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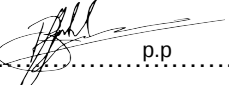
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EXECUTIVE SUMMARY

This report entails the detail designs for the scope forming part of the Leseding Transformation Upgrade project. The designs are done in such a manner to satisfy the requirements stipulated in the Northern Grid User Requirement Specification (SURS).

The 2017 Northern Grid Transmission Development Plan (TDP) has identified that the 2 x 500 MVA 400/132 kV transformation at Leseding Substation will exceed firm capacity in 2023 due to load growth in the area. The main trigger for this load growth can be attributed to an increase in mining activities and possible smelting operations in and around Leseding and Merensky substations. Leseding Substation is interconnected to Merensky Substation through the underlying 132 kV Distribution network and a 400 kV Transmission line. Upon further investigation, it was confirmed that Leseding Substation would exceed firm capacity, but the 2018 Groblersdal Master Plan suggested that this will only happen in 2025.

To address the transformer capacity challenges at Leseding Substation, the following option were investigated:

Option 1: Do nothing

Option 2: Shift some of the 132 kV load to Merensky Substation

Option 3: Add a 3rd 500 MVA 400/132 kV transformer at Leseding Substation

Option 3 was the preferred option and was thus implemented in this design.

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1. INTRODUCTION

This document provides design status information on the completed detail design phase for Leseding Transformation Upgrade project. This document is a major input to the formal design review process at the end of the design phase and describes the design process and technical output for the phase. The document contents provide an overview to the technical reviewers who will then, where required, use the actual design documents for performing their review.

The purpose of the detail design phase is to:

1. Establish a complete design, i.e. to produce all the component specifications, engineering drawings and other design documentation for procurement, fabrication, installation, construction and commissioning;
2. Ensure integration (utilities, mass and energy, system control, interfaces, etc.) of sub-system detail designs;
3. Finalise the layout designs with actual component data as input and resolve clashes;
4. Integrate operating and maintenance designs;
5. Consolidate and standardise bulk items for procurement;
6. Formalise the acceptance test procedures for product validation; and
7. Develop construction, installation and commissioning procedures.

1.1 SYSTEM IDENTIFICATION

Leseding substation is in the Northern Grid, approximately 120 km South-East of Polokwane in the Limpopo province. The substation will be identified by drawing LES23P04-SE-D6 and LES23P04-SE-D7, for the detail design phase.

The coordinates of Leseding Substation are 24.4387° S, 30.0165° E.

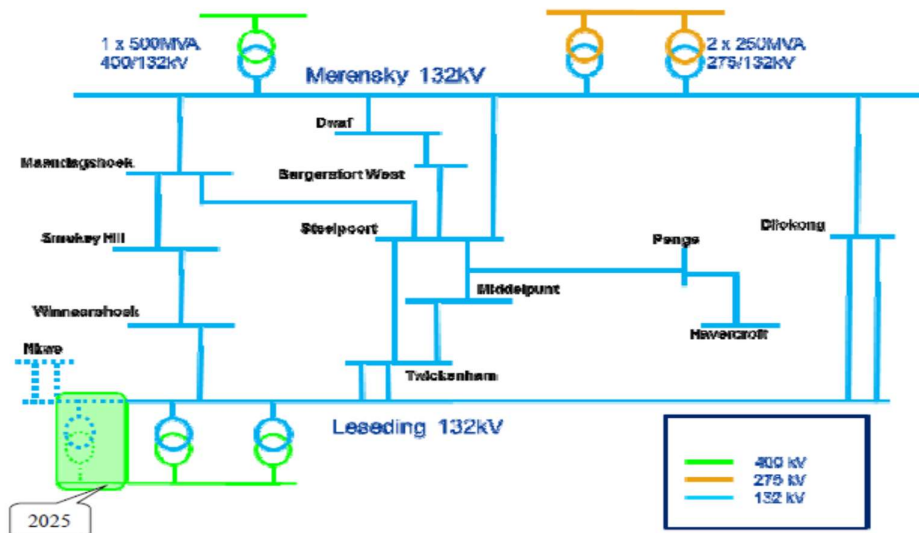
1.2 SYSTEM OVERVIEW

The system refers to the substation. Substations are the points in the power network where transmission lines and distribution feeders are connected through circuit breakers or switches via busbars and transformers. This allows for the control of power flows in the network and general switching operations for maintenance purposes.

Leseding substation is in the Northern Grid. The station has 2 x 400/132/22 kV 500MVA transformers. Leseding supplies 5 x 132kV lines namely Winnarshoek 1, Twickenham 1, Dilokong 1, Tjatane 1 & 2, and supplies Witkop 1, Merensky 1 and Duvha 1 at 400 kV. (See Figure 1 for network diagram).

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Network Diagram

1.3 PURPOSE OF THE PROJECT

There is a possible 300 MVA smelter load that could materialise between Leseding and Merensky substations. This was studied as a sensitivity to test the robustness of adding a third transformer at Leseding Substation as a long-term solution. Adding a third transformer is robust enough to accommodate this integration, should it materialise, however the integration of the smelter will raise the need to assess the transformation at Merensky Substation. This will be looked at in more detail as part of the Merensky Substation transformation assessment project in 2019 as the 2 x 250 MVA 275/132 kV transformers are aging (currently both 43 years old) and will be up for refurbishment in the near future.

2. SUPPORTING CLAUSES

2.1 SCOPE

This document provides an overview of the engineering processes followed and the system design status at the end of the detail phase. The document includes the results of technical assessments to determine compliance with stakeholder requirements, technical risks identified, lessons learned during the design process and outstanding issues for this design phase. This document further provides references to the design output documentation.

This document does not provide design cost, schedule or other project management type information.

2.1.1 Purpose

This document summarises the status and outcome of the detail phase design related activities and describes the achievement of the design goals, in terms of meeting stakeholder requirements. This document, together with the design output documentation of this phase, is submitted for review.

2.1.2 Applicability

This report has been compiled for use within Eskom Holdings SOC Ltd in general and for use by Eskom Stakeholders.

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2.2 NORMATIVE / INFORMATIVE REFERENCES

2.2.1 Normative

- [1] Leseding Substation Transformation Upgrade Planning Report (GP_18/86)
- [2] User Requirement Specification (240-86056088)
- [3] Geotechnical Report (PRJ_R_1/Rev0)
- [4] Substation Layout Design Guideline (240-55922824)
- [5] Standard for Implementation of Substation Layouts for Transmission Substations (240-109644476)
- [6] Substation Engineering Product Realisation (240-55921217)
- [7] South African Grid Code
- [8] Occupational Health and Safety Act (OHS Act) 85 of 1993
- [9] Eskom Maintenance Management Policy (32-1205)
- [10] Substation and Facility Maintenance (TST41-794)
- [11] Eskom Generation and Wires Operating policy (240-43008621)
- [12] Eskom Safety, Health, Environment and Quality policy (32-727)
- [13] Operating Regulations for High Voltage Systems (32-846)
- [14] The application of the National Building Regulations (SANS 10400-XA)
- [15] Energy efficiency in buildings (SANS 204)
- [16] Standardized Specification for Civil Engineering Construction (SANS 1200)
- [17] IEEE Guide for Safety in AC Substation Grounding (IEEE std 80)
- [18] Standard for Labelling Outdoor High Voltage Equipment within Eskom Transmission (TSP41-1009)
- [19] Process Control Manual (PCM) for Perform Substation Engineering (240-53459042)
- [20] Process Control Manual (PCM) for Perform Technical Assessment (240-46977482)
- [21] Soil Resistivity Testing For Substation Applications (240-96393507)
- [22] Earth Electrode Resistance Measurement standard (240-101940513)
- [23] The Transmission Substation Earth Fault Application Guide (240-95773230)
- [24] Design Review Procedure (240-53113685)
- [25] Terms of Reference for Design Review Teams presiding over Power Delivery Infrastructure Designs in Eskom (240-606480018)
- [26] Direct Lightning Stroke Protection of Substations (240-109589380)
- [27] The Design Philosophy for 400kV Tubular Conductor Busbar Yards (240-95242252)
- [28] Standard for operational floodlighting in substations (240-83382076)

2.2.2 Informative

IEEE Guide for Safety in AC Substation Grounding (IEEE std 80)

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2.3 DEFINITIONS

2.3.1 Classification

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

2.4 ABBREVIATIONS

Abbreviation	Description
CLN	Customer Load Network
CoE	Centre of Excellence
EIA	Environmental Impact Assessment
SLDG	Substation Layout Design Guideline
kV	Kilovolt
MTS	Main Transmission Substation

Table 1: List of Abbreviations

2.5 ROLES AND RESPONSIBILITIES

The roles and responsibilities are defined in the responsibility matrix contained in the Project Management Plan. Internal to Substation Engineering, Ayanda Mbense, Stanley Beukes, Shivern Singh and Senzo Duma are the design leads for Electrical and Civil.

