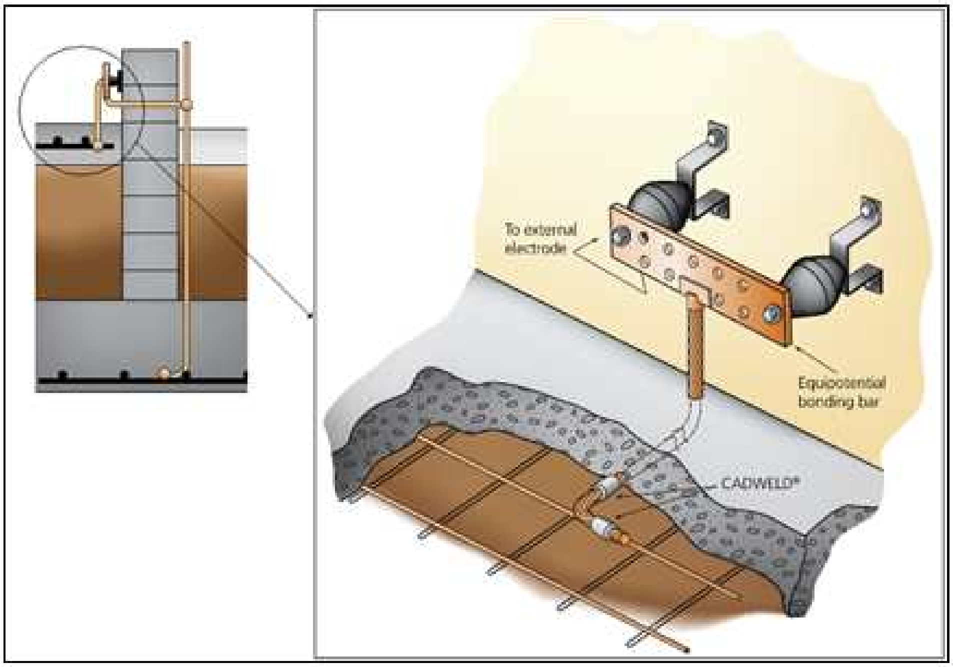

Figure 24: Structural steel earthing [18]

