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OPTIMISATION OF RECLOSER PLACEMENT METHODS ON MEDIUM VOLTAGE DISTRIBUTION NETWORKS

RENALDO STRYDOM

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Supervisor: Prof. P.E. Hertzog

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Declaration

I, RENALDO STRYDOM, identity number _____________ and student number _________, do hereby declare that this research project submitted to the Central University of Technology, Free State for the Master of Engineering in Mechanical Engineering, is my own independent work; complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules, and regulations of the Central University of Technology, Free State; and has not been submitted before to any institution by myself or any other person in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification.

Renaldo Strydom
23-03-2022

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Central University of Technology, Free State

Dedication

I dedicate this dissertation to my parents who gave me what I needed to achieve success, and to my wife for her support and patience during this process.

Abstract

Re-evaluating methods in any business is essential, as it reinforces knowledge and improves methodologies. Improving the reliability of electrical distribution networks is key for a utility like Eskom. Having fewer customers without electricity during an outage and more income for the utility is the focus of this study. Eskom's standard for placing reclosers (automatic breakers) focuses on reaching their performance targets and not on the financial costs and benefits thereof.

The purpose of this study is to present a method to optimise the placement of reclosers on the distribution networks. Eskom could, by focusing on the financial benefits of recloser placement, improve their performance targets as well as save more money on fault conditions. A method using cost-benefit analysis (CBA) is used and explained to analyse the placement of reclosers on an electrical distribution network.

Mathematical calculations and a matrix table are used to determine the maximum number and sequence of placement of the reclosers to be installed on the networks. The findings of this study show that placing reclosers on the network using this method will pay for itself in a short period. The results show the financial benefits as well as performance improvements.

By using the proposed method, the exact placements for reclosers may be indicated and less guesswork will be required from the engineers. The study was done using data from actual distribution networks. Possible future studies can be done by combining recloser placements with other protection-sensing equipment such as Fault Path Indicators or Current Voltage Monitors.

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List of Abbreviations

CAPEX	-	Capital Expense
CBA	-	Cost Benefit Analysis
CENS	-	Cost of Energy Not Served
CIH	-	Customer Interruption Hours
DG	-	Distributed Generation
DSLI	-	Distribution Supply Loss Index
DTC	-	Design To Cost
DXNorm	-	Distribution Network Optimization Modelling Project
ENS	-	Energy Not Served
ESI	-	Electricity Supply Industries
FMS	-	Fault Management System
IPP	-	Independent Power Producer
KPI	-	Key Performance Indicator
LF	-	Load Factor
LPU	-	Large Power Users
MAIFI	-	Momentary Average Interruption Frequency Index
MYPD	-	Multi Year Price Determination
NEPS	-	Network and Equipment Performance System
NERSA	-	National Energy Regulator of South Africa
NMD	-	Notified Maximum Demand
OPEX	-	Operating Expense
POD	-	Point of Delivery
PPU	-	Pre-paid Users
Ps	-	Payback Period
ROI	-	Return On Investment
RoR	-	Rate of Return
RTU	-	Remote Terminal Unit
SAIDI	-	System Average Interruption Duration Index

SAIFI	-	System Average Interruption Frequency Index
SPU	-	Small Power Users
TS	-	Transmission System
W/O	-	Works Order

CHAPTER 1: BACKGROUND AND INTRODUCTION

1.1 Background

The Reliability program within the Distribution Business of Eskom focuses on providing acceptable performance levels for the network infrastructure of its customers and generators, taking the investment criteria as required from the Distribution Grid Code into account. Any underinvestment will have long-term implications and affect the following:

- The well-being of current customers.
- The performance of the networks.
- The aspirations of future customers and generators.

Economic growth, usual market conditions and the capacity of the asset base determine the need for capital investment in the Distribution section. It is essential that the networks perform effectively to ensure that the existing and potential customers and generators may reap the benefits of acceptable performance levels from the network grid.

South Africa's national electricity utility – Electricity Supply Commission (Eskom) aims to be one of the top five utilities in the world. Although a specific System Average Interruption Duration Index (SAIDI) goal has not been explicitly defined as part of the strategic intent, Eskom Distribution has placed a focus on improving SAIDI performance and has set a current long-term objective to reduce SAIDI. Currently reducing it from 45.8 hours to 38.8 (2012-2017). However, when comparing SAIDI to other utility companies (in both developed and developing nations), Eskom ranks last [1]. Currently the target is 38, which has been achieved in recent years.

Eskom has introduced several network performance improvement initiatives in the past to improve its reliability. These initiatives include the Eskom's security of supply (2008 – 2011) and Operational Excellence (2011 onwards). The most recent strategy and innovations to improve on the reliability of the Distribution networks that will be focused on are demonstrated in Table 1:

Table 1: Focus table for improving reliability [2]

Network reliability improvement strategy	**Interventions**
Limit the impact of outages	• Implement fuses at transformers • Add reclosers to isolate upstream networks from faults • Use back-feeding capability (where it exists) • Reduce the number of customers per feeder by adding more feeders or splitting existing feeders • Add additional lines and/or substations for redundancy

In the previous strategies mentioned and the current strategy to improve the reliability and performance of the networks, it is always mentioned that the installation and addition of reclosers on networks will improve these initiatives.

Eskom's current standard for recloser placements looks to improve the SAIDI as this is arguably the utility's most important key performance indicator (KPI). Eskom must reach these KPI targets to receive the necessary funding agreed on in the multi-year price determination (MYPD).

To improve the SAIDI figures, Eskom must isolate the faulty part of the network to ensure as many customers stay connected. They can do this by strategically placing reclosers on the network to do so. The standard looks at the number of customers as well as the length of the network (backbone and tee-offs) and determines how many reclosers will be installed/placed. It is up to the engineers to place these reclosers on the network and they will be placed on the network where most customers can be isolated [3]. An actual case study will be used where reclosers will be placed on networks using a cost-benefit-analysis and the significance of the financial aspect and benefits towards the utility will be shown. Recloser installations are an investment and will only be deemed viable if the benefits exceed the costs over a certain period. Higher paying customers affect the cost-benefit-analysis more severely than smaller customers (different tariffs) do. The strategy to drive down the technical performance KPIs such as SAIDI is not necessarily a good financial investment, thus an intervention of financial viability must be investigated.

1.2 Problem Statement

The problem is that Eskom's current standard for placing reclosers on the distribution networks mostly focuses on improving the SAIDI figures. Electric power utilities should also focus on return on investment (ROI) when considering placement of reclosers. The standard for recloser placement on medium voltage distribution networks only looks at two criteria's — the number of customers and the length of the line. Eskom should be looking at more criteria when placing of reclosers on the network, namely:

- Type of customers.
- Tariff of customers.
- Load of customers.

During the lifespan of a network, new sections of lines are built over time, and more customers could have been added or removed. When reclosers break, it is in most cases replaced at the same position, even though the placement of the recloser could have been improved. The review of recloser placements must be done timeously to keep the recloser placements on the network optimal. The placement of reclosers are also not regulated within Eskom as various employees can have a recloser installed without any studies having been done.

In this study, an alternative possible solution will be investigated and evaluated, namely the financial viability of recloser installations.

1.3 Research Questions

The following research questions were formulated for this study:

- What benefits will be achieved by using a cost-benefit analysis (CBA) methodology to place reclosers on distribution networks?
- Will placing reclosers using the CBA method improve the technical performance of the distribution network?
- In what order should reclosers be placed if not all can be placed at once, and which recloser will be the most crucial to install compared to others on the distribution network?
- What criteria should be used when placing reclosers on our distribution networks?
- Will the placing of reclosers for large power users have benefits?
- Is SAIDI the correct indicator when it comes to recloser placements?

1.4 Aim of the Study

This study aims to improve Eskom's current recloser placement standard/method on their medium voltage distribution networks. There are various factors that will play a role in the outcome of the research, leading to the following objectives:

- To use a CBA methodology to place reclosers.
- To do a payback period calculation.
- To assess the financial viability of recloser placements.
- To improve technical performance (SAIDI) figures.

The reason for using a CBA methodology in recloser placements on the network is specifically because Eskom must start focusing on financial viability as well as their KPI figures when installing reclosers onto the networks. The payback period will be a motivational factor for installing reclosers. The mathematical calculations will show the benefits achieved by using a CBA methodology to place reclosers. SAIDI is the main focus of the business KPI's when it comes to the performance of the networks. If the SAIDI figures can be improved by using CBA methodology and if it can be justified with a payback period, it can possibly become part of Eskom's current recloser placement methodology.

1.5 Methodology

The research in this dissertation will be based on the Free State networks using the Eskom's technical network performance database. Choosing a long network with plenty of customers has the best chance of improving and optimising the recloser placements, but to show and test for a new or improved method of recloser placement, other networks will have to be tested as well.

The network must have a number of all three different types of customers namely Large Power User (LPU), Small Power User (SPU) and Prepaid User (PPU) for optimum tests to be done. The three different customer types and reclosers will have to be identified on the network. The three different customer categories will thus be analysed, and the tariff associated with them will be determined to establish the income received from them.

The following criteria on networks will be considered:

- Lengths (some networks are over 500 km long whereas some networks currently do not have any reclosers).
- Number of customers on networks below 5000.
- Type of customer/Eskom customer load database (prepaid users, small power users, and large power users).
- Tariff of customers (different tariffs are used on different customers and influences the billing and income).
- Numbers of faults (more than average faults in the Free State area for the last three years).
- Types of faults (environmental, equipment failure, etc.).

Eskom's fault database will be used to analyse the faults for the last three years in the Free State area. The Eskom fault database can be used to determine the money lost by Eskom during a power interruption by using the tariffs issued to the customers. Using the CBA methodology and the relevant equations, it can be determined how soon Eskom will receive their ROI. Once the number of reclosers are determined, their placement and sequence on the distribution network will be determined using a matrix table.

1.6 Benefits of the Research

The research may have a positive impact on the reliability of the utilities distribution networks. All Eskom distribution reliability improvement methods are based on the targets set out by National Energy Regulator of South Africa (NERSA); this includes recloser placement. The problem with this is that NERSA does not focus on how the SAIDI target is reached as long as the reliability is within target and thus creates a problem for certain customers of Eskom.

The LPU and SPU customers are going to suffer the most under these types of conditions that are set out by NERSA, as the bulk of customers affecting SAIDI is the PPU customers. Thus, the value of this research will indicate that placing reclosers to cater for larger power users should have financial benefits. The research should show that the performance of the distribution networks will improve by using the CBA methodology.

1.7 Delimitations of the Study

The research will only focus on the financial aspect of improving the reliability of the distribution networks by optimally placing reclosers. The financial aspects are namely:

- Cost of Energy Not Served (CENS).
- Cost-benefit Analysis (CBA).
- Payback period (Ps).

Furthermore, the performance figures should automatically also improve. Actual distribution networks in the Free State will be used in the research, with customers and protection devices.

1.8 Outline of the Study

The dissertation is categorized into five chapters as follows:

Chapter 1: This chapter covers the background and introduction to this current study. Firstly, this chapter highlights the problem statement, followed by the research questions, and aim of the study. Lastly, the methodology, benefits of the research, and delimitations of the study are also elaborated on.

Chapter 2: This chapter covers some of the available literature that was reviewed for the relevant field of study, the main focus being history of recloser placements, recloser placement methods, measurement indicators, NERSA, and the Grid Code. The section on recloser placement methods includes previous studies on recloser placement adoptions as well as common theories and technology adoptions and were used as guidelines. The sections on the measurement indicators are determined by the NERSA and Grid Code parameters, which must be taken into consideration for the study.

Chapter 3: This chapter emphasises the methodology of the research. It discusses the research methodology, research design, research approach, placing of reclosers, sequence of recloser installations and the delimitation of the study. The research approach also includes the CBA methodology.

Chapter 4: This chapter focuses on the data analysis and results obtained in the study and has four main sections of results (tariff comparisons, FSOU customer demographics, case study and general results, and recloser placement rankings). Each section is discussed and described on its own and results are visually presented in the form of graphs, tables, and figures.

Chapter 5: The final chapter focuses on the conclusion regarding the results obtained in the study. The discussion section debates the results obtained where the implications section deliberates on the various findings of the research. The conclusion looks at the combined outcome of both the discussion and implications of the chapter.

1.9 Summary

In this chapter, the background and introduction to the study were discussed. Firstly, the problem statement was described, followed by the research questions to be answered by the study. Additionally, the research objectives were described. Furthermore, the value of the research, which includes the reliability, performance, and financial benefits of a CBA recloser placement method, was explained. This was followed by the research design. Lastly, the delimitations of the study were presented.

The next chapter discusses the literature reviewed for the various components and technologies used in this research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The previous chapter was an introduction to the study and covered the background and problem statement of the study was discussed, which focussed on Eskom standards of placing reclosers as it mostly focuses on improving their SAIDI figures. Placement and installation of all reclosers are not regulated and the financial viability of reclosers placements are not considered. The research questions and aim of the study were also discussed. Furthermore, the methodology of the study was briefly discussed, as well as the benefits of the research, delimitations of the study and outline of the study.

This chapter presents the literature review, which covers the reliability of distribution networks, recloser placement methods, and measurement indicators. This chapter will further outline the challenges and benefits of improving recloser placements of medium voltage (11 or 22 kV) distribution networks.

2.2 History of recloser placements

Improving reliability of distribution networks has remained the object of numerous exploration studies for years. Studies have emphasised an excessive diversity of perspectives from various fields, including Design to Cost (DTC), fuse placement, recloser placement, link placement, normally open points, back feeding/ring feeding, etc. The first reclosers were created in the 1940s for isolating fewer customers during fault conditions (Transient faults) on the distribution networks [4].

In an attempt to define the importance of recloser placements on the distribution networks, a performance target model is created. This technique is measured by their relevant KPIs [5]. These KPIs are usually measured by the SAIDI and System Average Interruption Frequency Index (SAIFI) targets, which in turn are set by analysing the data over a certain period and looking at the network trends.

An alternative method for the importance and placing of reclosers on distribution networks is by using a CBA. The early development of CBA in France and the US is independent from the aspects of historical background, personnel, approaches and standardization [6]. The CBA is used to determine if the benefits of a project exceed the costs [7]. The CBA methodology can be used in many applications and was thus later used for electrical networks [8]. Various methods (ant topology, loads, failure rates, and repair rates, pareto optimality multi-objective function) are used today to place reclosers on electrical networks, including the CBA methodology that will be explained in more detail later.

2.3 Recloser placement methods

Constant improvements are required by utilities for performance enhancement as well as cost savings. The targets are more difficult to reach with each passing year and new and innovative methods are required to reach them [9]. Methods used to improve the reliability on distribution networks are vast; within this dissertation the focus will be on the recloser placements on medium voltage (11 or 22 kV) distribution networks [10]. The recloser placement methodologies will be explained below.