2.6 PROCESS FOR MONITORING

This document will be revised as and when new information comes into light during the detail design phase of the project.

2.7 RELATED / SUPPORTING DOCUMENTS

The detail design report will be submitted with a copy of detail design drawings outlined in Appendix A, B, C and D of this report.

3. DETAIL DESIGN INFORMATION

3.1 SCOPE OF DETAIL DESIGN

3.1.1 Scope of Work

The high-level scope of work is summarised as follows:

As per SURS[2]:

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- Extend 132kV busbar.
- Extend 132kV yard.
- Install and commission a third 1 x 500MVA 400/132kV transformer.
- Add a bus section (with associated bus zone protection) on the 132kV busbar.
- Equip and commission all new infrastructures at Leseding Substation with all associated primary and secondary plant.

In addition, there will be other works that will be required to execute this scope of work. Some of these identified at this stage, and will be further investigated:

- Upgrade safety and security fences to latest standard (Entire Substation).
- Install a Guard House, as per latest standard.
- Cater for storage area during construction.
- Perform Geotech Studies in Concept Design Phase.
- Investigate Control room damages due to unstable ground conditions and make comments going into detailed designs.
- Install another 132kV Bus Coupler, to prevent islanding of a portion of the 132kV Busbar, with the installation of the New 132kV Bus Section.

3.1.2 Project Scope limits

The work to be done is limited to the scope as identified by the User Requirement Specification and the additional scope resulting from the design requirements due to stakeholder engagement.

3.1.3 Project Exclusions

All work unmentioned in the project report and drawings is excluded. Work that will be added to the scope of work retrospectively should be done so via formal written communication, or revision to the SURS.

3.1.4 Adjacent or Related projects

- Leseding SS – 2 x 132kV Feeders (Nkwe 1 & 2)
- Leseding Substation – 16 MVA NMD Increase for Marula Mine
- Waterberg Generation Integration Fault Level Management Plan project (Execution Phase)

3.1.5 Project Stakeholders and Resources

Tx PDD	Sashan Marion
Northern Grid	Carel Van Coppenhagen
Grid Planning	Caroleen Naidoo
Integration	Amanda Hadebe
Substation Engineering	Stanley Beukes

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Substation Engineering	Sithembiso Mabena
PTM&C	Christinah Mohloki
Northern Grid Chief Engineer	Rukesh Ramnarain
Leseding EA	Joseph Mohlala
Environmental	Gift Matsabatsa

3.2 PROJECT DESIGN INPUTS

The following is a summary of the key substation design aspects for this project:

Network Requirements (Minimum): Factor	Description	
Network nominal voltage	400kV	132kV
Normal operating range	±5%	±10%
Equipment highest voltage	420kV	145kV
Minimum Rated lightning / Surge Impulse withstand	1425kV	550kV
Continuous rating	3150A	2500A
Reliability	N-1	N-1

Table 2: Network Requirements

Rated Physical Environment: Factor	Description
	Polokwane, Limpop
Ambient Temperature, Max	40 °C
Ambient Temperature, Min	-3.5 °C
Lightning Density	5-10 flashes to ground/km²/year
Rain Fall (highest per day)	58 mm
Thunder (mean)	19.1 days/year
Snow (mean)	0 days/year
Max. Wind Speed	39.2 m/sec
Pollution characteristics	Normal
Geographical Area	Inland
Altitude	1310m

Table 3: Site Conditions

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Other site conditions are documented in the Environmental Impact Assessment Report and should be taken into account in formulating the design solution.

3.3 KEY DESIGN ASSUMPTIONS

- The environmental authorisation will not dictate changes to the position of the proposed solution.
- The information and user requirements provided by Grid Planning are accurate.
- The detail design will be based on equipment as per the Eskom National Contract (ENC) in place at the time.
- The information received from Planning is accurate.
- The Geotechnical Studies will be done and will be required for the final earthing assessments to be completed in the detailed design phase.
- Any changes to the scope can be accepted with the revised SURS.

3.4 DESIGN APPROACH

3.4.1 Planning Inputs

The major design inputs are from Grid Planning in the form of the approved planning report [1] and approved user requirement specification [2]. The other inputs were system records and stakeholders' input.

3.4.2 Design Process

The design process followed is in adherence to the Substation Engineering Product Realisation document [5] and Process Control Manual (PCM) for Perform Substation Engineering [19].

3.4.3 Design Outputs

The design outputs are stipulated in the Substation Engineering Product Realisation document [6].

3.4.4 Design Verification

The detail design outputs are packaged in the form of a presentation and presented to the Substation Engineering Design Review Team (DRT) for support of the project to be presented to the Power Delivery Engineering Review Team for approval.

The outputs also undergo a peer review within the Substation Engineering centre of excellence.

The design reviews are done in accordance with the Design Review procedure [24] and the PDE DRT terms of reference [25]. The design review ensures that the most efficient design solution is selected taking into account the life cycle of the asset. This includes technical feasibility, technical risks, capital cost, life cycle costs, safety, constructability, maintainability and outage management amongst others.

Some of the aspects considered during design review are:

- Compliance of design to stakeholder (user, regulatory, statutory, environmental) requirements.
- Compliance of designs to design standards, philosophies, practices and codes.
- Compliance to the relevant PCM's.
- Demonstration of sound engineering thinking where a unique solution has to be provided (design approach, rationale, assumptions, modelling, calculations, simulations).
- Review, challenge and approval of the technical designs at the various PLCM stage gates.
- Practicality of the implementation proposal for the design solution.
- Ensure that all documents required to procure, construct, install, commission, operate and maintain the designed system or component have been submitted for review and acceptance.

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- Safety in design (design is safe to construct, operate, maintain and dismantle).
- The design has considered and incorporated all aspects of constructability, procurement, operability, maintainability, sustainability, reliability, availability, testability, expandability, disposability also and including inspection and commission capabilities.
- Risks have been identified, assessed, documented and mitigated.
- Check if design is ready to proceed to the next design phase or to the execution phase.
- Recommendations of previous design reviews have been incorporated in the revised design.
- Design changes and modifications to be referred back to DRT.
- Engineering changes are managed in line with what is described in the PCMs.

Any changes to the design, reported on in this document by any of the DRT committees, will be reported on in a revision of this document.

3.4.1 Design Criteria

The design criteria and guidelines used are based on Section 5-1 of the Substation Layout Design Guide [4] and Standard for Implementation of Substation Layouts for Transmission Substations [5].

3.4.2 Codes and Standards

The designs are governed by Grid Code [7] and are additionally required to be in compliance with Occupational Health and Safety Act [8].

3.5 KEY DESIGN DRIVERS

The key design drivers are land acquisition challenges, space constraints, cost reduction, outage reduction, constructability, procurability, maintainability, operability, safety, reliability and expandability.

3.6 DESIGN OPTIONS CONSIDERED

Different design options were taken into consideration. The options are as follow:

- **Option 1: Do nothing**

This option is not feasible because as the load demand continues to grow, Leseding Substation will no longer be able to supply the entire load during N-1 conditions. This will be a violation of the South African Grid Code and will further limit growth and compromise the reliability of the substation. It will also hamper maintenance and refurbishment.

- **Option 2: Shift load to Merensky Substation**

This option is not adequate because Merensky Substation is already highly loaded. The commissioning of Sekhukhune substation in 2024 will slightly deload Merensky Substation from 573 MVA in 2023 to 447 MVA in 2024. This means that a maximum of 53 MVA can be transferred to Merensky Substation; otherwise Merensky Substation will also exceed its firm capacity. This option is therefore also not feasible as it will result in Grid Code violations and will compromise the reliability of Merensky Substation.