APPENDIX I: CONTINUITY TEST SHEET

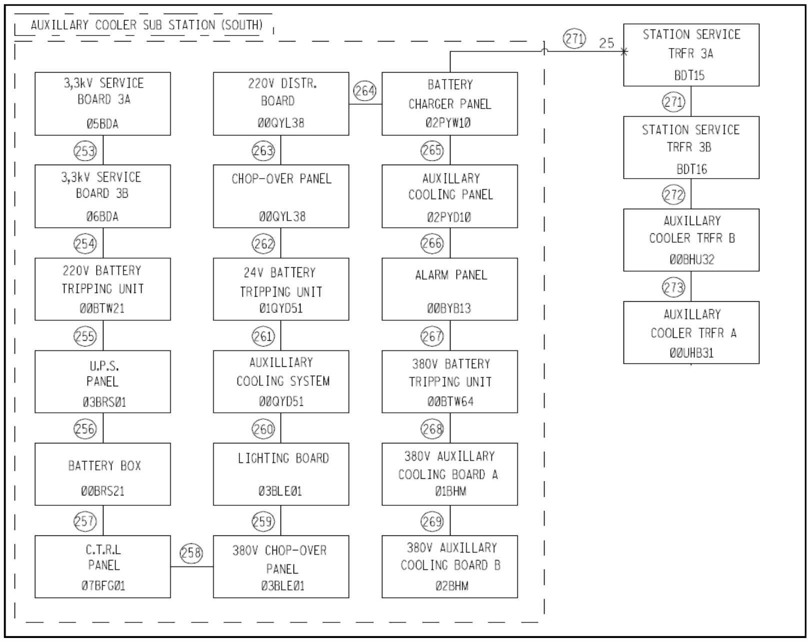

Figure 25: Example of continuity drawing

Table 9: Example of continuity test report

Number	From	To	Reading 1 (mΩ)	Reading 2 (mΩ)	Reading 3 (mΩ)
			Date:	Date:	Date:
253	3.3kV Service Brd 3A	3.3kV Service Brd 3B			
254	3.3kV Service Brd 3B	220V Battery Trip Unit			
255	220V Battery Trip Unit	UPS Panned			
256	UPS Panned	Battery Box			
257	Battery Box	C.T.R.L. Panel			
258	C.T.R.L. Panel	380V Chop-Over Panel			
259	380V Chop-Over Panel	Lighting Board			
260	Lighting Board	Aux Cooling System			
261	Aux Cooling System	24V Battery Trip Unit			
262	24V Battery Trip Unit	Chop-Over Panel			
263	Chop-Over Panel	220V Distribution Brd			
264	220V Distribution Brd	Battery Charger Panel			
265	Battery Charger Panel	Aux Cooling Panel			
266	Aux Cooling Panel	Alarm Panel			
267	Alarm Panel	380V Battery Trip Unit			
268	380V Battery Trip Unit	380V Aux cooling Brd A			
269	380V Aux cooling Brd A	380V Aux cooling Brd B			
271 (25)	Battery Charger Panel	Station Service Transformer 3A			
271	Station Service Transformer 3A	Station Service Transformer 3B			
272	Station Service Transformer 3B	Aux cooler Transformer B			
273	Aux cooler Transformer B	Aux cooler Transformer A			

APPENDIX J: MAINTENANCE ROUTINE

Table 10: Minimum activities for ELPS maintenance routine [17]

Number	Description of action	Reason for action	Frequency	Duration	Unit outage
1	Inspect air terminations (ATS)	Provide path for lightning current	6 months	2 d	No
2	Inspect down conductors (DCS)	Provide path for lightning current	6 months	4 d	No
3	Inspect bonding of air terminations to down conductors	Ensure a proper path for lightning current	6 months	1 w	No
4	Inspect continuity of external lightning protection	Ensure a proper path for lightning current	6 months	1 w	No
5	Tight bolted joints of external lightning protection	Ensure a proper path for lightning current	6 months	1 w	No
6	Inspect bonding of down conductors/steel structures to earth tails	Improve continuity and provide safety (bring touch potential down)	6 months	1 w	No
7	Tighten bolted joints to earth tails	Ensure good connection when current flow	6 months	5 d	No
8	Inspect galvanic continuity of cable support systems (cable racks, conduit) - take care at 90° bends	Interference to control cables is undesirable (biggest cause by magnetic coupling)	6 months	1 w	No
9	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
10	Test continuity of external lightning protection	Without continuity is risk of damage high during surges (keep the resistance $\leq$ 12 mΩ)	1 year	2 w	No
11	Test galvanic continuity of cable support systems (cable racks, conduit) - take care at 90° bends	Interference to control cables is undesirable (biggest cause by magnetic coupling – keep the resistance $\leq$ 12 mΩ)	2 year	2 w	No
12	Test the resistance of the ELPS relative to earth at all reference points	Ensure there is a proper connection down to earth	5 years	1 w	No