2.3.1 Globally

Many studies have been done by industries and academics to find the best possible method to place reclosers. This document will not show the detailed mathematics etc. of these methods but was assessed and will give an indication of the purposes of each and how they are measured (performance and financially). Each utility will have their own target or focus point as to recloser placement — some focus on improving performance and others focus on saving costs. Some methods in placing reclosers on distribution networks are mentioned below and in Table 2.

- Ant colony algorithms [11].
- Loads, failure rates, and repair rates [12].
- Pareto Optimality Multi-objective Function [13].

Table 2: Summary of recloser placement methods

Recloser placement method	Focus area	Benefits	Disadvantage
Ant topology	• Improve the distribution system reliability • SAIDI • SAIFI	Improved reliability	Financial benefits are unknown.
Loads, failure rates and repair rates in distribution systems	• Improve the distribution system reliability. • Maximize utility's profits	Improved reliability	Data used might have errors. Data uncertainty in failure rates and repair times. Connected loads, failure rates, and outage durations are estimated.
Pareto Optimality Multi-Objective Function	• Improve the distribution system reliability. • SAIDI • SAIFI	Improved reliability	Formulation used can only be used on switches in distribution networks. The formulation will be more complex if other protective equipment were to be added to it.

It is important to note that these methods are also used in Distributed Generation (DG), which are smaller scale power producers that connects to Eskom's electricity networks. They are also known as independent power producers (IPPs) and are private power producers that connects to Eskom's network [14]. They are assisting electricity utilities with their electricity generation constraints. Examples of these DG's are solar power (photovoltaic) and wind power.

These different methods and algorithms were created for the same reason and that is to either improve reliability of the network and/or minimize/reduce costs. These methods and algorithms will look at reducing the number of customers affected, improve the performance figures (reduce outages to customers) and possibly reduce the costs of energy not served.

2.3.2 Eskom utility

Traditional placement methods of reclosers used by Eskom in a MV distribution network include:

- Pareto/Top300 network model.
- Manual placement of reclosers.
- Network per zone analysis.
- Eskom's planning standard.
- Customer segmentation analysis.

In all five methods used by Eskom, networks are selected by giving priority to larger numbers of customers and not larger customers.

The focus points mentioned in the above methods are driven by reducing the number of affected customers during fault conditions to improve network reliability and performance targets. Financial savings are not the main consideration.

It is important to note that the Eskom methodologies used to place reclosers are based on improving the performance KPI figures and these KPIs are important, because NERSA dictates it to be so. There are working and care groups within Eskom that determine the methods of the placement of reclosers.

The purpose of the Pareto/Top300 network model, manual placement of reclosers, and network-per-zone analysis is to reduce the number customers per network. Smaller networks in turn means fewer customers affected during fault conditions. Eskom's planning standard is used to determine the maximum number of reclosers to be placed in new networks. The customer segmentation analysis include CENS to customers in certain categories.

Adding reclosers will always improve the network's KPIs (SAID, SAIFI), but it must be taken into consideration that spending too much money to isolate more customers will cause the utility to not regain the money spent in an acceptable time. The longer the network and the more customers there are, the more difficult it becomes to isolate more customers as the costs will increase towards the utility.

2.3.2.1 Pareto/Top 300 network model

Every year, Eskom provides a list of networks that is compiled as the biggest/highest contributors in terms of unplanned customer interruption hours (CIH). These are called the Pareto networks, as the belief is that 80% of the effects come from 20% of the causes and by fixing the causes, they will have a knock-on effect of clearing the other 80%. Thus, focusing on repairing the worst networks (20%) will have a far greater effect than focusing on the better performing networks (80%) [15]. These networks will usually contain many customers and to improve the KPI performance figures, namely SAIDI and SAIFI, more recloser installations are required. By installing reclosers, fewer customers will be isolated during fault conditions. Eskom has a 'thumb suck' rule that suggests that with every 1000 customers, or at every 40 km, a recloser should be placed on the network.

By focussing on the biggest contributor of CIH, the SAIDI and SAIFI figure will automatically come down and improve the technical performance figures.

2.3.2.2 Manual placement

One can clearly identify an optimal location for recloser placements by using human logic compared to complicated logic i.e., algorithms etc. A disadvantage of this method is that it is dependent on the person analysing the network on where the recloser will be placed and it might be different depending on who analysis the network.

One can use the fault events of a network to place reclosers. This will isolate the customers during fault conditions. The number of customers can also be taken into consideration, as isolating only the faulty part of the network ensures more customers stay connected during fault conditions. This will improve performance KPIs during fault conditions. Site visits will have to be done, because in some cases, the locations are not easily accessible. This can cause problems when trying to open or close reclosers in cases of them locking out, etc. Another factor that must be taken into consideration is the communication in the area as not all locations have communication for radio or modem devices. This is crucial as communication is required when opening and closing reclosers/breakers remotely as well as receiving alarms from the Remote Terminal Unit (RTU) device.

The geographical area might also be prone to lightning strikes and this should be taken into consideration when placing a recloser. Environmental issues with animals such as birds must also be taken into consideration as bird flappers, etc. might be used to lessen the faults on the network, thus installing a recloser might not be beneficial.

Installing a recloser will lessen the number and duration of faults but it cannot stop faults from occurring. Another disadvantage of this method is that incorrect fault events/wrongly recorded event data can obscure the placement of reclosers. These recloser placements can have less impact and be less effective.

2.3.2.3 Eskom's planning standard

Eskom's planning methodology uses tables to determine the optimal number of reclosers required per MV network for reliability purposes. To determine the maximum number of reclosers, three tables are used. Table 3 indicates the maximum number of reclosers based on the number of customers per network length.

Table 3: Number of reclosers determined by the customer rule [3]

Network length min (km)	Network length max (km)	Maximum no of customers per recloser
0	20	200
20	40	300
40	80	300
80	135	300
135	Unlimited	450

Table 4 indicates the number of reclosers that are determined by the length of the network. i.e. if the network length is 12 km the maximum number of reclosers to be installed will be 12 / 3 = 4.

Table 4: Number of reclosers determined by the network length rule [3]

Network length min (km)	Network length max (km)	Maximum number of reclosers per km of network
0	20	1/3
20	40	1/5
40	80	1/8
80	135	1/12
135	Unlimited	1/30

Table 5 indicates the maximum number of recommended reclosers per network for reliability purposes and shall be used as a cap for the number of reclosers derived from Table 3 and Table 4.

Table 5: Capped number of reclosers per network [3]

Network length min (km)	Network length max (km)	Capped number of reclosers
0	20	0
20	40	1
40	80	3
80	135	5
135	Unlimited	Network length divided by 26

Eskom's traditional method focuses on the number of customers that can be isolated during fault conditions. By adding relcosers more customers are removed from the faulty part of the network. This will improve the KPIs. With this methodology, the engineer will still have to decide where on the network the reclosers must be placed. Mistakes can be made, as not all engineers will decide on the same locations, especially inexperienced engineers.

2.3.2.4 Customer segmentation analysis

In Eskom's attempt to improve reliability on their distribution networks, they appointed a consulting company (EON) to oversee their processes and come up with a suggestion for improvements. This task created the "Distribution Network optimization modelling project" (DXNorm) as the utility knows it today.

The objectives set out by the DXNorm was as follows:

- Analyse the operating expense (OPEX) interventions on MV networks.
- Analyse HV substations (contribution to MV network).
- Develop a high-level approach for strategic decision making, to analyse the implications of capital expense (CAPEX) and OPEX projects on the MV network performance figures and aspects of revenue implications or CENS (cost of energy not served).

Benchmarks and target levels had to be found for comparison. For the target levels, the KPI for SAIDI was chosen as to what they should base their model on. The equipment failure rates were combined with the segmenting of customers on the network in different classes (types of customers), environment, pollution, and lightning in area. This revealed a telling SAIDI level. Comparisons were used that assigned the failure rates with the equipment used in each segment of the network. Historical data was used to analyse the time it usually takes to correct a certain fault on a network, and this is then used to determine what the total outage duration (SAIDI) will be over a one-year period.

The model/tool that was created made provision to add a recloser to the network and allows the user to recalculate the SAIDI. This should show an improvement on the SAIDI figure as the restoration time and number of affected customers should be lessened. The approximate cost of additional reclosers vs the benefit of the SAIDI improvement is then given as an output.

Note: in all the above-mentioned algorithms etc., it is important that the data provided — type and number of customers, failure rate, network lengths, settings, and equipment installed etc. — is correct. If the data is incorrect, it can obscure the results.

2.3.2.5 Network per zone analysis

In the per-zone analysis, customers are segmented into groups. Once grouped assessments can be made, history and data can be measured and decisions on how to improve zone performance can be made. The data that will be analysed will include historic faults, failure rates, network lengths, and connected load information. Installing a recloser before the zone prone to the most failures will improve the performance and have the best effect on the distribution network.

Using the historic failure rates of distribution networks will give an indication of the typical performance to be achieved by the specific network and its zone. If the equipment stays the same, a simulated SAIDI figure can be calculated. These two results can be weighed up against each other. If the actual performance is worse than the simulated performance, the cause must be investigated. Possible reasons could be:

- The environment has possibly worsened or changed (animals, weather or geographical).
- Poor maintenance or no maintenance.
- Equipment installation practises were substandard.
- Equipment used was substandard (incorrect equipment).

A geographical layout of an electrical network can be seen in Figure 1, showing the typical zone analysis.

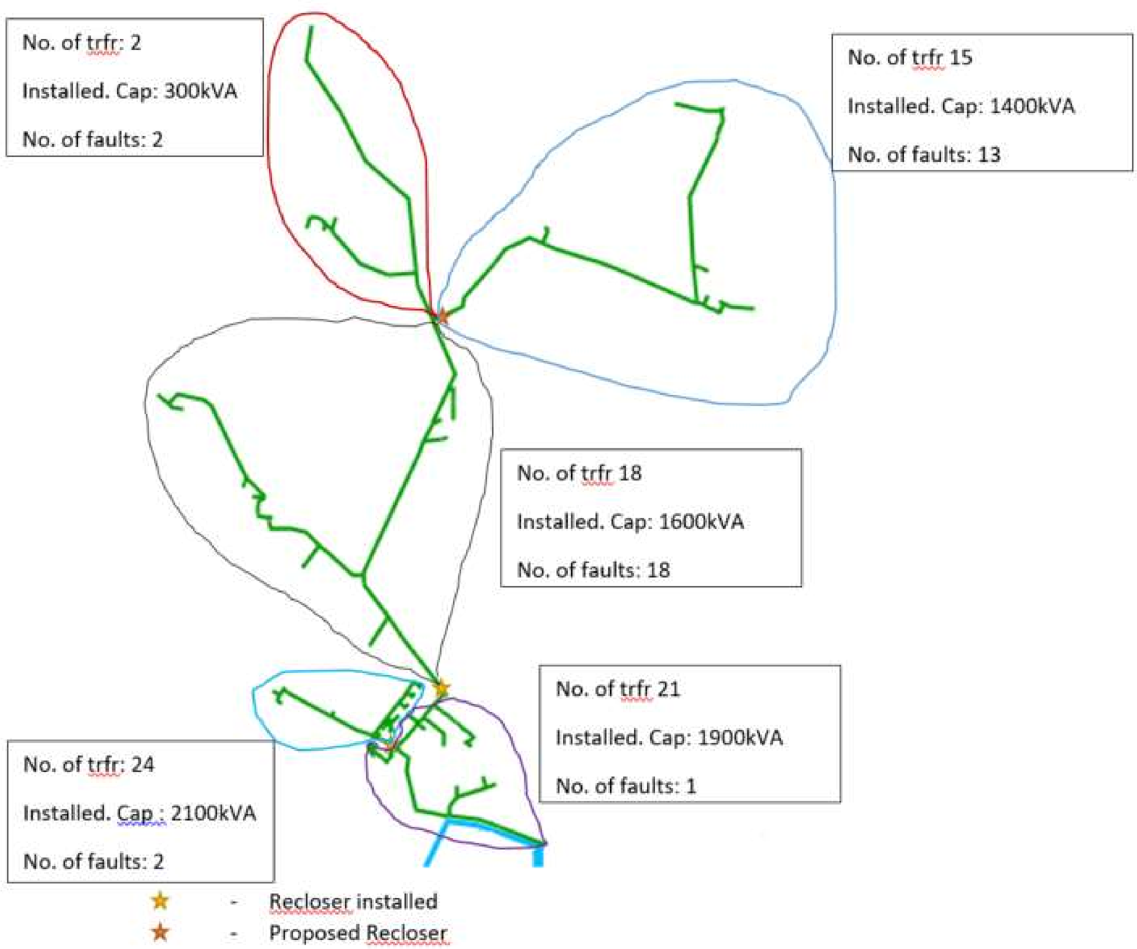

Figure 1: Geographical layout of an electrical network per zone analysis

Note: Each type of fault must be marked geographically.

If changing the above-mentioned points will cost more to rectify, it might be warranted to run the equipment to failure. Only then, can the necessary equipment be changed or a possible recloser be installed to lessen the customer losses in the case of failures, depending on what is financially more viable. A geographical diagram can be used to plot the data to identify zones in which performance is below standard/target. Possible recloser placements can also be plotted to improve networks performance.

2.4 Measurement indicators

Indicators are observable, specific and measurable to show changes or progress towards achieving a goal. The changes indicated by the indicators should show the progress either good or bad towards achieving the set-out goal.

2.4.1 Performance

Utility performance monitoring is one of the major strategies used to benchmark its performance. Eskom's KPI used for improving performance uses the SAIDI, SAIFI and momentary average interruption frequency index (MAIFI) values but is not bound by them. During fault conditions a fault current will flow, which is determined by the fault impedance, source, and impedance back to the source. During fault conditions, the voltage will dip/drop in relation to the magnitude of the fault current. The South African user specification standard classifies dips into Y, X, S, T and Z categories, shown in Table 6 below [16], [17].

This standard places the responsibility of the voltage dips in the Y area with the customer as they are suspected of occurring frequently in the HV and MV networks. The number of allowed dips for other areas are limited. The X areas (X1 and X2) reflect normal voltage dips with normal clearance times. Customers are to protect their equipment/plant against at least X1-type dips. The T-type area of voltage dips occur due to close-up faults and are not expected to happen regularly, but the utility should address if it becomes excessive. S-type area voltage dips occur with impedance protection schemes or with delayed voltage recovery. The S-type area voltage dips are not as common as X- and Y-type. Z-type area voltage dips are uncommon in HV systems and reflect problematic protection operations. The allowed number of S-type dips are less than X-type dips with the sum of S- and X-type dips is more than T-type dips.