- **Option 3 (Preferred Option): Add a 3rd 500 MVA 400/132 kV transformer at Leseding Substation**

This option will increase firm capacity at Leseding Substation from 500 MVA to 1000 MVA. It will also deload Merensky Substation by approximately 74 MVA. There are two planned future transformer bays at

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Leseding Substation, one of which will be used to install the third transformer; however, this will require an extension of the 132 kV yard and busbar. There are no thermal, voltage and crossflow violations. There is a slight increase in the fault levels after the commissioning of the third transformer but there is no exceedance, all the equipment in the substations will be adequately rated.

Option 3 is the recommended option. The existing servitude and rights are maintained. Operators will follow all ORHVS guidelines for Operations

3.7 ELECTRICAL DETAIL DESIGN

3.7.1 Design Philosophies

Leseding substation has two voltage levels 400 & 132 kV. The 400 kV busbar is built with 250 x 6mm aluminium tubes with 1 x bus section and 2 x bus couplers (BUS COUPLER "A" & "B"). The 132 kV busbar is built with 200 x 6mm aluminium tubes with 0 bus sections (1 will need to be equipped) and 1 x bus coupler (BUS COUPLER "A"), another Bus Coupler B will be equipped. The switchyard is air-insulated with the applicable minimum phase-to-earth and phase-to-phase clearances.

The substation configuration is double busbar selection with bypass bus for the 400 kV and for 132 kV it is double busbar selection. The double busbar with bypass offers more flexibility to make use of the bypass bus to perform maintenance without disturbing supply which is an extension of the double busbar configuration which offers flexibility allowing each circuit to be connected to either of the two busbars. It is also possible to move circuits from one busbar to the other while they are energised. The double busbar design provides for "n-1" contingencies in accordance with the requirements of the South African Grid Code [9].

The substation comprises of 2 x 400/132 kV 500 MVA transformers with 2 x transformer future bay, 3 x 400 kV feeder bays (1 x 400kV spare bay), 5 x 132 kV feeder bays (7 x 132 kV spare bay).

3.7.2 Substation Design Specifications and Configuration

3.7.2.1 Fault Level Studies

System Voltage (kV)	1 Φ Fault Level (kA)		3 Φ Fault Level (kA)		Designed Fault Current (kA)
	Current	New	Current	New	
132 kV	16.2	18.8	25	28.7	31.5
400 kV	9.3	9.4	16.7	16.7	25

Table 4: Fault level studies for the Leseding substation

3.7.2.2 Primary Plant Equipment

System Voltage (kV)	Rated normal current (A, min)	Short-circuit withstand current (kA, min)	CT Bus Zone Ratio	BIL (kV, min)	Minimum Specific creepage distance (mm/kV, min)
132 kV	3150	40	1/1600	550	25
400 kV	3150	50	1/1600	1425	25

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Table 5: Equipment/Cable/Conductor Selection and Ratings

3.7.2.3 Busbar Design

	400kV	132kV
Busbar Configuration	Double BB with Bypass	Double BB
Busbar Type	AL. Tube (250x6mm)	AL. Tube (200x6mm)
Busbar Phase Spacing	7010 mm	3000 mm
Busbar rated Current	5780A (@ 85°C)	4750A (@ 85°C)

Table 6: Busbar Design

3.7.2.4 Conductor Selection

Description	Conductor Rating (A)		Conductor Type
132 kV Bus Section, Bus Coupler & Transformer Bay	1970 (@ 75°C)	2700 (@ 90°C)	Twin Bull
400 kV Transformer Bay	1970 (@ 75°C)	2700 (@ 90°C)	Twin Bull

Table 7: Cable/Conductor Selection and Ratings

3.7.2.5 Electrical Clearances and Clearance Constraints

This section should describe the electrical clearances and clearance constraints applicable to the design. Include the summary table of clearances like the one below (table 8)

System Nominal Voltage (kV)	Minimum Electrical Clearances		Working Clearances	
	Phase to earth (mm)	Phase to Phase (mm)	Vertical (mm)	Horizontal (mm)
132	1200	1650	3700	2300
400	3200	4000	5700	4300

Table 8: Electrical clearances of the HV equipment to be used in the design.

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3.7.2.6 Station DC Voltage

The existing station DC voltage is 110 V.

3.7.2.7 Insulator Type

Equipment insulator will be either composite silicone rubber type or ceramic type insulator. If these are ceramic, these need to be RTV coated.

3.7.2.8 Station Construction Supply

Construction supply will be obtained from the existing auxiliary supply via 2 x 11/0.4 kV 315 kVA aux transformers.

3.7.2.9 Station Auxiliary Supply

The station auxiliary supply is detailed in the PTM&C detail design report.

3.7.2.10 Yard Lighting

The illumination levels for any substation shall be according to the latest OHS-act [8]. The Floodlighting installation shall provide a minimum average illumination level of 10 lux in both 132 and 400 kV high voltage yards and 20 lux at the transformer bays and reactor bays, with a uniformity ratio of 5 lux within the high voltage yard being considered.

The new yard lighting design will be in strict accordance with the standard for operational floodlighting in substations [28].

Below is the result of the simulation done for yard lighting at Leseding substation. The results show an average illuminance of 40 lux (more than the stipulated minimum of 10 lux) and uniformity ratio of 1:3.9 (less than the stipulated maximum of 1:5)

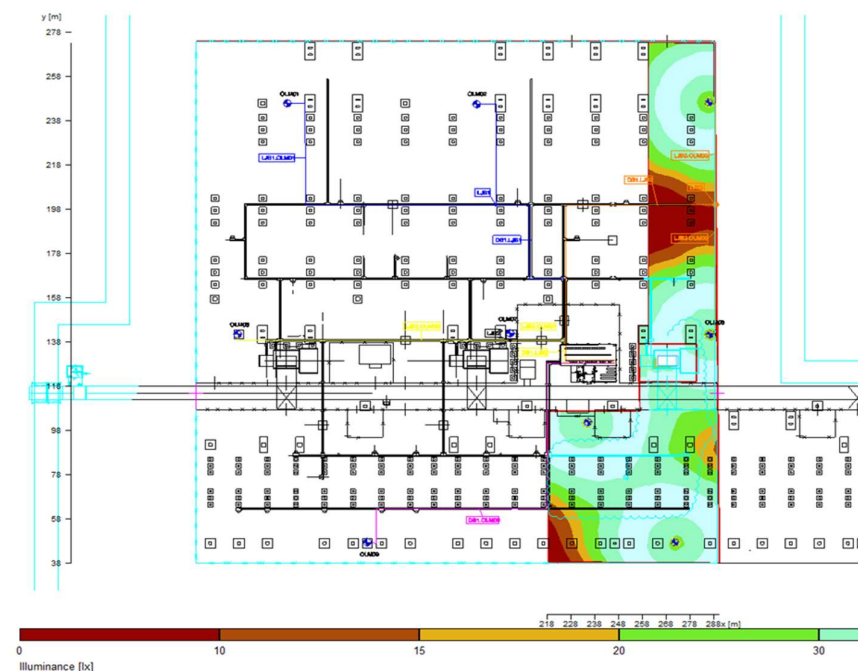


Figure 1: Illumination simulation results of Leseding substation.

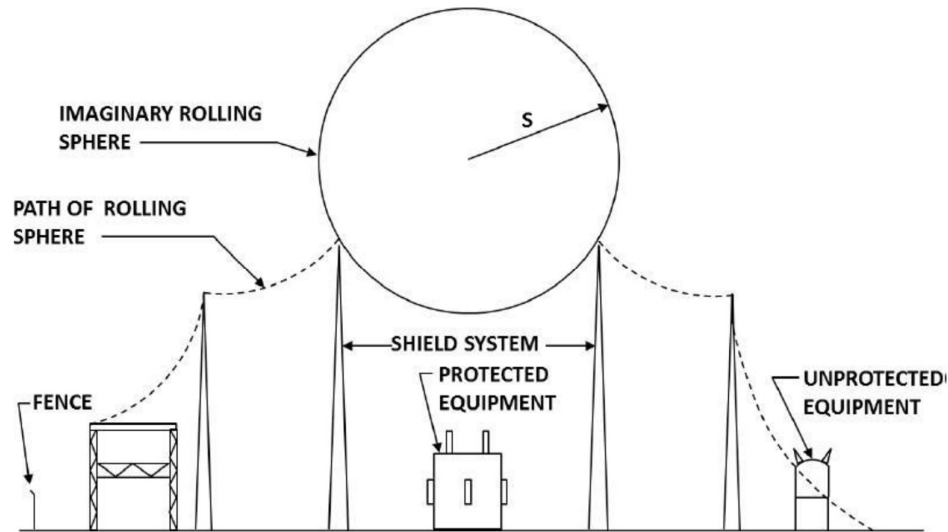
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3.7.2.11 Direct Lightning Stroke Protection

Direct Lightning Stroke Protection will be achieved by using a rolling sphere method as prescribed in the Direct Lightning Stroke Protection of Substations [26].