APPENDIX K: TEST AND COMMISIONING CHECK SHEET

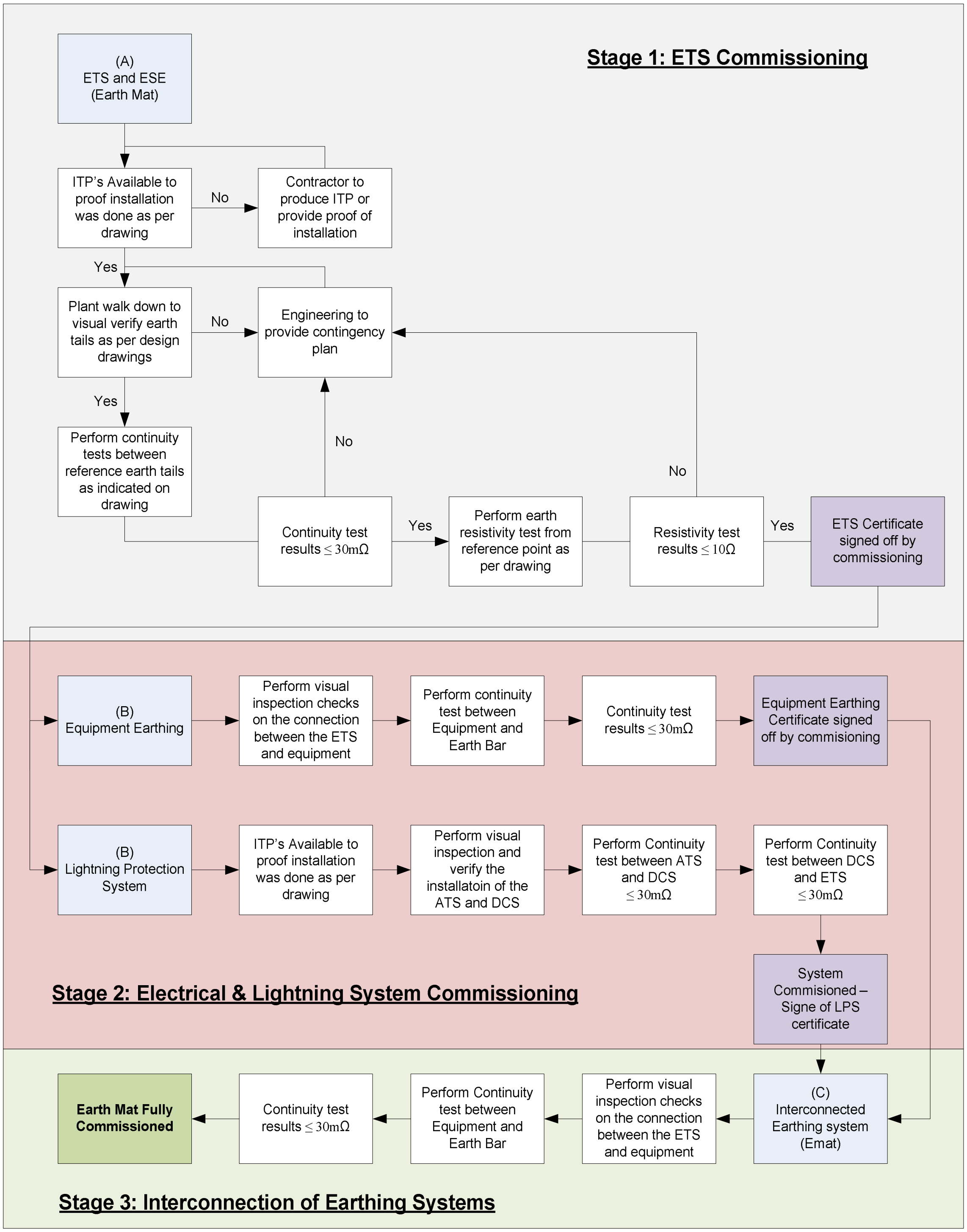

Figure 26: Conceptual commissioning plan

APPENDIX L: SUPPLIER DEVELOPMENT AND LOCALISATION

The development of the ELPS must meet the NNB Supplier Development and Localisation (SD&L) objectives. This is to ensure government objectives and initiatives are achieved by identifying opportunities for local BBBEE companies to design, construct, manufacture, deliver and install the ELPS. Table 11 highlights the main SD&L objectives regarding the ELPS that needs to be developed during basic/detail designs and works information stages of the project.

Table 11: SD&L information on ELPS

General Information		
Maturity of Local Market	High	
Local Markets Expenditure	100%	
BBBEE opportunity	Yes	
Local to Site Opportunities	High	
Project Opportunities		
	Local / Foreign	**Spend**
Design	Local	100%
Manufacture	Local	100%
System Installation	Local	100%
Commissioning / Testing	Local	100%
Maintenance	Local	100%