Table 6: Voltage dip classification by duration and depth [17]

Remaining Voltage (%)	**Duration 20 < t ≤ 150 (ms)**	**Duration 150 < t ≤ 600 (ms)**	**Duration 600 < t ≤ 3000 (ms)**
90 > u ≥ 85			
85 > u ≥ 80	Y		
80 > u ≥ 70			Z1
70 > u ≥ 60	X1	S	
60 > u ≥ 40	X2		Z2
40 > u ≥ 0		T	

The remaining voltage (%) given is the deviation from the system voltage compared to the nominal declared voltage. The duration of the dip is measured in milliseconds. i.e., X1 dip will have a voltage dip of 70 > u ≥ 60 percentage of nominal declared voltage and duration of dip being 20 < t ≤ 150 (ms). Voltage dip information reveals if protection equipment worked correctly, if reclosers are slow to operate, and what type of faults occurred.

The purpose of these performance indicators (SAIDI, SAIFI, MAIFI) is that NERSA uses these KPIs to measure the performance of the utility and then configure the MYPD. Adding additional reclosers or optimizing the placement of these reclosers is intended to lessen the duration of outages as well as their frequencies.

The SAIDI shows the average duration of a sustained interruption the customer would experience per annum. It is commonly measured in customer minutes or customer hours of interruption.

SAIDI's equation is as follows:

$$\text{SAIDI} = \frac{\sum\text{Customer interruption duration}}{\text{Total number of customers served}} = \frac{\sum\text{riNi}}{\text{NT}} \tag{1}$$

Where: Ni = the number of interrupted customers for sustained interruption event during the reporting periods

Nt = the total (average) number of customers served for the reported period

ri = the restoration time for event i.

SAIFI (system average interruption frequency index) shows how often on average the connected customer would experience a sustained interruption per annum.

SAIFI's equation is as follows:

$$\text{SAIFI} = \frac{\sum\text{Number of customer interruptions}}{\text{Total number of customers served}} = \frac{\sum\text{Ni}}{\text{NT}} \tag{2}$$

Where: Ni = the number of interrupted customers for sustained interruption event during the reporting periods

Nt = the total (average) number of customers served for the reported period.

To measure the effect of momentary interruptions (under 2 minutes up until 2017/2018 and 5 minutes after 2018), the MAIFI indicator will be used. The MAIFI of a network indicates how often on average the connected customer would experience a momentary interruption per annum.

MAIFI's equation is as follows:

$$\text{MAIFI}=\frac{\text{Total number of customer momentary interruptions}}{\text{Total number of customers served}} \quad (3)$$

2.4.2 Financial

A cost-benefit analysis (CBA) is a systematic evaluation of economic advantages and disadvantages from a set of investment alternatives. Typically, a "base case" is compared to one or more alternatives. A cost-benefit analysis will determine what advantages an alternative will provide and what costs are needed to realize the project [18], [19].

The cost-benefit analysis equation is as follows:

$$\begin{aligned} \text{CBA} &= \frac{\text{Nett Benefits}}{\text{Nett Costs}} \\ &= \frac{\text{Savings in CENS}}{\text{Recloser repair} + \text{replacement} + \text{maintenance} + \text{install}} \\ &= \frac{\text{CENS before} - \text{CENS after}}{\text{Recloser costs}} \end{aligned} \quad (4)$$

From the equation mentioned above, it can be assumed that when a value of more than one is reached, the project may continue as the benefits outweigh the costs. When the total benefits (B) equal or surpasses the costs (C), a value of one or more will be achieved as indicated below:

Project beneficial when = $B \geq C$

Alternatively, if the costs outweigh the benefits, the figure of the CBA will be lower than one and thus the project will prove non-beneficial and should not continue in a case like this.

Project non beneficial when = $B < C$

This is demonstrated in the Figure 2 below:

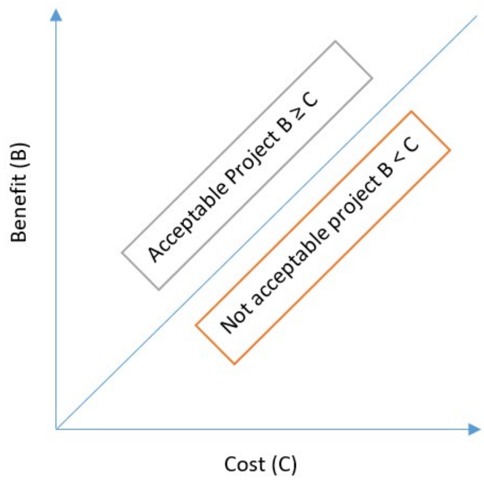

Figure 2: Cost-benefit analysis diagram

The CBA tool can be used to demonstrate to an investment committee which projects should be focused on and which projects to prioritize. The CBA tool can also show project planners which type of network to build and where in the network additional reclosers should be placed.

The objective of a cost-benefit analysis is to translate the effects of an investment into monetary terms, as benefits only incur over time (long term) while capital costs are incurred in that initial year.

A cost-benefit analysis is a tool for assisting project managers when they are evaluating and comparing different alternatives. Alternative comparisons are done at different points in the project development process, including concept development, environmental documentation, design, and construction.

A cost-benefit analysis tries to answer the questions: “Economically speaking, are the benefits worth the investment?” and “When will the return on investment be realised?” These questions are posed in different ways at different points in the project development process.

- **Project planning:** Economically speaking, are the benefits of installing a recloser worth the project costs (compared to the current system)?
- **Design and environmental study:** Economically speaking, are the benefits of location "A" worth the project costs? How does location "A" compare to "B", "C", or even "D"?
- **Construction planning:** Economically speaking, are the benefits of an outage worth the recloser installation and CENS (compared to keeping the electric network as is)?

Figure 3 shows a typical flowchart when using a CBA methodology in a project life cycle. In theory, an ideal cost-benefit analysis would project and evaluate all possibilities, but this is a difficult task, since it would involve uncertainties. Data is very seldom 100% accurate.

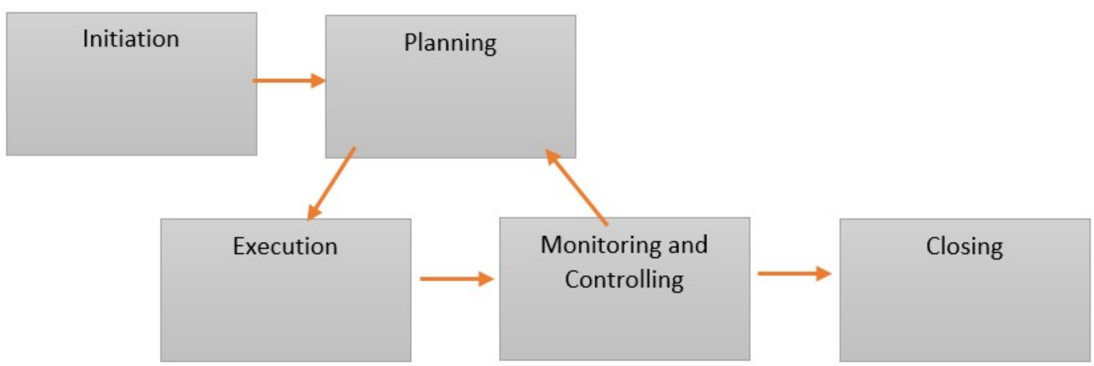

Figure 3: CBA used throughout the project life-cycle flowchart

Benefits of reclosers on an electric network investment are the direct, positive effects of that project; that is to say, the desirable things obtained by directly investing in the project. Ideally, the installing of a recloser needs to reduce the number of outages and faults to the customers, eliminate long delays especially during peak hours, or reduce time of rectification of faults on the distribution networks.

2.4.2.1 Value-based distribution network reliability planning

Investments related to the provision of electric service reliability should be more explicitly evaluated considering their cost and benefit implications. The intention is to relate the benefit of uninterrupted power supply as a means to rationalise the cost of optimal or additional recloser placements on distribution networks. A cost-benefit analysis approach attempts to locate the optimal placement of reclosers on the distribution networks where the total cost includes the utility investment cost, operating cost, maintenance cost, and customer interruption costs to the utility. The underlying principle of value-based planning is illustrated in Figure 4 below.

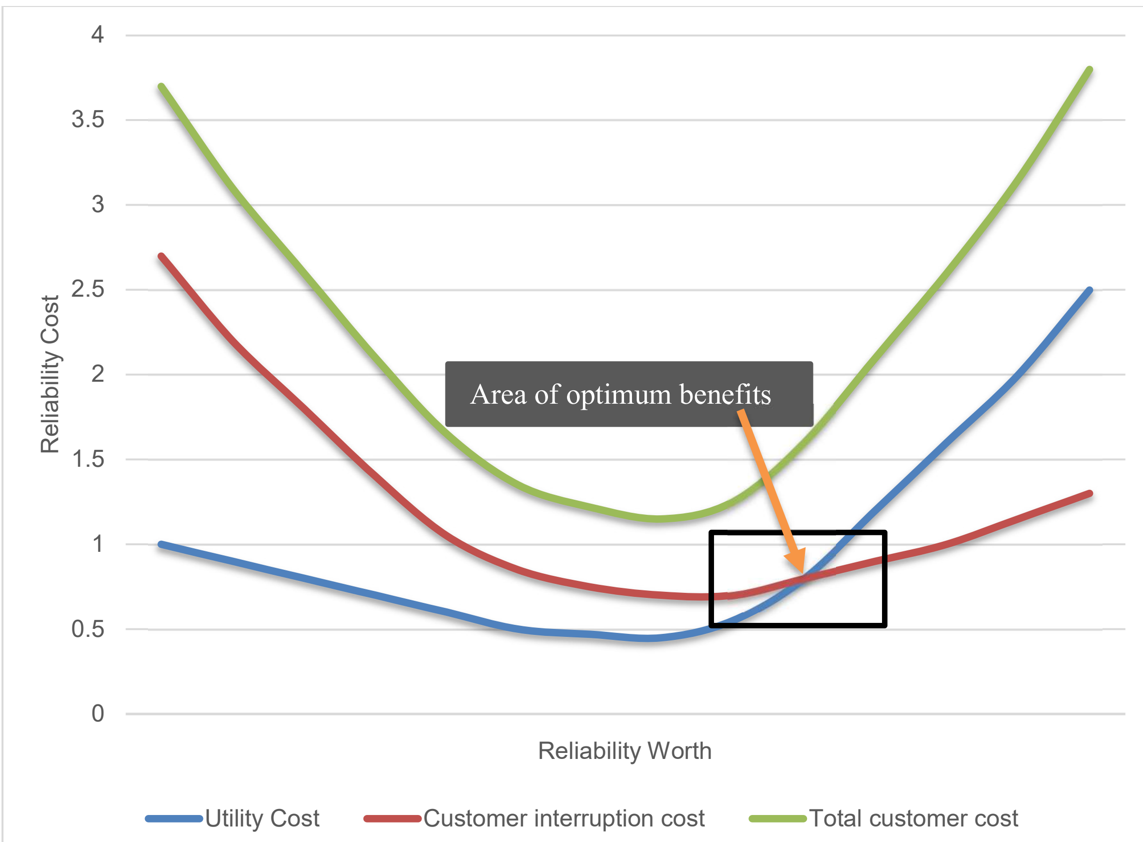

Figure 4: Reliability cost vs reliability worth

Figure 4 illustrates how the utility (Eskom) costs and customer interruption costs are combined to give a total customer cost. The utility's cost curve shows how customer rates increase as more money is spent (building additional supply network or substations) for increased reliability levels and ultimately keeping the customers connected if one part of the network is interrupted. The customer interruption cost curve shows how customer cost of interruptions decreases as the distribution system reliability increases. For low levels of distribution network reliability levels, the customer interruption costs are significantly high.

However, the utility cost can also increase significantly in the additional costs of restoring the system to a normal operating state and the loss of revenue (i.e., the utility cost curve shown in Figure 4 is based on the belief that increased costs will achieve higher levels of distribution network reliability). When the customer and utility interruption costs are combined and minimized, the utility's customers will receive the least cost service.

Analysing using the value-based distribution network reliability planning, means that a given level of service reliability can be examined in terms of the costs and the worth to the customer and utility. Thus, providing an optimized or additional recloser on the electrical network. In order for Eskom to not affect the customers' tariff increases too much, a regulator must be put in place, namely NERSA. They set up the MYPD, which determines the annual tariffs and increases towards the customers of the utility.

2.5 NERSA

The National Energy Regulator of South Africa (NERSA) is a regulatory authority established as a juristic person in terms of Section 3 of the National Energy Act, 2004. NERSA's mandate is to regulate the electricity industry in terms of the Electricity Regulation Act, 2006. NERSA requires certain criteria concerning the network reliability improvement [20].

2.5.1 NERSA and how they influence reliability improvement

NERSA's intention for Eskom distribution is to lower the impact of electricity interruptions by minimising the number of customers interrupted and the durations thereof.
NERSA determines the electricity prices and the increases granted to Eskom by using a Multi-Year Price Determination (MYPD) model. Reliability improvement funds are

granted to Eskom to improve their networks and make them more reliable.

The objectives of the MYPD are as follows:

- To provide a systematic basis for revenue/tariff setting.
- To provide efficiency incentives without leading to unintended consequences of regulation on performance.
- To appropriately allocate commercial risk between Eskom and its customers.
- To ensure consistency between price control periods.
- To ensure Eskom's sustainability as a business and limit the risk of excess or inadequate returns, while giving incentives for new investments, especially Eskom generation.
- To ensure reasonable tariff stability and smoothed changes over time consistent with the socio-economic objective of the government.

The MYPD methodology was created through NERSA consulting with stakeholders. It incorporates Rate of Return (RoR), incentive-based principles and incentive schemes, and the energy efficiency demands side management (EEDSM) schemes. The RoR methodology states that the revenue to be earned by Eskom should be the same as the efficient costs to supply electricity plus a fair return on the rate base. NERSA's first implementation of the Multi-Year Price Determination (MYPD1) for the Eskom business was during the 2006 to 2009 financial year period [21]. Research was done and it was decided that the SAIDI would be used to regulate the business. The design for the MYPD1 was based on data that was available at the time from Eskom Distribution that indicated that Eskom was averaging about 50 hours.

The design of the service incentive scheme encourages Eskom to earn additional revenue if its performance improves or pay a penalty if its performance deteriorates and will be allowed its revenue requirements if it maintains its existing performance.

2.5.2 NERSA's take on distribution service incentives/penalties

NERSA will use a single index called SAIDI as a key performance indicator that gives a good overall indication of the utility's performance. SAIDI is a measure of both frequency of interruptions and duration of interruptions.