The technique involves rolling an imaginary sphere radius at busbar level over the surface of the substation. The sphere rolls up and over (and is supported by) the lightning masts, shield wires and other grounded metal objects intended for lightning shielding. A piece of equipment is protected from a direct stroke of lightning if it remains below the curved surface of the sphere by virtue of the sphere being elevated by shield wires or other devices. Equipment that touches the sphere or penetrates its surface is not protected from direct stroke of lightning.



The lightning coverage will be extended for the new extension and equipment.

3.7.2.12 AC Reticulation

The AC Reticulation is detailed in the PTM&C report.

3.7.2.13 Bill of Material for Major Equipment

Item No.	Equipment	Comment	Total Quantity
400 kV Yard			
1	Conventional Isolator	TBC	1
2	Pantograph Isolator	TBC	1
3	Circuit Breakers	TBC	1
4	Current Transformer	TBC	3
5	Earthing Switch	TBC	1
6	Surge Arrestor	TBC	3
7	Transformer	500MVA 400/132/22 kV	1
		132 kV Yard	

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8	Surge Arrestor	TBC	3
9	Earthing Switch	TBC	1
10	Current Transformer	TBC	9
11	Circuit Breakers	TBC	3
12	Pantograph Isolator	TBC	3
13	Conventional Isolator	TBC	3
14	Voltage Transformer	TBC	3
15	Post Insulators	TBC	30

Table 9: Bill of Material for Major Equipment

Substation Earthing

The following Eskom standards will be used for the earth mat designs of the Leseding substation:

- 240-96393507 - Soil Resistivity Testing for Substation Applications
- 240-95773230 – Transmission Substation Earth Fault Application Guide
- 240-134369472 – Substation Earth Grid Design Standard
- Earthing Standards 0.54/393.

For the Leseding substation earthmat design and studies see Appendix B.

3.7.3 External Interfaces

Not applicable under this scope.

3.7.4 Facilities Required

All facilities are catered for under the existing substation.

3.7.5 Maintenance Concept and Maintenance Design

The maintenance philosophy for this substation will be strict adherence to [9], [10] and [14] in addition to the Original Equipment Manufacturers (OEM) requirements. The maintenance policy refers to a number of standard(s)/specification(s) documents that must be coherently adhered to in order to achieve its purpose.

Safety of personnel is of paramount importance when designing a substation. The design caters for maintenance needs by arranging equipment such that there are sufficient working clearances, and portions of the system that can be isolated to work on. While working clearance to live metal is desirable for the

safety of personnel engaged on operations or maintenance; it is not practical to ensure that such clearance exists from every position in a high voltage yard which a person might conceivably be able to occupy.

Since personnel cannot be prevented from getting off the ground it is concluded that working clearances shall apply at ground level only. A person stepping off the ground cannot rely on having working clearance and must take whatever other measures that may be necessary to ensure his own safety.

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The design furthermore provides for the following:

- Access to equipment – The 400 and 132 kV yards can be accessed from the main substation (concrete) access road, through the respective 6 m gates provided. Service truck access is provided for to all equipment in each of the yards. Minimum separation distance of 6 m is applied for between any equipment/steelwork and fencing. There are various control cable crossings and each of these will be provided with suitable ramps in accordance with 0.54/390 sheet 37.

3.7.6 Operating Concept and Operating Design

Operating philosophy for the substation will be in accordance with [11]. The policy refers to a number of standard/specification documents that must be coherently adhered to in order to achieve its purpose. 400 kV double busbar with bypass arrangements which is widely used within the Eskom network exist at both Stations. The arrangements are standard and are well known by designers, operators and National Control. Operating risks at these substations will therefore be no greater than at any other Eskom substation employing the same busbar configurations.

All controlling apparatus will be permanently labelled so as to identify the system or part of the system on the electrical machinery which it controls, and where such control apparatus is accessible from the front and back these markings shall be on both the front and the back of the label.

Also, an operating diagram will be made available to the substation to assist with operating. This drawing serves to indicate all motorized switching equipment (e.g., circuit breakers, isolators, earth switches etc.) within the substation along with their relevant labels.

Operating requirements will be in accordance with the requirements as set out in [12].

3.7.7 Safety Concept

It is important that substations be safe for the general public and for operating and maintenance personnel. Practical approaches include the employment and training of qualified personnel, appropriate working rules and procedures, proper design, and correct construction. The safeguarding of equipment is also considered in substation design. Personnel working standards are prescribed by regulations issued by [10]. Furthermore, all operating, and maintenance personnel should work within the rules and regulations stipulated in [12] and [14].

The substation designs are performed in accordance with the relevant Eskom standards, including [8] and [9].

The earthing system design will be performed in accordance with [24] and associated references. The objective of effective earthing of a substation is of the utmost importance in ensuring the safety of personnel and protection of equipment. This is achieved by providing a means to dissipate electric currents into the earth under normal and fault conditions without exceeding any operating/equipment limits or adversely affecting continuity of supply. The earthing design limits the touch and step voltages to within safe limits.

3.8 SITING

3.8.1 Site Selection

Leseding Substation is an existing substation.

3.8.2 Site Characteristics

3.8.2.1 Geotechnical

Ground/Soil conditions are not favourable in the area. Geotech Studies will determine the extent of ground works required.

3.8.2.2 Topographical Survey

The topographical survey was conducted on the portion in which the 132kV terrace extension will occur. The topographical survey extended to the existing access road.

3.8.2.2 Hydrological Characteristics

Leseding Substation has Mean Annual Rainfall of 500mm with an expected 16 days/year of days of thunder annually.

3.8.3 Site Layout

The coordinates of Leseding Substation are 24.4387° S, 30.0165° E. The site layout can be found on the Key Plan LES23P04-SE-D7

3.9 CIVIL AND STRUCTURAL DESIGN

3.9.1 General

The civil infrastructure will be designed in accordance with the SANS standards [14][15][16].

3.9.2 Buildings

With regards to the building, the control building has been assessed during the concept phase and this show substantial damage due to heaving as the substation is built under active clay material. The objective of the third transformer is to investigate the repair off the control room which guards to the sustained damage due to be geotechnical action. The access control building will also form part of the scope of work in which the building will form part of the security upgrade

3.9.3 Earthworks

The third transformer will require the existing terrace to be extended therefore the design will look into the cut to spoil of the insitu material and to fill with engineered material as the site is underlined by material which is not conducive for substation foundations. All earthworks' activities will be done in accordance to the SANS 1200 and the appointed contractor shall comply with these standards for all earthworks activities that will be required during the project. Fill material will be required to be stockpiled on site. Also, during the extension of the terrace, the retaining concrete revetment will be also relocated in the process.

3.9.4 Foundation, plinths and trenches

All foundations will be standard foundations as we will be equipping a new transformer bay as part of the new ENC's. A standard transformer plinth design will be used for the proposed transformer unit that will be installed as part of the 3rd transformer project.

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3.9.5 Fencing

The project will include all types of fencing to be upgraded. The current state in which existing fences on site is that the security fence is only comprised of the safety fence while the non-lethal fence being piggy backed. This is no longer the standard and therefore will have to be upgraded. According to the security studies that we conducted in the area have recommended that a concrete wall be installed at the site. Therefore, a new 3 tier fence layout has been proposed will include a concrete wall, non-lethal fence and inner security barrier fence which will be comprised of welded mesh. This new fence will be installed bearing in mind the future expansion of the substation. The existing HV yard safety fence, will be also extended when the terrace for the new the transformer is completed. As part of the earthing standard additional yard stone will be also install at 100 mm thickness throughout the extension.

3.8.6 Roads

The access road on the site is existing but it has been identified for upgrade due to the poor condition that's it's currently in. The upgrade will assist with regards to the transportation or delivery of the new transformer power unit.

3.8.7 Structural Steel

All new steelwork structures will be installed as part of the project.