The service incentive scheme for SAIDI is applied as follows:

- New electrification customers will be excluded from the calculation of SAIDI.
- The set incentive targets must show relevance to the value of the improved performance.
- For the MYPD2 control period, the SAIDI referred to is inclusive of both controllable and uncontrollable events (e.g., thefts, transmission-caused problems, etc.) to ensure consistency with historical performance.
- Incentives payable to Eskom should not be more than the value of improved performance or less than the cost needed to achieve it.
- Incentives/penalties should be capped to limit customer's exposure to higher prices.
- Eskom distribution to report regularly, indicating their reliability expenditure and their SAIDI to date against the target. This report must also include commentary on the causes of any improvement or deterioration.
- Any transmission events of magnitude >1 minute and any force majeure events resulting in SAIDI hour greater than one, are to be excluded from the calculations.

During the MYPD1, Eskom Distribution indicated it wanted to improve its SAIDI figure by 20% to 30% from 50 hours to 35 hours. Eskom ended the year on 51.51 hours and should have received a penalty of R210m on its MYPD2 revenue calculations. However, Eskom applied for a re-adjustment on its SAIDI hours for the penalty zone to start at 49.2 hours and received a penalty of R30.42m [22].

These reasons included:

- Only 2 years of historical data was used to set the first years SAIDI target of 50 hours.
- Reliability projects take a minimum of 3 years to show SAIDI improvements.
- No exclusion events were given in the first MYPD year. This is unfair as some of the causes of interruptions are not distribution's fault i.e., weather (tornado),

transmission causing power failure to distribution, etc.

The second implementation (MYPD2) was during the period 2010 to 2013 and some of the rules changed for this period as follows:

- Eskom is to report on SAIDI performance every 6 months.
- A 50% weighting will be applied for planned outages.
- Controllable and uncontrollable events are included in performance figures.
- Outages caused by vandalism or theft will be treated as unplanned outages.
- Incentive rewards and penalties will be reviewed every 12 months during the MYPD2 period, and the total will be applied during the MYPD3's revenue calculation.
- New electrification customers will only be added to the customer base during the beginning of the new financial year.

Incentive scheme event exclusions included:

- Generation caused events.
- Transmission-caused interruptions.
- Load shedding caused by generation capacity shortages.
- Customer-caused events.
- Integrated Power System (IPS) system constraints.

During the MYPD2 period, Eskom Distribution was averaging 52 hours. Eskom Distribution indicated that they wanted to improve its SAIDI figure by 20%. A target was set to improve the SAIDI from 52 hours to 42-47 hours. If this was not to be achieved, a penalty capped at R10m would be implemented towards the utility. MYPD3 period was implemented for 5 years (2013-2018). Eskom would, apart from SAIDI, also be measured on SAIFI and Distribution Supply Loss Index (DSLI) figures to determine its incentives and performance factors at the end of the MYPD3 period. For the MYPD3 period, the target was 39 SAIDI hours. Eskom achieved 38.9 SAIDI hours. The SAIFI target was set at 20 events and Eskom achieved an average of 18.9 events [23]. Eskom Distribution earned a reward of R263 million for its performance results on SAIDI, SAIFI and DSLI. See

Figure 5 below for SAIDI and SAIFI performance.

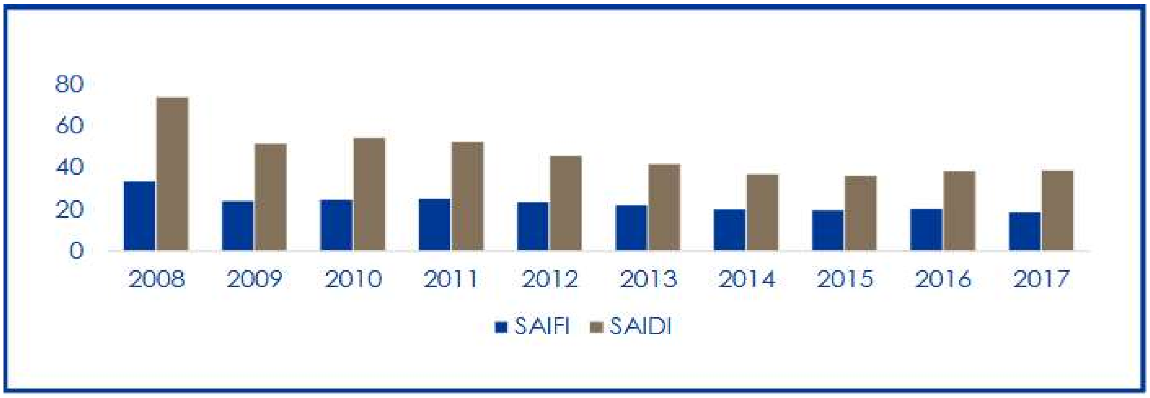

Figure 5: SAIDI, SAIFI performance [23]

All Eskom distribution reliability improvement methods are based on the targets set out by NERSA. The problem with this is that NERSA does not focus on how the SAIDI target is reached, as long as the reliability is within target and this creates a problem for certain customers of Eskom. The problem is that the LPU and SPU customers are going to suffer the most under these types of conditions set out by NERSA, since the bulk of customers affecting SAIDI is the PPU customers. This can cause the SPU and LPU customers to become independent power producers to not only supply their own electricity, but also supply into the electrical. Thus, a grid code was created for this scenario to be done safely.

2.6 Grid Code

A liberalisation on the energy sector in South Africa has been approved by the government to propose a strategy to reform the electricity supply industry (ESI). Support and numerous arrangements are needed to support implementation of a new industry structure. The arrangements fall into three groups: stakeholder and commercial arrangements, government policy, and instruments issued by NERSA in line with that policy. NERSA issued licences, regulations, codes of conduct, directives, guidelines, and revenue and tariff determinations [24]. Government policy permits open and non-discriminatory access to the transmission system (TS) as set out in the Energy White Paper.

NERSA has undertaken the responsibility to develop the Grid Code with the cooperation of stakeholders. NERSA's responsibility is to ensure that stakeholders and future market participants have the opportunity to provide input to the development and ongoing updating of the Grid Code. The Grid Code Advisory Committee (GCAC) is a body comprising stakeholders whose function is to review proposed changes to the Grid Code and make recommendations to NERSA regarding the Grid Code.

The objective of the SA Grid Code will ensure the following:

- Relevant information is made available to and by the industry participants to comply to the grid code requirements.
- Accountability of all parties that are defined for the provision of open access to the TS.
- Obligations of participants are defined for safe and efficient operation of the TS.
- Minimum technical and design requirements are defined for service providers.
- Pricing principles and major technical cost drivers of service providers are transparent.
- Minimum technical requirements are defined for units of the customers connecting to the TS.
- Where IPS is required, the System Operator shall evaluate and determine its need.

The Grid Code has the following sections:

- System operating code – defining rights and obligations of participants regarding operation of the IPS.
- Metering code – specifying the requirements for tariff metering at the TS interface level.
- Governance Code – detailing all aspects of the Grid Code governance.
- Information Exchange Code – specifying information requirements and obligations of all parties.
- Network Code – focusing on the technical system capacity, quality of supply – (QOS) and reliability of the network requirements.
- Transmission Tariff code – specifying objectives and structure of transmission tariff

and methodologies employed.

The Grid Code defines what is understood by non-discrimination through the definition of transparent and consistent procedures, principles and criteria. The Grid Code is to provide assurances to providers, NERSA and customers.

The service providers, under the Grid Code are responsible for:

- Providing open access on agreement standard terms to all parties to connect or use the TS.
- Show no interest in whose product is being transported.
- Ensure investments are made within the requirements of the Grid Code.

It is clear that NERSA wants Eskom to improve on its reliability. By improving on the reliability, the performance figures will improve, the customers will have less power outages and Eskom will profit more. The installation of reclosers — either optimal or additional — will help improve performance figures and in doing so, improve the reliability of our electricity networks.

2.7 Summary

In this chapter, the literature review of the study was presented. Firstly, the history of recloser placements was discussed and analysed as the basis for global and local methods. Thereafter, the methods for measuring the electrical networks performance and financial indicators were completed. These include the SAIDI, SAIFI, and CBA methods. This was followed by investigating what the regulators consider will improve the reliability of the electrical networks and how they would go about ensuring Eskom does so.

The next chapter presents the methodology of the study. This includes a description of the research methodology, research approach and design, data collection instruments, pilot study, ethical considerations.

CHAPTER 3: RESEARCH METHODOLOGY

Chapter 2 was dedicated to presenting the literature review of the study. The literature review covered the history of recloser placements and the placement methods on electrical networks, the measurement indicators, and the important bodies regulating Eskom. This chapter consists of the research methodology which includes the research methodology, research design, research approach, placing of reclosers, sequencing of recloser installations and the delimitation of the study.

Research methodology is the process used to collect information and data for making business decisions. The methodology may include publication research, interviews, surveys, and other research techniques, and could include both present and historical information [25], [26]. Such an approach is necessary for establishing and determining problems relating to recloser placement methodologies. A research method for establishing a CBA for recloser placements should provide phases of research progress to meet necessary objectives. These phases will include design, data collection and data analysis.

3.1 Research methodology

The research methodology used in this current study was the CBA research methodology. This current study adopted the use of data being collected using the utility's systems which are analysed and filtered as necessary. This methodology was applied to improve the reliability of the distribution networks by focusing on the financial benefits when installing reclosers on distribution networks.

A CBA methodology was considered, as Eskom is currently in a financial crisis. Thus, focusing on the financial aspects and possibly the performance aspects might benefit the utility whereas improving the reliability of a utility's network by focusing on the KPIs might not necessarily be the best way forward. Certain criteria must be taken into consideration when trying to establish a methodology and these will be researched in the design.

3.2 Research design

When using a CBA method to determine the placement of reclosers on a distribution network, it should reveal the following to the person using it:

- Number of reclosers to be placed.
- Optimum locations of reclosers on the distribution network.
- Financial benefits associated with the recloser placements.

To get all the relevant information needed to complete a CBA analysis of the distribution network, certain data must be acquired. These reports will have data on the specific distribution network regarding the following:

- Number of customers.
- Type/size of customers.
- Tariffs assigned to customers.
- Number of transformers.
- If relevant, the number and location of current reclosers.
- Number, type, and location of faults (events history).
- Performance figures.

Depending on whether a new or existing distribution network needs to be analysed, a decision must be made using the above-mentioned information to determine the most beneficial distribution network for the CBA study.

In order to cover most bases of the methodology, networks were used which included different customer groups. To install additional or reposition reclosers on the distribution networks, criteria need to be in place to select from a sample set. The study was based on networks in the Free State area, whereby reclosers are only installed on 11 – 22 kV distribution networks. The following criteria were used when selecting a distribution network:

- The network must be an 11-22 kv overhead line.
- At least 3 years of data must be available for analysis of specific distribution network (unless it is a new distribution network).

- All tariff data must be available for different types of customers (pre-paid users, small power users and large power users) on the distribution network.
- Power consumption of network or customers must be available.

In the Free State, there are many distribution networks of which choosing one with the necessary criteria was not too difficult. For the purpose of this study, these networks must cover all the different types of customers, line lengths, etc.

The financial benefits will be determined using a CENS methodology to show the improvement that could have been found if reclosers were placed using the CBA methodology. A payback period will calculate the time it will take the utility to receive a ROI.

3.3 Research approach

Using a CBA methodology should be able to assist in making the decision to install a recloser on a distribution network. The CBA should assist with determining the following:

- Whether installing a recloser is financially viable.
- Number of reclosers to be installed.
- Position of the new reclosers on the distribution network.

To calculate the CBA, a couple of other calculations need to be made. These will include determining the losses of the utility’s income due to outages, the payback periods on investments made to install reclosers, etc. It must not be forgotten that when an outage occurs, customers are inconvenienced for this period, as most customers will not have electricity during the outage period. During short momentary interruptions, the customers in normal households will probably not take serious steps, but might start investing in expensive alternatives i.e., generators, solar power sources, etc. when interrupted for hours or even days. This is something a utility wants to avoid as they will have less income from these customers, making placing of reclosers more important.

If customers have commercial properties and businesses, an interruption can prove costly. The time of day is also an important factor as to when the interruption occurs since during peak working hours interruptions are even more detrimental to the customer. For the purpose of this study, investigation towards the customer's losses that occur during interruptions will not be investigated, but the CENS toward the utility will be calculated. During calculations, the momentary or transient faults will be ignored as they do not form part of the performance figures and the losses are very low during these short periods. The study will focus on the calculation for the CBA of the utility.

3.3.1 CBA for the utility

To determine the CBA of the utility, the benefits and costs will be compared in order to decide on whether to continue with the project of installing a recloser on a distribution network.

The benefits of installing reclosers are:

- Remote switching.
- Shorter fault times.
- Fewer affected customers.
- Improves fault finding times.

Installing a recloser should yield a reduction in the CENS. Installed reclosers are visible to the control centre, which has the capability of switching the reclosers remotely, shortening the interruption towards the customer and keeping the customer on the network which means more income towards the utility. It also possibly lessens the need to dispatch the technical officials to the field to do fault finding. This reduces the possible overtime that would have been paid towards the employee. The benefits regarding the data received from the recloser should also not be forgotten as the recloser can provide valuable information to the control centre. Isolating customers with a recloser during planned outages is also beneficial as more customers can be "online" and fewer customers are being isolated, meaning more income toward the utility.

The costs to install reclosers include the following:

- Repair.
- Replacement.
- Maintenance.
- Installation and commissioning.

Repair costs can include sending of the recloser to the manufacturer for fixing. Remembering that during this time if a fault were to occur, more customers will be interrupted, resulting in income losses towards the utility. Replacement costs incurred can include the actual breaker, control box, structure, or radio communication equipment. It must first be established what needs replacement. This can include driving to the point. If it can be repaired on site, it will cost only one trip, but if new equipment is required, it will have to be ordered and another trip will have to be made to replace it.

Eskom used to do maintenance on the reclosers up until 2016 and thereafter decided to run the equipment to failure [27]. Installation and commissioning of equipment must be taken into consideration as it takes time and money to do this and if live work cannot be used, the customers will be without electricity during the outage and installation and commissioning of the recloser. To determine the actual cost of the item mentioned above is not an easy task and achieving 100% accuracy is very difficult. For the purpose of this study, the material and an estimate of installation and commissioning costs are used.