3.8.7 Drainage

Drainage will also form part of the scope of work. For the stormwater drainage, it will be linked to the existing drainage systems and modifications will be done where necessary. The fire protection is also existing, and the 3rd transformer will be linked to this system however depending on the size of the transformer or the oil capacity, the oil dam may also be required to be upgraded.

3.10 CONTRACTING AND PROCUREMENT STRATEGY

3.10.1 Identification of Long Lead Items

A list of all the long lead items with the estimated lead times are provided in Table 10 below. All risks associated with the procurement of materials and equipment rest with the IPP.

Item No.	Description	Delivery time (months)
1	Transformers	12 - 18
2	Isolators	6 - 9
3	Circuit Breakers	6 - 9
4	Earthing Switches	6 - 9
5	Current Transformer	6 - 9
6	Surge Arrestors	6 - 9
7	Post Insulators	6 - 9

Table 10: Long Lead Items

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3.10.2 Alternative Materials considered

Equipment will be ordered from the Eskom National Contract that will be in place at the time of ordering equipment. Where no ENC's are in place, equipment will have to be sort by following the latest applicable Treasury/Eskom Commercial processes.

The advantage of using equipment and materials that are on Eskom's contracts caters for readily available spares, as well as a guarantee that sourced equipment and materials are technically suitable for their intended application.

3.11 DESIGN ASSESSMENT

3.11.1 Operability Assessment

The operability of the system meets the minimum criteria. The configuration allows for safe working clearances and all controlling apparatus will be labelled to identify the system or part of the system on the electrical machinery that it controls. In addition, the operating diagram will be issued just before commissioning to assist with operating the station [13][18].

3.11.2 Reliability, Maintainability, Availability Assessment

Safe working clearances will be incorporated in the substation design, as specified in the Substation Layout Design Guide [4], to allow for maintenance and inspection to be conducted in a live yard.

3.11.3 Procurability Assessment

Procurement of all primary plant equipment and bulk items will be conducted by the Commercial Department during the execution phase of the project. The detail design will be completed on the assumption that the applicable equipment will be procured on the existing Eskom National Contract (ENC).

3.11.4 Constructability Assessment

No major constructability risks are foreseen at this stage of the project. Working in a live yard is a risk and to mitigate the risk, outages are required.

3.11.5 Inspectability and Testability Assessment

The substation equipment layout design allows for working clearances in section 4-1[4] to perform inspection and testing safely without substation shut down. The testing and inspection procedures to be done in cognisance of the following standards [10][13].

3.11.6 Expandability Assessment

The expandability of the substation has been taken into consideration and feeder populating planned bays. this allows for other feeder to exit the station without any line crossing required now or in the future. This is achieved by pre-allocating spare and future bays for the required end-state of the substation in appropriate positions.

3.11.7 Technology Assessment

Only standard and proven equipment is to be utilised in this design. The equipment will be supplied off Eskom National Contracts.

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3.11.8 Design Simplification

This will be based on the design parameters as per the User Requirement Specification [2]. Also applicable is the Substation Layout Design Guide [4] which serves two main objectives. The first objective is to assemble into one manual (or set of manuals) as much basic design data as possible and the second objective is to introduce a measure of Standardisation. During the detail stage of the project, multidisciplinary design review sessions are held with the various stakeholders to ensure that the objectives of the project are met and all stakeholders are satisfied that the best and correct design is delivered. Refer to Eskom Group Technology Engineering Design Review procedure [24] for further details regarding this process. All relevant CoE's within the project perform their departmental internal reviews. This procedure is applicable to this project in its entirety.

3.11.9 Value Engineering Procedure

Value Analysis can be defined as a process of systematic review that is applied to existing product designs in order to compare the function of the product required by a customer to meet their requirements at the lowest cost consistent with the specified performance and reliability needed. This is a rather complicated definition and it is worth reducing the definition to key points and elements:

1. Value Analysis (and Value Engineering) is a systematic, formal and organized process of analysis and evaluation. It is not haphazard or informal and it is a management activity that requires planning, control and co-ordination.
2. The analysis concerns the function of a product to meet the demands or application needed by a customer. To meet this functional requirement the review process must include an understanding of the purpose to which the product is used.
3. Understanding the use of a product implies that specifications can be established to assess the level of fit between the product and the value derived by the customer or consumer.
4. To succeed, the formal management process must meet these functional specification and performance criteria consistently in order to give value to the customer.
5. In order to yield a benefit to the company, the formal review process must result in a process of design improvements that serve to lower the production costs of that product whilst maintaining this level of value through function.

In the construction industry, value engineering, value analysis and value management are all titles used to describe a structured process to examine the function of infrastructure to ensure that it is delivered in the most cost-effective way.

The value engineering was achieved through following the design approach detailed in section **3.3** of this report and following the design review procedure [24]. The analysis of the design involves subjecting the design proposal to systematic review during the detail design stage to ensure that the detail design meets user requirements, without over-specification, at the lowest possible cost.

3.11.10 Dismantling and Demolition Requirements

All earthworks' activities will be done in accordance to the SANS 1200 and the appointed contractor shall comply with these standards for all earthworks activities that will be required during the project. Fill material will be required to be stockpiled on site. Also, during the extension of the terrace, the retaining concrete revetment will be also relocated in the process.

3.12 SAFETY ASSESSMENT

3.12.1 Industrial Safety Assessment

As far as practicable, the designs at Leseding Substation ensures that no failure will lead to life threatening situations for any person or to unacceptable damage to the environment or the installation. Safety assessment is aimed at ensuring that a safe, practical design is carried out. The safety assessment is based on adhering to safety rules as specified in section 5-1 of the Substation Layout Design Guide.

3.12.2 Fire Safety Assessment

No fire risks foreseen, apart from the general electrical failure, resulting in fires. No further assessment was considered, given the remote nature of the site.

3.12.3 Environmental Assessment

Summary results of environmental assessment.

3.13 SECURITY DESIGN

According to the security studies that we conducted in the area have recommended that a concrete wall be installed at the site. Therefore, a new 3 tier fence layout has been proposed will include a concrete wall, non-lethal fence and inner security barrier fence which will be comprised of welded mesh. This new fence will be installed bearing in mind the future expansion of the substation. The existing HV yard safety fence, will be also extended when the terrace for the new the transformer is completed.

3.14 TEST AND COMMISSIONING

Testing and commissioning will be done according to relevant standards and procedures, these are captured in the PTM&C design report.

3.15 PLAN OF IMPLEMENTATION

3.15.1 Project Outage Requirements

Outages will be required on the following bays:

- 400 kV Busbar 1 & 2
- 132 kV Busbar 1 & 2

3.15.2 Transportation Plan

No major transportation risks are foreseen at this stage of the project. The existing access road will be upgraded as part of the project to mitigate the risks of equipment damage due to transportation. Caution needs to be taken on community route leading to the substation as the municipality routes are in poor conditions.

3.15.3 Construction Plan

- i. Prepare terrace for 132kV busbar extension
- ii. At the existing yards, remove yard stone and stockpile the material
- iii. Excavate and cast equipment foundations
- iv. Install new fences and decommission unused fences
- v. Erect steelwork and mount the HV equipment

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- vi. Jumper conductors between equipment in the bays
- vii. Install control panels and JBs
- viii. Install cabling
- ix. Commission of primary plant and control plant.

3.16 RISK ASSESSMENT

A risk register has to be compiled for the project and to be managed by project manager during construction. The possible risk identified is:

- i. Working in vicinity of a live equipment
- ii. Working in a live yard
- iii. Working close to live apparatus
- iv. Network risks and loss of loads
- v. Undocumented underground facilities, including pipes and live cables
- vi. Equipment ordered, versus equipment on designs. If there are changes to equipment, after designs are completed, this will lead to re-design.

3.17 ENGINEERING COST ESTIMATION

Costing will be carried out by the Eskom project management team.

3.18 LESSONS LEARNED

Constant stakeholder engagement and communication is essential. This will ensure that stakeholders are afforded an opportunity to raise concerns in relation to designs and that the concerns are mutually discussed with a view of finding a common agreement and buy-in of the design solution.