The CENS before and CENS after will be determined by comparing the network's recloser installations before and after installation. Because installation of equipment is expensive and to change the current standards used to determine recloser installations for a specific study is not easily motivated, the actual installations of reclosers could not be done on the actual networks. Even though this could not be done, the data captured by the utility can be used to determine the benefits of recloser installations. This can unfortunately not be done at 100% accuracy as determining the exact location of faults is not always known. By using the data, a minimum and maximum potential improvement can be determined to give an idea of the potential of the CBA methodology used to place reclosers on the distribution network. The recommendation is to use at least one year's data but using 3 years' data will be more ideal. The reason for this is that, for that specific year there might be a few faults, but the year before or after may have plenty of faults on the specific network as predicting the number of faults is not entirely possible. For this reason, 3 years' data would be ideal to determine the placement of reclosers.

If the CBA's value is not equal to or bigger than one (CBA≤1), it means that the recloser should not be placed at this location. If the CBA value is found to be bigger than one (CBA≥1) then it is recommended to install a recloser.

The CBA can also be used to determine the value of the reclosers currently installed. The CENS can be used to determine the loss of income the utility has during a recloser being bypassed. If a fault were to occur and the recloser is on bypass, it means that more customers will be without electricity and will not be isolated during fault conditions. The following formula is used to determine the CENS:

$$\begin{aligned} \text{CENS} &= \text{Cs} \times \sum_{h=i}^{h=i+n} \text{Ph} \\ &= \text{summated unit cost of interruptions (C)} \times \text{ENS} \end{aligned} \tag{5}$$

Where: Ph = the load averaged for a period of an hour

i = is the integer that counts for the duration of the outage (fault)

Cs = the summation of unit cost interruptions

When determining the Energy Not Served (ENS) on a network, the total energy consumption per year must be available. The total network consumption will indicate the consumption during the year, which in turn will indicate different loads as the seasons change and as the customer base changes. Determining each customer's load proves difficult as the meters are usually placed at the substation to determine the total load of the network, thus measuring the entire network and not the load per customer. An example of the loads captured on a specific network is displayed graphically below in Figure 6:

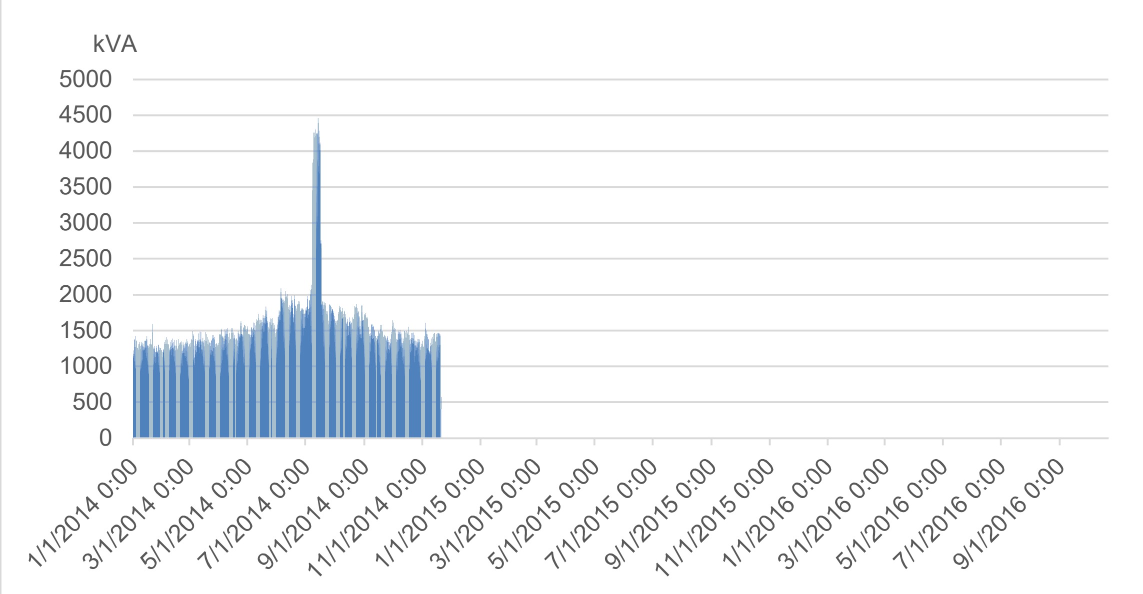

Figure 6: Network load for a network during 2014-2016 period

A load factor (L.F.) is used to determine the average load of all customers during a certain period [28], [29]. It can be defined as the average load divided by the maximum (peak) load. The average load of a specific distribution network can be determined by using the Fault Management System (FMS) report, which is a collection of loads measured by a metering unit at the substation.

The formula for the load factor can be seen below:

$$L.F. = \frac{\text{Average load (kVA)}}{\text{Maximum load (kVA)}} \tag{6}$$

To calculate the CENS, the installed capacity is affected by the L.F. to get an average load consumed during the year for the specific network. The average load can be calculated as follows:

$$Ph = Ppeak \times L.F. \tag{7}$$

Where: Ppeak = summation of the customers peak or maximum loads.

The summated unit cost of interruptions is determined by using Eskom's tariffs towards their customers. Each customer has their own tariff on which they are billed. An example of tariffs used by Eskom can be seen in Table 7.

Table 7: Eskom customer tariffs 2017/2018 [30]

Customer segment	**Energy charge (R/kWh)**	**Eskom tariff name**	**Note:**
Residential, Urban, Pre-paid (PPU)	1.0566	HomeLight 60 A	0 – 600 kWh
Residential, Urban, Pre-paid (PPU)	1.1169	Homepower 1 to 4	0 – 600 kWh
Residential, Urban, Pre-paid (SPU)	1.7636	Homepower 1 to 4	> 600 kWh
Small Urban, Agricultural (SPU)	0.9483	Landrate 1	Single-phase 16 kVA (80A per phase) Dual-phase 32 kVA (80a per phase) Three-phase 25 kVA (40A per phase)
Small Urban, Agricultural (SPU)	0.5402	NightSave Urban Small	Transmission zone 300-600 km <500 V Low-demand season (September – May)
Large Urban users, Commercial (LPU)	0.6967	NightSave Urban Large	Transmission zone 300-600 km Voltage <500 V High-demand season (June – August)

Eskom has approximately 15 different tariffs that are used for different customers depending on what the customers' requirements are. For low usage, single-phase residential supplies in urban areas, the following charges will be dependent on the size of the supply.
For non-local authority billed and pre-payment metered customers, the inclining block rate (c/kWh) energy charges applied to all energy consumed are divided into two consumption blocks. These two consumption blocks are made up of the following tariffs as can be seen in Table 8:

Table 8: Homelight suite tariffs capacity of supply [30]

Homelight 20A	20A supply size Notified Maximum Demand (NMD) typically for low-consuming supplies
Homelight 60A	60A prepayment or 80A conventionally metered supply size (NMD) typically for medium- to high-consuming supplies

The capacity of supply is as follows: any combination of appliances can be used at the same time as long as the capacity of all appliances does not exceed a maximum of 4200 W for 20A limited supplies and 12 500 W for 60A limited supplies.
Any customer who wishes to upgrade their supply from 20A to 60A should be aware that a connection fee is payable. Table 9 shows the difference between the two Homelight tariffs and their energy charges.

Table 9: Homelight suite tariff [31]

Homelight 20A	**Energy Charge (c/kWh)**	**VAT incl.**
Block 1 (0-350 kWh)	91.46	104.26
Block 2 (>350 kWh)	103.51	118.00
Homelight 60A	**Energy Charge (c/kWh)**	**VAT incl.**
Block 1 (0-600 kWh)	103.39	117.86
Block 2 (>600 kWh)	175.74	200.34

Note: A connection charge reflects the location of the supply and the impact on upstream costs. Other tariffs have different seasonally differentiated c/kWh active energy charges, including losses based on the voltage of the supply and the transmission zone for seasonally differentiated R/kVA energy demand charges. These are based on the voltage of the supply, the transmission zone and charged on the chargeable demand in peak periods.

- R/kVA transmission network charge based on the voltage of the supply, the transmission zone and charged on the annual utilised capacity measured at the Point of Delivery (POD) applicable during all time periods.
- R/kVA distribution network capacity charge based on the voltage of the supply and the annual utilised capacity measured at the POD applicable during all time periods.
- R/kVA distribution network demand charge based on the voltage of the supply and the chargeable demand measured at the POD applicable during peak periods only.
- R/kVA urban low voltage subsidy charge applicable to > 66 kV supplies based on the voltage of the supply and charged on the annual utilised capacity measured at the POD applicable during all time periods.
- c/kWh ancillary service charge based on the voltage of the supply applicable during all time periods.
- R/account/day service charge based on the monthly utilised capacity of each POD linked to an account.
- R/POD/day administration charge based on the monthly utilised capacity of each POD linked to an account.
- c/kWh electrification and rural network subsidy charge applied to the total active energy measured at the POD in the month.
- c/kWh affordability subsidy charge applied to the total active energy purchased from Eskom at the POD in the month — applicable to non-local authority tariffs only — additional charges in the event of an NMD exceedance and in accordance with the NMD rules.

Upon calculating the CBA, some tariffs need a power factor calculation to determine the tariffs for i.e., Ruraflex and Nightsave.

Ruraflex charges that comprises the total tariffs are as follows:

1. Seasonally and time of use differentiated (c/kWh) active energy charges *(includes environmental levy).*
2. Network capacity charge (R/kVA) applicable during all time periods, differentiated by voltage and transmission zone.
3. Reactive energy charge (c/kVARh) applicable during entire billing period — only applicable during high-demand season.
4. Network demand charge (c/kWh).
5. Ancillary service charge (c/kWh).
6. Service charge based on the size of the supply (R/day).
7. Administration charge based on the size of supply (R/day).

Nightsave charges that comprises of the total tariffs are as follows:

1. Seasonally differentiated (c/kWh) active energy charges based on the voltage of the supply and the transmission zone *(including the environmental levy).*
2. Seasonally differentiated energy demand charge (which includes network costs) based on the voltage of the supply, the chargeable demand and the transmission zone, applicable during peak periods only.
3. Bundled (R/kVA/month — network capacity charge) transmission, distribution network capacity and distribution network demand charge based on the voltage of the supply, the transmission zone and the utilised capacity at the POD and applicable during all time periods.
4. Distribution network demand charge (c/kWh) based on the voltage of the supply and energy measured during all time periods.
5. Ancillary service charge (c/kWh).
6. Service charge based on the size of supply (R/day).
7. Administration charge based on the size of supply (R/day).

3.3.2 Calculation front page SAIDI and CENS

An interface or front page was created for calculating the SAIDI improvement as well as CENS savings. Several inputs are needed as can be seen below in the example Table 10. All other values required are completed on another tab, but because of all the values required, it cannot be displayed in a table format.

Table 10: Calculation front page for SAIDI and CENS

INPUT	**Values**	**Measurement Unit**
MV network maximum peak load capacity	30046	kVA
Average load measured	2924.9478	kVA
Load factor	0.097349	
Operating costs (Utility)	R0.677910	R/kWh
RESULTS		
SAIDI before	18.93	
SAIDI after	16.67	
SAIDI improvement	11.93%	
CENS before	R90 616.71	
CENS after	R75 406.35	
CENS savings	16.79%	

The input Table 10 makes place for where values can be inserted manually by the user. After all, if values have been inserted for the specific network, the results will reflect in Table 10 under results for the SAIDI and CENS. In order to calculate the SAIDI and CENS from the events over a certain period, the reclosers tariff prices must be known. As mentioned previously, Eskom has multiple tariffs for all types of customers and all these must be known, especially if the network has a variety of different customers. Within these tariffs, there are different charges and they can be viewed in the tariff booklets as mentioned before. There are too many to display in a table.

The events page displays all the events that occurred during a certain period, which form part of the values used to calculate the SAIDI and CENS. In Table 11 below is a breakdown of the events data fields.

Table 11: Events data fields explained

Data field	**Description**
Month	The month the event took place
Year	The year the event took place
State change location	Location (Pole number) on which the fault of device that operated was found (Breaker, link etc.)
NOFELC	Classification of events: N and O are planned events (Notified), F = Fault events, E = Emergencies, L = Live Work events and C = Customer requested/caused events.
Trace start date	Time fault occurred, up until time fault was corrected and power restored to customers. Influences the calculation when outage goes over different time periods or season, i.e., peak, off-peak, standard, high or low season. These dates also have time stamps.
Trace end date	
Trace Duration	The time the customer(s) was without supply. Usually calculated as trace end date minus trace start date. Measured in hours.
Customer affected	The number of customers affected during an outage.
Scenario	The fault can be identified and marked as the root cause of the event.
Failure Cause	Cause of failure is described.

Event notes	Notes given by the person closing the Works Order (W/O) that may help with identifying the fault or fault location.

During the calculations, a power factor is required with some rates used by the utility towards the customer. A power factor was used during the calculations and can be seen in Figure 7. The real power (kW) actually powers the equipment and performs useful work [32]. The reactive power (kVAR) is the power that magnetic equipment (Transformers and motors etc.) needs to produce the magnetizing flux. The apparent power (kVA) is the vectorial summation of the reactive and real power. The power factor is the ratio between the real power and apparent power [33]. Thus, the more reactive power there is, the lower the ratio of real power to apparent power and the lower the power factor. The less reactive power there is, the higher the real power to apparent power. If the reactive power reaches zero, the power factor approaches one.

$$P.F. = \frac{kW}{kVA} \tag{8}$$

Where: kW is the real power and kVA being the reactive power.

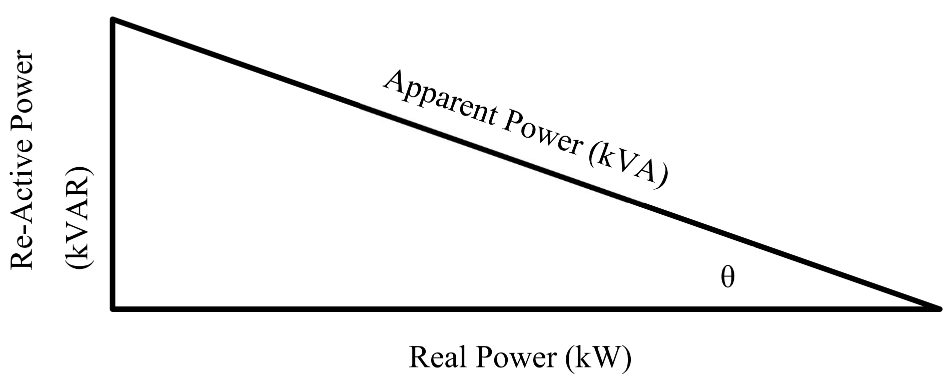

Figure 7: Power factor diagram [34]

A load factor was also taken into consideration, as the total installed power is not used at

100% capacity all the time. The power consumptions from customers differ depending on seasons, peak hours, load demand, etc. Load factor is a term that does not appear on the utility bill but does affect the electricity costs. The load factor indicates how efficiently the customer is using peak demand.

During the case study, it was identified that more than one type of tariff can be used on a single transformer point. This is because there are numerous customers connected to one transformer. Thus, during the calculation, the line voltage (400V) is divided by the square root of three to get the phase voltage of 230V.

$$\text{Phase voltage} = \frac{\text{Line Voltage}}{\sqrt{3}} \quad (9)$$

The circuit breaker max limit (Amps) is taken into consideration in order to calculate its possible power consumption. The apparent power is calculated, which will be multiplied by the number of customers connected to that specific tariff of that transformer.

$$P = (V \times I) \times \text{number of customers} \quad (10)$$

Where: V = voltage

I = current

This will sometimes give insight as to the actual power that the customers can consume at a specific transformer. In some cases, the power consumption seems to be more than the power that the transformer can or should supply. In these cases, the After Diversity Maximum Demand (ADMD) should be taken into consideration. It could be explained as the simultaneous maximum demand of a group of consumers, divided by the number of consumers, normally expressed in kVA [35], [36].

The ADMD of N consumers can be calculated as follows:

$$ADMD\ (N) = \frac{MD(N)}{N} \tag{11}$$

Where: MD = maximum demand of a certain number of customers

N = number of customers

On the other hand, with Eskom, a Notified Maximum Demand (NMD) is used, whereby the utilised capacity should theoretically equal the NMD. The NMD is written by the customer and accepted by the utility. All these different energy charges need to be taken into consideration when trying to calculate an accurate customer consumption and the CBA as each customer and tariff is different and impacts on placing a recloser on a distribution network.

After determining the number of reclosers to be placed on the network whereby each recloser's CBA is above one, the actual placement of the reclosers need to be determined. This involves using the system called GeoViewer.

3.4 Placing of reclosers

When establishing the placing of reclosers a system within Eskom can be used namely Geoviewer. The Geoviewer system can be used to view networks geographically [37], [38]. See Figure 8 below as an example of the Geoviewer system:

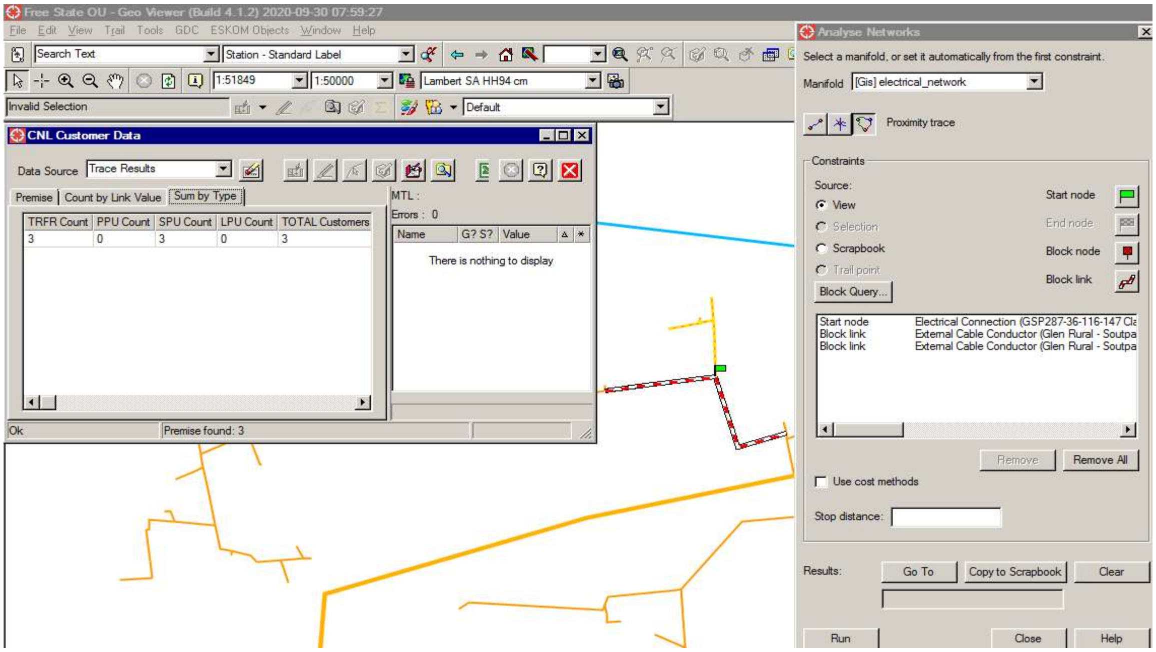

Figure 8: Geoviewer system for network data

Using a network model platform is benficial to visualise the network as well as the customers. The equipment installed can be found on the network and more specifically, where it is installed. Different types of models can be used for different purposes within a network [39]. Using the Geoviewer programme, blocking nodes can be used to block portions of the network that information is required from to focus on specific parts of the network if needed. Networks or part of the network that is desired can be traced to conclude a study. The green indicates the network where the red and white is blocked from the yellow part of the network. The Analysing Networks tool is used for plotting and tracing the network's results and the results are displayed in the CNL Customer Data tool. Any portion of the network can be traced up until the desired number and type of customers needed to get a CBA of more than one to make the project viable. Once the pole location is found and identified where installing a recloser will be viable, it can be captured. Once all the pole numbers have been captured, the sequence in which the reclosers are placed must be determined. This is important, as there are not always finances or labour available to install all the reclosers at the same time or within a certain period i.e., a year.

3.5 The sequence of recloser installations

Apart from installing the number of reclosers on the networks as per the calculations used, the benefits must be imperative. If calculations show the CBA to be more than one, there are more factors to consider, i.e., the number of reclosers placed in series shall be limited to four due to protection grading constraints, plus a substation breaker [40].

Other determining factors will be fault history, telecommunication in the area, geographical obstacles, etc. These all play a vital role in the placement of reclosers. For the optimum placement of reclosers, it is crucial to consider and compare the different parameters. For this to happen, a questionnaire was compiled to acknowledge what parameters are important to consider.

Installing the reclosers already determined by the CBA methodology is of utmost importance as will be demonstrated using a matrix (shown and explained below).

3.5.1 Questionnaire identifying the important parameters to be taken into consideration

A quality questionnaire is imperative for good results, it must have a clearly defined objective to provide the basis for the questionnaire in order to collect data on multiple variables, while meeting the basic metric characteristics [41]. The metric characteristics of a measuring instrument are called the characteristics of the instrument on the basis of which it is judged to be useful and the justification of the conclusions drawn from the results obtained from its application, with the greatest attention being paid to validity and reliability. Assessing the validity of a measuring instrument assesses its focus on the target object of measurement. Content, criteria and construct validity are most commonly discussed. When assessing the content validity, the extent to which the relevant content of the measurement object is "covered" is determined by the instrument and is the representation of individual contents appropriate?

Ten customer network centres (CNCs) were asked to give their view on what the important criteria are when considering recloser placement in their geographical areas in the Free

State. The supervisors discussed the important factors to be considered when placing reclosers with their team which included technicians and technical operators. They were asked to give weight values to Table 12 below and add any other criteria they thought valuable.

The questionnaire comprised the following as can be seen in Table 12:

Table 12: Questionnaire matrix

Recloser location	Network Voltage	Communication	Number of failures on t-off	Geographical obstacles	Sensitive customers	T-off length	Lightning density area.	Total weight
Weights example		Yes continue, No stop	10	20	10	20	10	100
RRO203	11 kV	Yes	25	20	10	10	10	100
RR250	11 kV	No						

The feedback from the CNCs were taken and the weights distributed accordingly.
The criteria for the matrix include:

- Communication
- Number of failures on t-offs
- Geographical obstacles
- Sensitive customers
- T-off length
- Lightning density

3.5.1.1 Communication

Communication is extremely important because if there is no communication in the area, the recloser cannot be remotely controllable (visible) to the control centre and the supervisory control and data acquisition (SCADA) system. Prior to any recloser installation, the visibility must first be checked. When testing for the communication of the recloser installation, there is a minimum signal strength that will be used to determine if the location of the recloser will be viable. If cell phone reception (namely GPRS signal) is available, then a modem will be used as communication device. Alternatively, if Eskom's own radio signal is available, then the Trio radios will be used [42]. If both are available, any choice can be made between the two. Minimum signal strengths are as follows: GPRS ≤ 90dbm and Radio ≤90dbm [43].

If the communication signal strengths are below the minimum target, then an alternative location must be selected for the recloser installation. The path loss programme is used to determine the signal strength of the specific area using GPS co-ordinates [44], [45]. The path loss programme measures the reduction in power density or attenuation of electromagnetic waves as it moves through space [46]. The electromagnetic waves are influenced by terrain contours, environment (buildings, mountains, trees, vegetation, etc.), distance between transmitter and receiver, height of antennas, and the propagation medium (dry or moist air).

3.5.1.2 Number of failures on t-offs

Equipment used by Eskom has a limited life span with certain associated failure rates. The failure of equipment on the distribution networks are inevitable, but determining their location is important, especially in the placing of reclosers. With failure rates occurring past a certain t-off, a recloser installation could assist in isolating those customers. Even though a recloser will not stop the equipment failure, it will help isolate the customers during fault conditions. Network and Equipment Performance System (NEPS) is used for fault history data and the number of faults in the last three years are analysed before any action is taken. Using the region's KPI figures, especially the SAIFI figure, will give a good overall idea of the average number of events per customer. When using the matrix in Table 13, the network is already selected and the specific number of faults/events can be analysed and used to create its necessary weighting. I.e. if the average number of events is six then the weighting can be made as follows:

Table 13: Fault/event weighting

Weighting	Number of faults/events
1	0-4
2	5-8
3	9-12
4	13-16
5	>16

3.5.1.3 Geographical obstacles

Apart from the actual equipment failing, the geographical obstacles affect the replacing or fixing of equipment as it can influence how accessible the terrain is, for example crossing of rivers and mountains or rough terrain. Site visits or Google maps can be used to determine obstacles. In such cases, careful consideration must be taken with recloser installations. This is demonstrated in Table 14.

Table 14: Geographical obstacles weighting

Weighting	Geographical difficulty
1	Easily accessible
2	Caution
3	Difficulty found
4	4x4 vehicle required
5	Nearly impossible to reach

3.5.1.4 Sensitive customers

These customers can range from farmers, bakers, hospitals, etc. These can be customers who are running businesses which means that if they lose power, they lose business and income. They can thus in turn possibly demand losses from the utility. Also, if hospitals or certain farmers were without power, it can have devastating consequences. These sensitive customers should be taken into consideration when placing reclosers. If customers can be specifically identified, their importance can also be determined with more accuracy. To make things simpler, the following weighting can be used. If there is a SPU customer it will be counted as one and if there is a LPU customer it will be counted as two. The number of customers wil be counted i.e. two SPU and two LPU customers as 2 + (2 x 2) = 6 customers, thus leading to a weighting of two being used. This is demonstrated in Table 15.

Table 15: Sensitive customer weighting

Weighting	Number of SPU and LPU customers
1	0-5
2	6-11
3	12-17
4	18-23
5	>23

3.5.1.5 T-off length

The length of the network usually means that physically getting to the fault in order to fix it takes longer, as demonstrated in Figure 9 displaying the length of networks in the Free State. It should be noted that even though the graph only displays 400 networks, the Free State has over 1 100 networks. The length of the networks is too small and virtually irrelevant for the graph's purpose, for this reason only 400 networks are displayed in Figure 9.

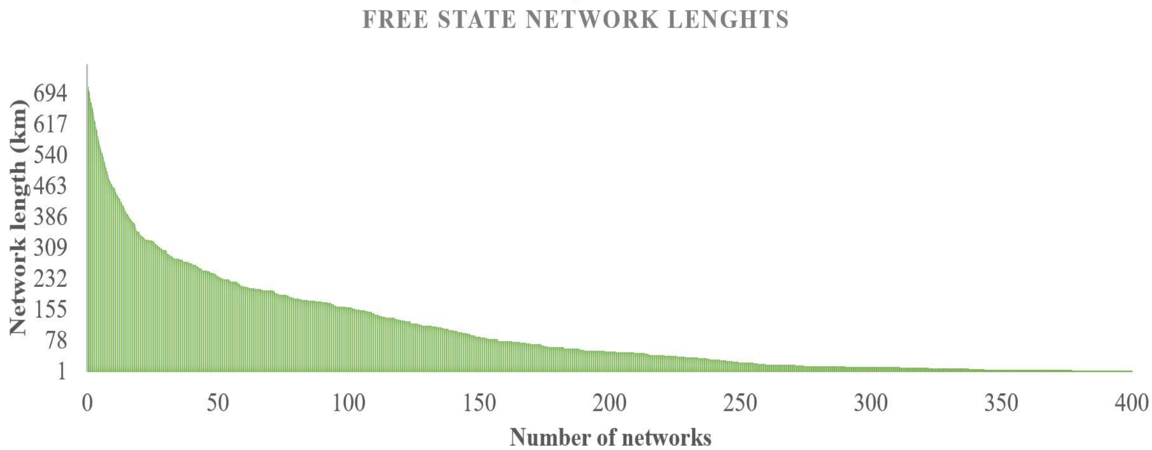

Figure 9: Free State network lengths

If the network is long and it takes time to get to faults, a system called Smallworld is used. It has network data including network length, equipment, customers, etc. [47], [48]. This becomes an important factor when installing reclosers as it can drastically reduce the time taken to correct faults on the networks. Once the specific network has been selected and pole numbers for each recloser has been found, the lengths of the t-offs can be measured and averaged. I.e., if the average length of the t-offs is 10 km, then the weighting can be compiled as demonstrated in Table 16.

Table 16: T-off length weighting

Weighting	T-off length
1	0-5 km
2	5< length ≤10 km
3	10< length ≤15 km
4	15< length ≤20 km
5	>20 km

3.5.1.6 Lightning density

If the area were known for its lightning strikes, it would probably be recommended to place reclosers elsewhere as receiving a lightning strike on the recloser is not recommended. In some special cases, reclosers can be placed to isolate customers who are prone to lightning strikes. The (Fault Analysis and Lightning Location System) FALLS is used to analyse and confirm the number and position of lightning flashes per year [49], [50]. If the network has already been selected, a FALLS study can be done on the specific network for a specific period. After the study has been concluded, the averages can be determined for the weighting of the matrix i.e., if the average lighting density strikes were found to be 30 for the period selected, then the following weighting table can be made as demonstrated in Table 17.

Table 17: High lightning strikes weighting

Weighting	Number of lightning strikes/km²
1	0-12 km²
2	12 < strikes < 24 km²
3	24 < strikes < 36 km²
4	36 < strikes < 48 km²
5	>48 km²

The weighted parameters of the named criteria can be seen in Table 18 that is reflected in the matrix.