4. AUTHORISATION

This document has been seen and accepted by:

Name	Designation
S Maharaj	Substation Engineering Senior Manager
Nkuli Pompi	Substation Engineering: Middle Manager: Electrical
Benny Tladi	Substation Engineering: Middle Manager: Electrical
Andile Maneli	Substation Engineering: Middle Manager: Civil
Sashan Marion	Transmission PDD
Carel Van Copenhagen	Northern Grid Chief Engineer
Caroleen Naidoo	Grid Planner
Rukesh Ramnarain	Transmission Substation Engineering (Chief)
Amanda Hadebe	Tx Integration Engineering
Stanley Beukes	Transmission Substation Engineering (Electrical)
Ayanda Mbense	Transmission Substation Engineering (Electrical)
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Name	Designation
Gift Matsabatsa	Environmental

5. REVISIONS

Date	Rev.	Compiler	Remarks
March 2025	1	Ayanda Mbense	First Issue

6. DEVELOPMENT TEAM

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

Ayanda Mbense

Stanley Beukes

Shivern Singh

Senzo Duma

7. ACKNOWLEDGEMENTS

All stakeholders involved.

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APPENDIX A: DETAIL DESIGN OUTPUT DOCUMENTS

Document Number	Rev.	Document Title	Remarks
Les23P04-SE-D3	1	Major Proformas: Equipment	First Issue: QS
Les23P04-SE-D6	0	Leseding Station Electric Diagram	Not For Construction
Les23P04-SE-D7	0	Leseding Key Plan	Not For Construction
Les23P04-SE-D9	0	Leseding Foundation & Trench Layout	Not For Construction
Les23P04-SE-D10	0	Leseding Earthmat Layout	Not For Construction
Les23P04-SE-D11	0	Leseding Overhead Earth Wire	Not For Construction
Les23P04-SE-D12	0	Leseding Tubular Busbar Layout	Not For Construction
Les23P04-SE-D13	0	Leseding Steelwork Marking Plan	Not For Construction
Les23P04-SE-D16 SHT 1	0	400/132kV Bay layout & Equipment Schedule Cover Sheet	Not For Construction
Les23P04-SE-D16 SHT 9	0	400kV Transformer 3 Bay	Not For Construction
Les23P04-SE-D16 SHT 9A	0	400kV Transformer 3 Earthing Sheet	Not For Construction
Les23P04-SE-D16 SHT 33	0	132kV Transformer 3 Bay	Not For Construction
Les23P04-SE-D16 SHT 33A	0	132kV Transformer 3 Earthing Sheet	Not For Construction
Les23P04-SE-D16 SHT 35	0	132kV Busbar 1 Bus Section 1	Not For Construction
Les23P04-SE-D16 SHT 35A	0	132kV Busbar 1 Bus Section 1 Earthing	Not For Construction
Les23P04-SE-D41	0	Terrace Layout	Not For Construction
Les23P04-SE-D43	0	Drainage Layout	Not For Construction
Les23P04-SE-D44	0	Transformer Plinth	Not For Construction
Les23P04-SE-D45	0	Barrier Fence Layout	Not For Construction
Les23P04-SE-D46	0	Security Fence Lighting Layout	Not For Construction
Les23P04-SE-D47	0	Operational Floodlight Drawing	Not For Construction
Les23P04-SE-D50	0	Buildings(Control/Access Control/Storage Yard/Consumable Store/Workshop)	Not For Construction
Les23P04-SE-D51	0	Buildings: Electrical Reticulation and Air Conditioning	Not For Construction
Les23P04-SE-D75; D76; D77;D78;D79;D80;D81;D85	0	Minor Proformas: Tubular Clamps; Conventional Clamps; Conductors; Earthing; Hardware; Labels; Steelwork; Tubular Busbar	First Issue: QS
Les23P04-SE-D87	1	Leseding Detail Design Report	First Issue

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APPENDIX B: EARTHMAT DESIGN

1. EARTHING DESIGN PARAMETERS

Description	Detail
Design Standard	IEEE STD - 80
Design Parameters	
Fault Current (Maximum Single Phase)	31.5 kA
Grid Current	23 kA
Depth of earth mat	1 meter
Earthing material	Copper
X/R ratio	20
No. of 400 kV lines	3
No. of Shielding Wires per 400 kV structure	2
No. of 132 kV lines	N/A
No. of S/W per 132 kV structure	N/A
Safety Parameters	
Body Weight	50 kg
Max. fault clear time	0.5 sec
Surface layer resistance	3000 Ω /m
Surface layer thickness	100 mm
Safety resistivity Shoe (Wet used elastomer)	0 M Ω

Table 11: Earthing Design Parameters

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2. SITE CONDITIONS

The substation is built under active clay material. The objective of the third transformer is to investigate the repair off the control room which guards to the sustained damage due to be geotechnical action. Ground/Soil conditions are not favourable in the area. Geotech Studies will determine the extent of ground works required.

3. SOIL RESISTIVITY TESTING

Soil resistivity was measured on the 2nd of July 2024 outside the substation yard see traverses (P1→P2, P3→P4) on figure below. There tests were done without any obstructions. The weather condition was sunny and hot. The Megger DET 2/2 tester with a fixed test frequency of 128 Hz was used to conduct the tests.

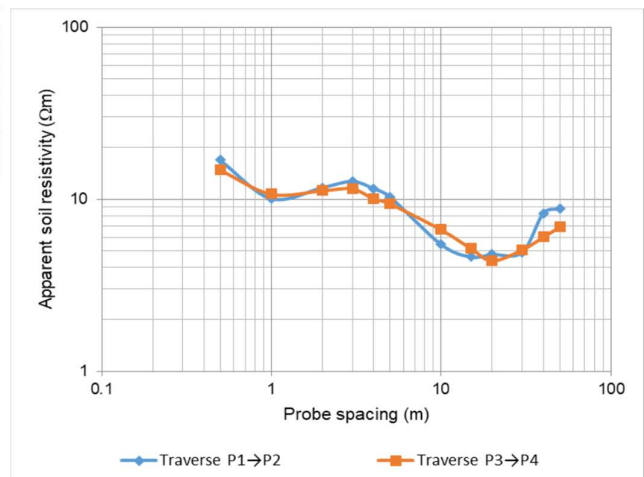
In addition to the measurement results, Table 12 also provides the traverse coordinates, as well as site and soil conditions. The measured results are graphically shown.



Soil Resistivity traverses and position in relation to Substation

Soil Resistivity measurement results and related information

		Traverse P1→P2		Traverse P3→P4	
Start Time		11:24		11:24	
Weather conditions		Sunny, hot		Sunny, hot	
Site conditions		Flat, Thick Thorn Bush		Flat, Thick Thorn Bush	
Soil conditions		Dry pickable Terff soil		Dry pickable Terff soil	
Traverse start coordinate		24°26'18.34"S	30° 1'9.78"E	24°26'18.60"S	30° 1'6.68"E
Traverse mid-point coordinate		24°26'20.45"S	30° 1'8.41"E	24°26'20.45"S	30° 1'8.41"E
Traverse end coordinate		24°26'22.54"S	30° 1'7.06"E	24°26'22.04"S	30° 1'10.45"E
Probe spacing	Geometric Factor	Tester Reading	Resistivity	Tester Reading	Resistivity
(a)	(K = 2πa)	(R)	(RK)	(R)	(RK)
m		Ω	Ωm	Ω	Ωm
0.5	3.14	5.37	16.870	4.71	14.797
1	6.28	1.605	10.085	1.706	10.719
2	12.57	0.93	11.687	0.894	11.234
3	18.85	0.674	12.705	0.611	11.517
4	25.13	0.459	11.536	0.401	10.078
5	31.42	0.329	10.336	0.3	9.425
10	62.83	0.087	5.466	0.106	6.660
15	94.25	0.049	4.618	0.055	5.184
20	125.66	0.038	4.775	0.035	4.398
30	188.50	0.026	4.901	0.027	5.089
40	251.33	0.033	8.294	0.024	6.032
50	314.16	0.028	8.796	0.022	6.912



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4. MODELLING AND SIMULATION RESULTS

The modelling and simulation of the earthmat was carried out in AutoGrid Pro which is a package in the CDEGS software.