Table 18: Matrix

Measurement Criteria	Recloser location	Communication	Number of failures on t-offs	Geographical obstacles	Sensitive customers	T-off length	Lightning density area.	Total weight
Importance of reclosers from most important to least								

important 1- most important								
Ranking	Pole numbers	Yes continue, No stop	Weight - 26%	Weight - 26%	Weight - 11%	Weight - 19%	Weight - 18%	Weight total - 100%

Even with all the necessary data collected, it is not 100% accurate and not all data is always available, so some delimitations must be accounted for.

3.6 Delimitation of the study

The importance of discussing the boundaries, limitations and boundaries of the studies is discussed in this subsection mentioned below. An example in this study is that the feedback from the W/O used to determine the fault's location, is not always detailed. Numerous times the feedback for a fault on the distribution network will be "fault not found". In such cases the fault's location is placed on the reclosers or substation breaker as they will open and break the supply.

Faults can occur at any time and any place. It is a variable that cannot be controlled, as a storm or lightning or a car crashing into an overhead line structure cannot be determined or predicted.

3.6.1 Assumption made in technical analysis

- Momentary interruptions are less than 2 minutes up until 2017/2018. It changed to 5 minutes since then (After 1 April 2018). A momentary interruption opens and closes a recloser in milliseconds, Eskom selected (2 minutes – 5 minutes) to provide for delays in the communication and recording systems – SCADA [51].
- Sustained/non-momentary interruptions are longer than 2 minutes up until

2017/2018 and longer than 5 minutes after 2017/2018 year.

- Sensitive earth fault protection is not allowed on recloser cycles.
- To count the number of lightning strike flashes on a MV network, a theoretical 1 km radius is selected around it.

3.6.2 Assumptions made during calculations

- Momentary interruptions are excluded from the cost of energy not served (CENS) calculations. Their impact is low due to short durations.
- An average of the measured load is taken over a period of a year and then compared to the actual supplied power (Load factor – L.F.). The assumption is made that all customers are using the same L.F.
- Pre-paid energy consumption cannot be measured as their meters are not measured and analysed by Eskom. Purchasing of electricity can vary depending on many criteria (income, seasons, etc.) thus, the amperes of the breakers are taken into consideration during calculations.
- Not all the faults captured in W/O have correct fault locations when feedback is given. Recloser locations are given as fault location even though faults occurred further down the distribution network. In these cases, current recloser locations will be used to calculate fault history benefits of new reclosers.
- During the CBA calculations, it is assumed that the losses (faults, maintenance, overtime, driving-petrol, etc.) to Eskom during the history of the recloser can be obtained from Eskom's annual operating costs.

Chapter 4: DATA ANALYSIS AND RESULTS

In the previous chapter, all the different aspects were shown for the CBA methodology. For every piece of the network that has a CBA of one or more, the option of a recloser might be viable depending on the setting's grading. After the number of reclosers has been calculated for the electrical network, the matrix table will be used to rank the reclosers from most important to least important.

In this chapter, the results of this study are discussed. The results show the calculation and comparison of different tariffs, the different types of customers found in the Free State Operating Unit, and the actual electrical networks used in this case study

The results of this study might bring a new perspective to utilities, engineers, and network designers, enabling them to make a better-informed decision when installing reclosers on an electrical network.

4.1 Tariff comparisons

To complete the CENS calculations needed for the CBA analysis, the tariffs from each customer need to be known. For this reason, a number of actual customer kilowatt hour figures were taken with their respective tariffs. Certain tariffs require unique data to complete the calculations. Two years of data were provided to complete the analysis for calculations. In the case of Ruraflex tariff customers, their cost calculation includes many charges, including high and low energy charges with peak, standard, and off-peak tariffs. Fourteen of the total number of Ruraflex customers on a specific network were compared as this was the data that was provided. The following was found in Table 19:

Table 19: Ruraflex average peak, standard peak, and off-peak percentages

High demand peak consumption percentage	High demand standard consumption percentage	High demand off-peak consumption percentage	Total high percentage
12,6%	51,7%	35,7%	100%
Low demand peak consumption percentage	**Low demand standard consumption percentage**	**Low demand off-peak consumption percentage**	**Total low percentage**
11,07%	40,7%	48,23%	100%

In the case study, seven of the Nightsave tariff customers were analysed. The costs included a high and low energy demand charge. This charge is very high but only applies to customers that use electricity during peak hours. Out of the seven customers, only one customer used electricity during peak hours. The average peak hour consumption was 2.25%. Nine tariffs found on the electrical networks were compared to show which tariff will have the highest income towards the utility. The comparisons of the tariffs can be seen in Table 20.

Table 20: Tariff comparisons

Ranking	Tariff Type	Type of customer	Comparison percentage
1	Business rate 4	SPU	100,00%
2	Land rate 4	SPU	85,73%
3	Ruraflex	LPU	70,50%
4	Land rate1,2,3	SPU	43,68%
5	Business rate1,2,3	SPU	35,66%
6	Nightsave Rural	LPU	33,33%
7	Nightsave Urban	LPU	28,97%

8	Homelight 1 (60A)	PPU	19,15%
9	Homelight 1 (20A)	PPU	15,09%

The rankings above were done using the same size transformer with the same amount of kWh used; thus, the comparison could be made. In Table 20, the Business rate 4 tariff brings in the most income compared to Homelight 1 (20A), bringing in the least amount of income. It should be noted that in reality, this is not always the true picture as the transformer sizes differ and thus the kWh consumed by customers might be much more.
Thus, it could be said that the lower ranked tariffs might produce more income because of the size of its customers. In most cases, the size of the transformer for Landrate 4 is 25 kVA which means the kWh consumed is less compared to a Ruraflex or Nightsave customer that might have >200 kVA transformers, increasing the kWh usage. The tariffs will be categorised within the utility. Explaining the importance of the type of customer category and the utility's traditional method compared to the CBA methodology will be explained by the customers' demographics mentioned below.

4.2 Free State Operating Unit customer demographics

Depending on the customers' tariff, they are categorised into one of three categories, namely PPU, SPU, and LPU. Free State Operating Unit customer demographics are important as it provides details about the type and number of customers in the area. In Figure 10, a breakdown of the customer categories and their respective percentages for the Eskom Distribution networks in the Free State region are shown. Pre-paid customers are mostly rural settlements with connections between 20-60Amps. Prior to 2015, Eskom's regions had different borders, namely the North-Western Region. Since 2015, the region's borders were changed and the North-West Region became the Free State Operating Unit, hence the customer base can only be measured accurately from the year 2015 onwards.

As can be seen in the Figure 10, the vast majority of Eskom Distribution customers in the Free State Operating Unit is the pre-paid user, making up 91% of the customer base. The small power users only take 9% of the customer base and the large power users only take up 0,44% of the customer base. These figures will not change much over the next couple of years.

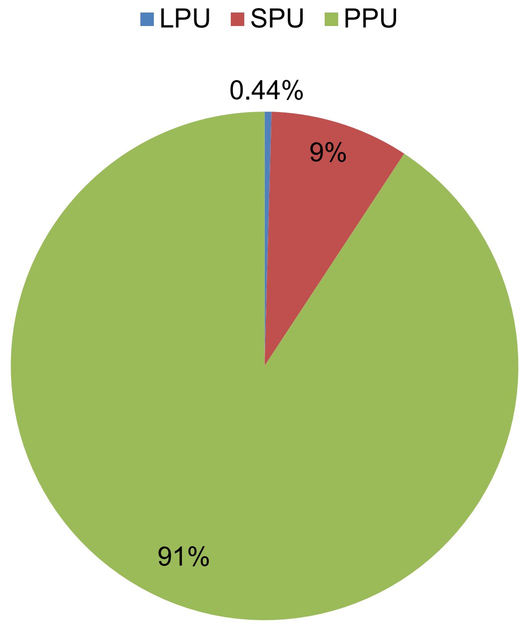

Figure 10: Eskom distribution customer breakdown in the Free State 2015-2016

Figure 10 shows why Eskom uses its traditional methodology to place reclosers. The PPU customers (91% of all customers in the region) are their focus area to improve SAIDI and reach their target set out by NERSA.

If we were to look at Figure 11, we would see a different side of the customer base. Figure 11 indicates the average kVA per customer type during the 2015 and 2016 years.

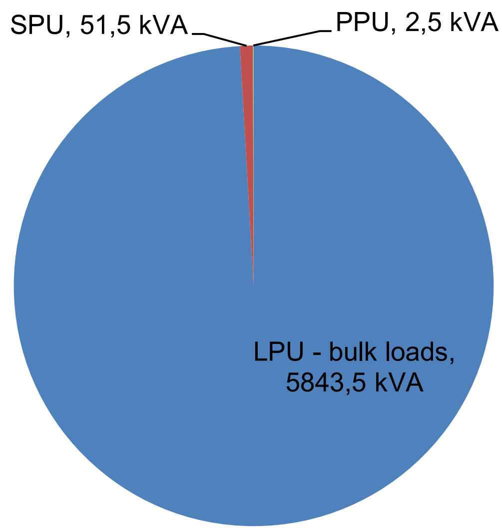

Figure 11: Free State average customer load per customer type

If Eskom were to take the average load per customer into consideration, it will start clarifying why using a CBA methodology might be a good initiative.

Figure12 demonstrates the customer loads per customer type. LPU customers contain 80% of the load, SPU customers contain 13% of the load, and PPU customers contain 7% of the load.

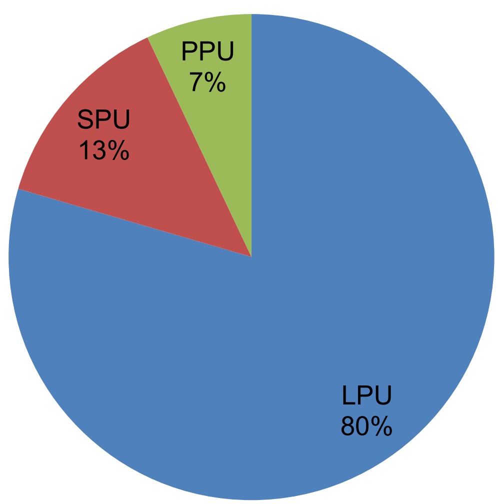

Figure 12: Eskom distribution Free State load per customer type

For this reason, the CBA methodology starts to make sense as looking at the LPU customers instead of the PPU customers, more money can be saved when a fault occurs. Focusing on the income values, from the type of customer and their tariffs, will prove invaluable towards the utility. To put this in perspective, an actual network was used in the Free State and the case study with its values are shown below.

4.3 Case study and general results

It is important to note that the customers on Network A were supplying low usage single-phase residentials in urban and electrification areas. This did not pose the level of difficulty that Network B possessed during calculations. The calculations for Network B proved more challenging as it was a long network with multiple customers and different tariffs. The methodology thus proved to work and could thus be used on most if not all 11 – 22 kV distribution networks.

It was found that the Eskom traditional methodology to place reclosers in Network A resulted in two reclosers being installed. Using the CBA methodology, it was found that nine reclosers could be installed on Network A. The CBA calculated results are displayed in Table 21.

Table 21: Network A's CBA and Ps results

Year	CBA	Ps (month)
2016/2017	11,25	1,07
2015/2016	10,64	1,13
2014/2015	11,47	1,05

Table 21 above shows that for the 2016/2017 year, eleven reclosers can be installed and have a ROI of one year, as can be seen by the CBA being 11,25. However, because of the network layout, only nine reclosers can be installed as shown in Figure 13 below. This is because of the protection settings that limit the number of reclosers being installed in series to being no more than four.

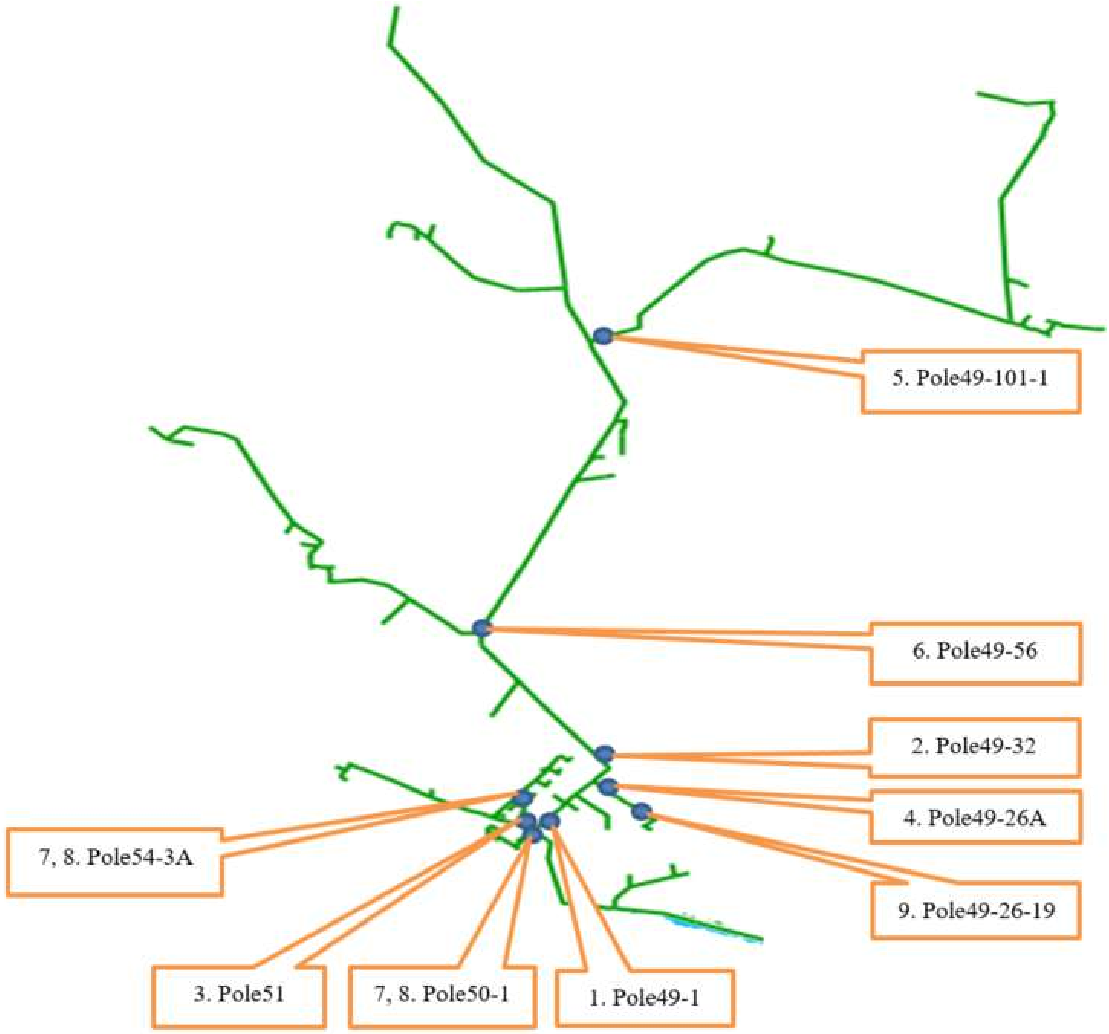

Figure 13: Network A recloser placement

The rankings of the reclosers were done using the matrix table, and the results can be seen in Figure 13. Ranked number one for the first recloser installation is Pole 49-1, and the last ranked and last recloser to be installed is Pole 49-26-19. In a case where reclosers have the same priority (carrying the same weight in the matrix), any one of the reclosers can be installed first. The pole numbers can be explained as follows i.e., Pole 49-32 means pole number 49 from the substation, the 32nd pole from pole number 49's t-off. This will be the location for the installation of the recloser on the network.