4.1 SOIL MODELLING

The soil is modelled as a uniform layer instead of the multilayer soil model due to the two-layer or multilayer computation tool not being available. Thus, an average soil resistivity value will be used as a first approximation. The approximate uniform soil resistivity may be obtained by taking an arithmetic average of the measured apparent resistivity data as shown in Equation below:

$$\rho_{a(av1)} = \frac{\rho_{a(1)} + \rho_{a(2)} + \rho_{a(3)} + K + \rho_{a(n)}}{n} \cong 9\Omega m$$

Where

$\rho_{a(1)}, \rho_{a(2)}, \rho_{a(3)} \dots \rho_{a(n)}$ Are the measured apparent resistivity data obtained at different spacing in the four-pin method.

n Is total number of measurements.

$$\rho_{a(2)} / \rho_{a(1)} = 1.8$$

For the above approach the soil data does not meet the criteria for the uniform soil " $\rho_{a(2)} / \rho_{a(1)} = 1.8$ "

since the variation in apparent soil resistivity with respect to depth is too great i.e: far from unity ($\rho_{a(2)} / \rho_{a(1)} \cong 1$) therefore such a soil cannot be represented as a uniform soil with a single soil resistivity value as per equation ...(1)

To approximate a non-uniform soil with a uniform soil model. One of the method is using the average of upper layer apparent resistivity for the touch and step voltage calculations and the average of lower layer apparent resistivity for the grounding system resistance calculation.

Upper layer apparent resistivity average:

$$\rho_{a(av_upper)} = \frac{\rho_{a(1_upper)} + \rho_{a(2_upper)} + \rho_{a(3_upper)} + K + \rho_{a(n_upper)}}{14} \cong 11\Omega m$$

Lower layer apparent resistivity average:

$$\rho_{a(av_lower)} = \frac{\rho_{a(7_lower)} + \rho_{a(8_lower)} + \rho_{a(9_lower)} + K + \rho_{a(n_lower)}}{14} \cong 6\Omega m$$

It must be recognized that the soil model is only an approximation of the actual soil conditions and that a perfect match is unlikely. However, it has been recognized that the two-layer representation of a soil is closer to the actual soil conditions compared to its uniform equivalent.

Without the modelling tool (CDEGS) the IEEE80-2013 hand calculation gives good proximity to assess the earthing design.

The resistance depends primarily on the area to be occupied by the grounding system, and from

$$R_g = \rho_{a(av_upper)} \left[\frac{1}{L_T} + \frac{1}{\sqrt{20}} \left(1 + \frac{1}{1+h\sqrt{20/A}} \right) \right] \cong 0.095\Omega$$

Where:

R_g is the substation ground resistance in Ω

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ρ_a is the soil resistivity in $\Omega m = 45 \Omega m$

A is the area occupied by the ground grid in m^2

H is the depth of the grid in m

L_T is the total length of buried conductor in m

Measured Grid resistance indicate $R_g = 0.063 \Omega$ thus utilising a factor of 1.5 the design will consider the new $R_g = 0.095 \Omega$

Next is to determine the fault current division factor S_f for the fault of 31.5kA selected a higher value from the stipulated URS value of 18.8kA. The substation earthmat is connected via shielding on the line towers to assist with the portion of the ground fault current to have an easy path back to the source. Therefore, it is established the corresponding values of symmetrical grid current I_g . The Grid current is given by:

$$I_G = D_f S_f I_g \cong 31 kA$$

Where

I_G is the maximum grid current in A

D_f is the decrement factor for the entire duration of fault t_f given in s

S_f current division factor

I_g is the rms symmetrical grid current in A

The soil results indicate a two-layer profile of which the top layer has higher resistivity with a thickness of 4m and the 2nd layer has lower resistivity with infinity depth assumed.

Design model

4.2 EARTHMAT MODELLING

It is to be noted that while voltage gradients are theoretically hazardous, and while it is impossible to ensure complete safety at all times and at all places, the low probability of all adverse factors occurring simultaneously makes it possible to design an earthing system of reasonable considerations.

4.3 MODELLING RESULTS

Scenario: 3k Ω yard Stone, No Safety Shoes, 30kA all structures to be earthed

4.3.1 First design

The design from the below table indicates the safety analysis where the test is for the spacing between parallel conductors to be 24m which is in line with the bay width of 24m at 400kV. Therefore, this analysis assesses the 400kV yard not considering equipment earth-tails. Safety analysis with this initial consideration shows that the touch & step voltage criteria is met to be safe with the GPR within limits.

4.3.2 Second design

The design from the below table indicates the safety analysis where the test is for the spacing between parallel conductors to be 13.2m which is in line with the bay width of 13.2m. therefore this analysis assesses the 132kV yard not considering equipment earth-tails. Safety analysis with this initial consideration shows that the touch & step voltage criteria is met to be safe with the GPR within limits.

Optimum design

The design indicates the safety analysis where all the test criteria are met and considered to be safe.

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To ensure safe step and touch voltages are adhered to within the substation the following shall be done:

- i. Initial yard stone rated $3k\Omega$ to be maintained.
- ii. All the structures shall be bonded to the earthmat,
- iii. Yard conductor spacing to be at most 8m apart and this can be achieved by earthtails for each equipment.
- iv. Strict control access to ensure anyone entering the substation must wear their safety gear (PPE) and the safety shoes must comply with Eskom specified safety boots.

4.4 GROUND POTENTIAL RISE (GPR) SIMULATION RESULTS

The safety of a person depends on preventing the critical amount of shock energy from being absorbed before the fault is cleared and the system de-energized. The maximum driving voltage of any accidental circuit should not exceed the limits defined below on the table:

	400kV yard bay width	132kV yard bay width	Optimum design
Design value	Qty = 10	Qty = 17	Qty = 3
Safe touch potential limit Etouch = 673	Mesh potential Em= 235	Mesh potential Em= 161	Mesh potential Em= 658
Safe step potential limit Estep = 2203	Step potential Es= 47	Step potential Es= 44	Step potential Es= 80
GPR limit 5000	GPR = 3100.895	GPR = 2905.049	GPR = 4250.033
Spacing between parallel cond (Cu)	24.356	13.7	109.6
Grid resistance	0.095	0.089	0.131

Where:

Ground potential rise (GPR): The maximum electrical potential that a substation ground grid may attain relative to a distant grounding point assumed to be at the potential of remote earth.

Etouch: The maximum touch voltage within a mesh of a ground grid

Estep: The difference in surface potential experienced by a person bridging a distance of 1 m with the feet without contacting any other grounded object.

5. CONCLUSION AND RECOMMENDATIONS

The safety of the grid at Leseding MTS for step and touch voltages is within safe limits within the HV yard with yard stone and for conductor spacing of the grid no more than 100m apart. Installed yard stones should be maintained to initial design of $3k\Omega$ wet resistance and 100mm surface layer thickness and grain size according to the specification "STANDARD FOR HV YARD STONES IN ESKOM SUBSTATIONS - 240-108982466" is key.

Safety boots signs and fault level must be clearly posted in the substation entrances / gates / fences etc. On the fences of the substation, it is recommended that the yard stones protrude 1m outer of the fences.

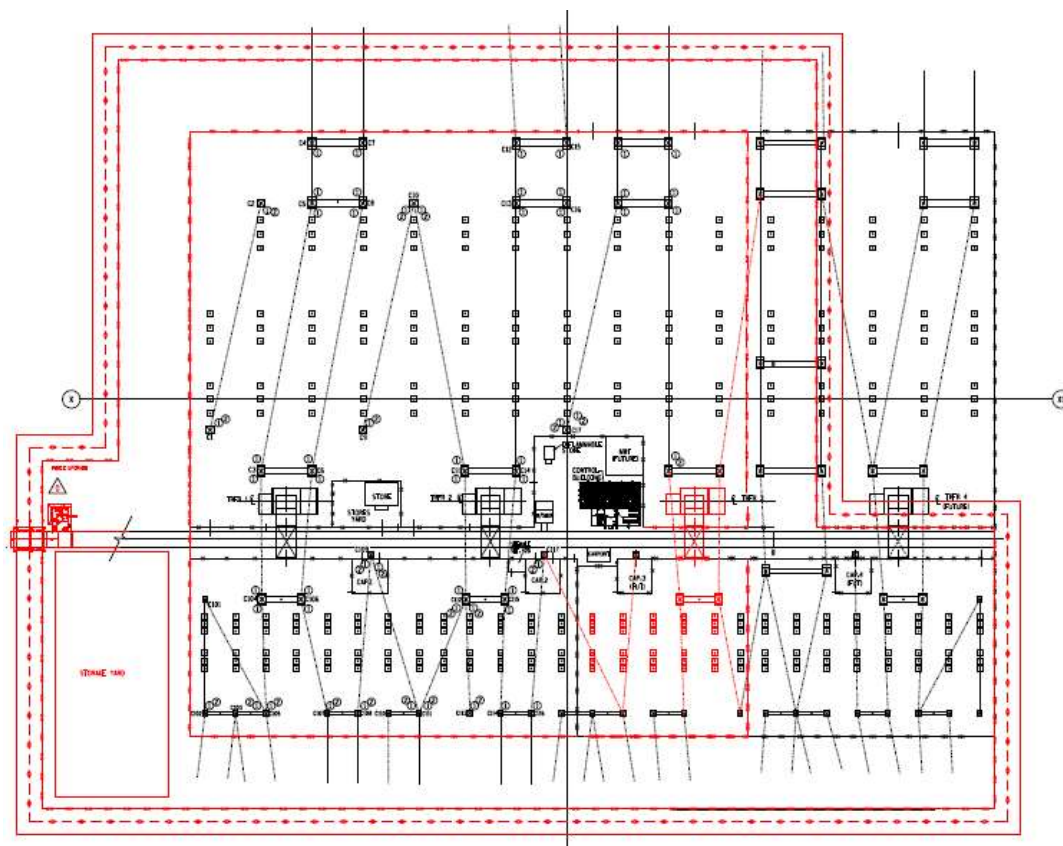
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APPENDIX C: DIRECT LIGHTNING STROKE PROTECTION CALCULATION

The direct lightning stroke protection have been completed in accordance with 240-109589380 "Direct Lightning Stroke Protection for Substations".

The substation makes provision for lightning coverage by installing earth wire peaks on the column structures where shield wires will be connected to provide additional coverage over the substations. The current and future shield wire routes are shown in the figure below.



Overhead shield wire arrangement (Les23P04-SE-D11)

Protection of the substation and equipment against direct lightning strikes will be achieved by using a rolling sphere method as prescribed in the Direct Lightning Stroke Protection of Substations [26].

The technique involves rolling an imaginary sphere radius at busbar level over the surface of the substation as shown in Figure 8. The sphere rolls up and over (and is supported by) the lightning masts, shield wires and other grounded metal objects intended for lightning shielding. A piece of equipment is protected from a direct stroke of lightning if it remains below the curved surface of the sphere by virtue of the sphere being elevated by shield wires or other devices. Equipment that touches the sphere or penetrates its surface is not protected from direct stroke of lightning.

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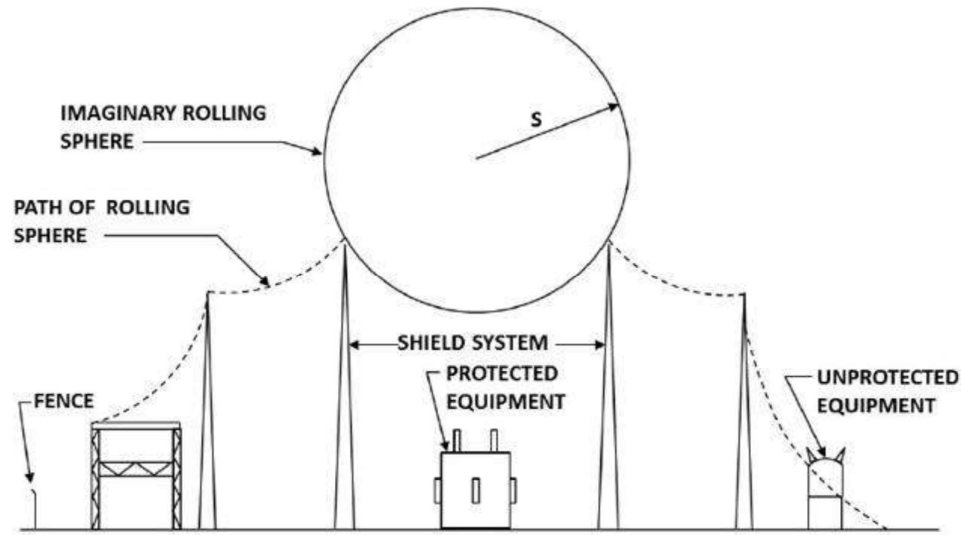


Figure 2: Illustration of rolling ball sphere protection

The size of the rolling sphere is influenced by the following parameters:

- R_C = Corona radius (m)
- R_e = Metallic radius of conductor
- V_C = BIL (Basic Insulation Level)
- E_0 = Limiting corona gradient (1500 kV/m)
- A = Bus Height
- S = Sphere Radius
- Z_s = Effective Surge Impedance
- d = Metallic Diameter of Conductor
- h = Average Conductor Height
- $k = 1$ for strokes to shield wire
- I_s = Return Current
- BIL = Basic Insulation Level

The following steps in accordance with the 240-109589380 standard was used for the calculation of the radius of the sphere (the equation numbers below refer to the 240-109589380 standard).

Step 1: Equation 9 for the calculation of the corona radius.

$$R_C \ln \left(\frac{2A}{R_C} \right) - \frac{V_C}{R_C} = 0$$

Where:

$V_C = 550\text{kV}$ (at 132kV and 1425 kV at 400kV)

$A = 'A'$ was assumed to be the busbar conductor heights (12.7m at 400 kV and 7.2 m at 132 kV)

$E_0 = 1500 \text{ kV/m}$

Step 2: Equation 11 for the metallic radius of the conductor (bull conductor was used)

$$r_e = \frac{1}{2} d$$

where:

d = Metallic Diameter of Conductor (considered as the diameter of the aluminium)

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tubes used for busbars 250 mm at 400 kV and 200mm at 132 kV)

Step 3: Equation 10 to calculate the Effective Surge Protection:

$$Z_S = Z_s = 60 \sqrt{\ln\left(\frac{2A}{R_C}\right) \ln\left(\frac{2A}{r_e}\right)}$$

Step 4: Equation 8 to calculate the Return Current:

$$I_S = \frac{2,2BIL_C}{Z_S}$$

Step 5: Equation 1 to calculate the Sphere Radius:

$$S = 2kI_S^{0.65}$$

The resultant radii of the rolling spheres for each of the 400 and 132 kV yards were to be:

- 400 kV yard: 51 m
- 132 kV yard: 20 m

These radii were drawn over the Korana substation and the resultant shielding achieved is shown in an extract from drawing Les23P04-SE-D11.

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APPENDIX D: BUSBAR DESIGN

The following standards were followed for Busbar Design:

- The Design Philosophy for 400kV Tubular Conductor Busbar Yards (240-95242252) [27]
- The Design Philosophy for 132kV Tubular Conductor Busbar Yards (240-97364660) [29]

	400kV	132kV
Busbar Configuration	Double BB with Bypass	Double BB
Busbar Type	AL. Tube (250x6mm)	AL. Tube (200x6mm)
Busbar Phase Spacing	7010 mm	3000 mm
Busbar rated Current	5780A (@ 85°C)	4750A (@ 85°C)

Table 12: Busbar design

1. BUSBAR DESIGN RESULTS

The post insulators for the busbars have also been selected in accordance with the Eskom Standard for Tubular Conductor Selection (240-68972068). The expected forces (F_{m3}) have been calculated based on the following formula from SANS 60865-1:2012:.

$$F_{m3} = \frac{\mu_0}{2\pi} \times \sqrt{\frac{3}{2}} (I_P)^2 \times \frac{l}{a}$$

Where:

I_P = Peak fault level (kA)

l = Conductor length between supports (m)

a = Phase spacing (m)

For the 400 kV tubular busbars, with phase spacing of 5,5 m, tubular support spacing of 20 m and fault level of 40 kA, the maximum force for a 3-phase bolted fault is calculated to be 6,8 kN and a 10 kN post insulators are selected accordingly.

For the 132 kV tubular busbars, with phase spacing of 3 m, tubular support spacing of 13,2 m and fault level of 40 kA, the maximum force for a 3-phase bolted fault is calculated to be 8,6 kN and a 10 kN post insulators are selected accordingly.

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6. CONCLUSION AND RECOMMENDATIONS

Busbar design parameters are guided various system inputs i.e; future expected nominal current, system fault currents per system voltage indicated from the grid planning report / URS. The parameters are then implemented to developed standard bays / busbar layout etc. to appropriately rate accordingly the busbar layout / design overall, including busbar bases, steel, post insulators and the sufficiently selecting the rigid busbar with appropriate dimensioning etc. as stated within this section and summarised in table 14.2

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