It should be noted that Table 22 indicates the minimum savings that could have been obtained and Table 23 indicates the maximum possible savings that could have been obtained. This is due to the feedback received from the W/O from faults being fixed in the field. Sometimes the faults are not found. In some cases, the recloser trips and its location is marked as where the fault was, although the fault is usually further down the network. For this reason, there are two tables provided to give a clear indication of the improvements that could have occurred using the CBA methodology.

Table 22: Minimum SAIDI traditional vs CBA methodology savings

Year	SAIDI traditional method	SAIDI CBA method	Minimum SAIDI saved	Minimum SAIDI saved percentage
2016/2017	61,27	56,46	4,8	7,85%
2015/2016	157,44	150,36	7,08	4,5%
2014/2015	21,16	5,59	15,57	73,58%
Total	239,87	212,41	27,45	11,45%

The SAIDI performance figure on Network A for the utility's traditional recloser installation method (which includes two reclosers during the three years), was 239,87. If the CBA method were to be used for the same network with the same faults and period, the SAIDI figure would have been 212,41, which means it would have had an improvement of 27,45 or 11,45%. The maximum possible SAIDI savings can be seen in Table 23.

Table 23: Maximum SAIDI traditional vs CBA methodology savings

Year	SAIDI current installation	SAIDI new installation	Maximum SAIDI saved	Maximum SAIDI savings
2016/2017	61,27	28,16	33,11	54,04%
2015/2016	157,44	119,44	38	24,14%
2014/2015	21,16	0,19	20,97	99,10%
Total	239,87	147,79	92,08	38,39%

Table 23 shows that the SAIDI could have been improved if the capturing of the faults were done with more accuracy. Thus, the improvement of 11,45% is taken as the minimum improvement from 2014-2017 (3 year) period. If the capturing of the faults could be more accurate, a possible improvement of 38,39% could have been obtained. The improvement for SAIDI made during the 2014-2017 (3 year) period can range from 11,45% - 38,39%.

When looking at the financial savings the following can be found in Table 24 below:

Table 24: Minimum CENS traditional vs CBA methodology savings

Year	**CENS traditional method**	**CENS CBA method**	**CENS savings**	**Minimum possible CENS savings**
2016/2017	R55 639,69	R55 243,89	R395,80	0,71%
2015/2016	R141 116,98	R135 092,30	R6 024,68	4,27%
2014/2015	R15 337,90	R3 896,34	R11 441,56	74,60%
Total	R212 094,57	R194 232,53	R17 826,04	8,4%

Table 24 above shows the minimum CENS savings and displays the utility's traditional method versus the CBA methodology. The CENS over the three-year period using the traditional methodology was R212 094,57. When using the CBA methodology, the CENS is reduced to R194 232,53, which is a saving of R17 826,04 or 8,4%. However, this figure is only the minimum savings as indicated by Table 24. This is because the feedback given during fault conditions is not always accurate. In Table 25, it reflects the maximum possible CENS savings that could have been obtained using the CBA methodology.

Table 25: Maximum CENS traditional vs CBA methodology savings

Year	CENS traditional method	Maximum possible CENS saved	CENS savings	Maximum possible CENS savings
2016/2017	R55 639,69	R25 810,33	R29 829,36	46,39%
2015/2016	R141 116,98	R31785,78	R109 331,20	22,52%
2014/2015	R15 337,90	R15236,10	R101,80	99,33%
Total	R212 094,57	R77 832,18	R134 262,39	34,34%

As can be seen in Table 25, the new CENS savings could have been as much as R134 262,39 because of the feedback not always reflecting the actual location of the faults. This means that an extra R116 436,35 saving could possibly have been obtained. This means the savings would have been a minimum of R17 826,04 and a possible maximum of R134 262,39. Using the CBA method over a three-year period (2014-2017) for this specific electrical network, the CENS can be reduced to between 8,4%-34,34%.

Network B was selected as it had a larger number of clients, a vast number of different types of tariffs and a longer network length. It was found that the traditional methodology to place reclosers in Network B resulted in ten reclosers to be installed, although only nine has been installed in the network. Using the CBA methodology, it was found that forty-three reclosers could be installed on Network B as can be seen with the CBA calculations coming to 42,98 in Table 26.
The recloser installations with their respective pole numbers, CBA and Ps can be seen in Table 26.

Table 26: Network B recloser pole placements, CBA and Ps results

Number of reclosers	Pole numbers	CBA	Ps (Annual)	Ps (Days)
1	Pole387	2,68	0,37	136
2	Pole266	2,09	0,48	175
3	Pole183	1,71	0,59	214
4	Pole181-47	1,20	0,83	304
5	Pole61	2,88	0,35	127
6	Pole84-86-31	1,90	0,53	192
7	Pole84-85	1,79	0,56	204
8	Pole84-76	1,00	1,00	366
9	Pole84-53-46	2,03	0,49	179
10	Pole84-53-1	1,77	0,56	206
11	Pole84-51-1	1,12	0,90	327
12	Pole84-32-1	1,59	0,63	229
13	Pole84-1	2,29	0,44	160
14	Pole60-16	2,44	0,41	149
15	Pole60-13-1	2,65	0,38	138
16	Pole60-12-1	2,66	0,38	137
17	Pole60-1	1,95	0,51	188
18	Pole15-44	1,06	0,94	345
19	Pole15-18-24	1,50	0,67	243
20	Pole15-18-1	2,82	0,35	129
21	Pole15-15	1,86	0,54	196
22	Pole15-2	1,99	0,50	183
		42,98 (Total)	**0,56 (Average)**	**206 (Average)**

This means that 43 reclosers can be installed for the 2014/2015 year and refund themselves in one year. However, because of the network layout and grading of the recloser protection setting, only 22 reclosers can be installed. These recloser installations will on average have a payback period of 206 days.

Each recloser placement is acceptable to the metholodology, because of it having a CBA that is more than one. The pole numbers indicates the location of each of these reclosers within Network B. According to the methodology and the results obtained the 22 reclosers can be placed at the locations indicated by the pole numbers within Network B. The placement of the reclosers on Network B is demonstrated in Figure 14.

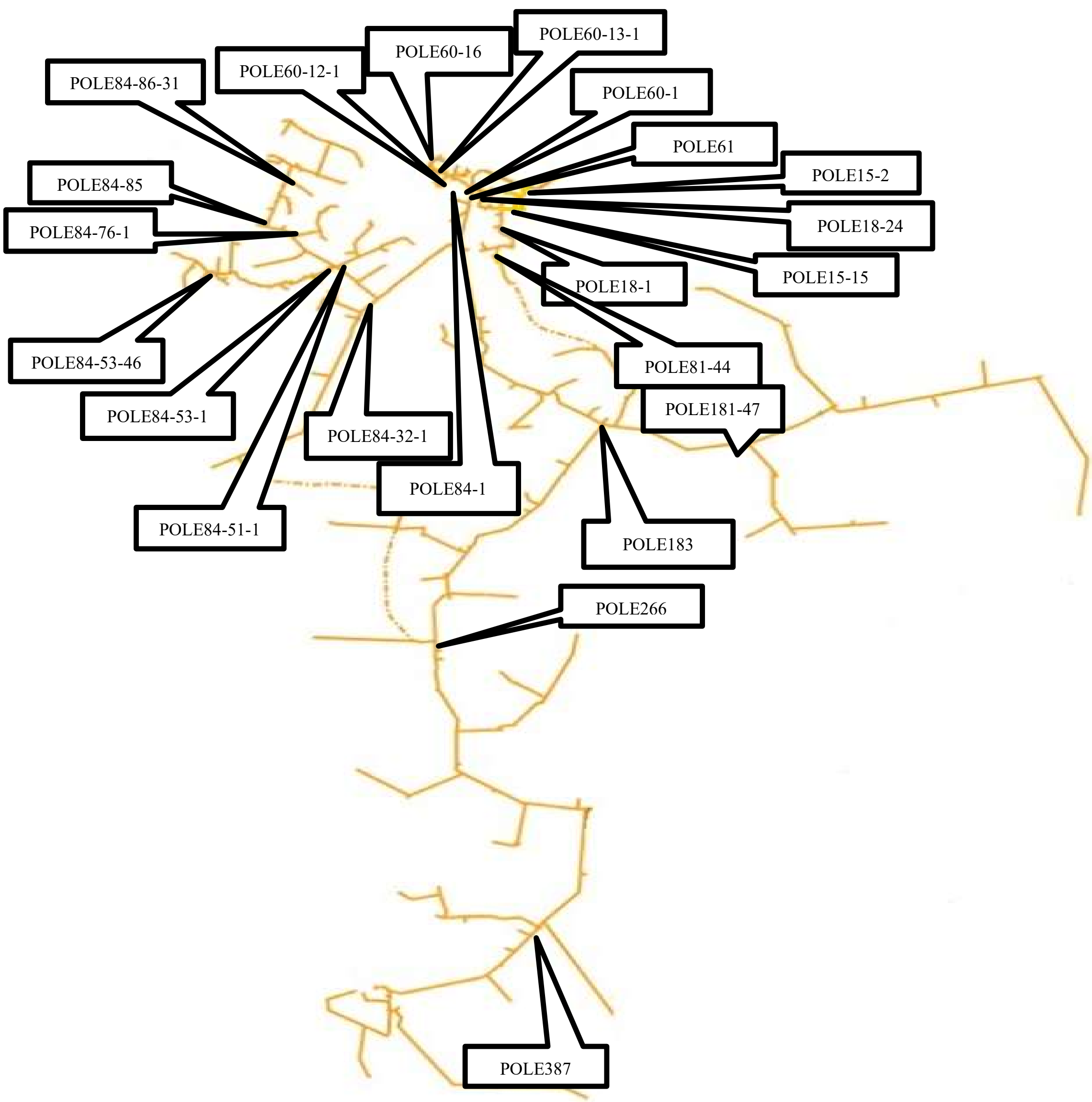

Figure 14: Network B's recloser placements

When comparing SAIDI figures for the traditional and CBA methodology, the results can be seen in Table 27.

Table 27: SAIDI traditional vs CBA methodology comparison

Year	SAIDI current installation	SAIDI new installation	SAIDI saved	SAIDI saved (percentage)
2016/2017	18,93	16,67	2,26	11,93%
2015/2016	12,47	11,77	0,7	5,59%
2014/2015	26,39	15,24	11,15	42,24%
Total	57,79	43,68	14,11	24,42%

The SAIDI performance figure on Network A on the current Eskom recloser installation method (which includes nine reclosers during the 3-year period) was 57,79. If the CBA method was used for the same network with the same faults and period, the SAIDI figure would have been 43,68, which means it would have had a saving of 14,11 with an average of 24,42% per annum. It could be considered that the actual SAIDI figures would have been different if the feedback during fault conditions were captured more accurately. There are cases where the fault location is not found.

A comparison of CENS traditional vs CBA methodology and resultant savings is illustrated below in Table 28.

Table 28: CENS traditional vs CBA methodology comparisons

Year	CENS profit (9 recloser)	CENS profit (22 recloser)	CENS profit savings	CENS profit savings (percentage)
2016/2017	R38 966,25	R31 954,76	R7 011,49	17,99%
2015/2016	R13 087,91	R11 871,79	R1 216,11	9,29%
2014/2015	R26 155,80	R15 205,31	R10 938,64	41,87%
Total	R78 209,96	R59 031,86	R19 166,24	24,51%

The CENS over the 3-year period was R78 209,96 using the traditional methodology. When using the CBA methodology, the CENS is reduced to R59 031,84, which is a saving of R19 166,24 with an average of 24,51% per annum. This takes into consideration that the actual CENS figures would have been different if the feedback during fault conditions were captured more accurately. There are cases where the fault locations are not found. To determine the rankings of the reclosers, the matrix table is used. Below is shown the actual workings of the matrix table used for network B.

4.4 Recloser placement rankings

After the number of reclosers are determined, the placement and sequence of installation will be determined by using a matrix table. The results from the matrix will be displayed in the tables below. It should be noted that all results shown in the tables below are ranked with a minimum value (floor) of zero and a maximum value (ceiling) of five. There are five categories within the matrix table that was established by means of engaging with fellow colleagues within the utility. These 5 categories with their results from Network B are mentioned below.

4.4.1 Communication results

As can be seen below in the figures and tables, there is in most cases more than one communication path. Eskom prefers to try and keep the communications on their own networks, which means choosing the repeaters instead of the MTN networks as it can be managed within the business. If there is no communication, the recloser cannot be installed at that pole as no communication is possible and thus no remote operating of the recloser is possible. Below is an example of the pathloss communication study done for the pole number 60-2.

In this study's findings, the researcher mentioned a recloser to be installed at pole number 60-1, but in the pathloss system, it is pole number 60-2. This is virtually the same area; the poles are less than 100 meters away from each other and sit horizontally on the same ground/altitude level from each other with no obstructions around them. Therefore, it can be trusted that the results from the Pole60-2 will be valid for Pole60-1. From Table 29, Figure 15, Figure 16 and Figure 17, the results of the pathloss study are displayed. It can be seen that if a modem were to be installed at Pole60-2, it will only be able to communicate to the repeater Tower MTN 2. If a radio were to be installed at Pole60-2, it will only be able to communicate to repeater tower Bergdam.

Table 29: Summary of Pathloss system communication results

Site	**Radio Site/MTN**	**Path Length km**	**RX Level dbm**	**Comment**
Pole60-2	MTN 1	5,33	-97,61	No go
	MTN 2	5,72	-78,20	Okay
	Eskom repeater	15,62	-67,46	Okay

As mentioned before, the cut-off signal strength used for the utility is ≤90dbm.

Figure 15 demonstrates a geographical image of the signal strength from the modem at Pole60-2 to the repeater tower at MTN 1.

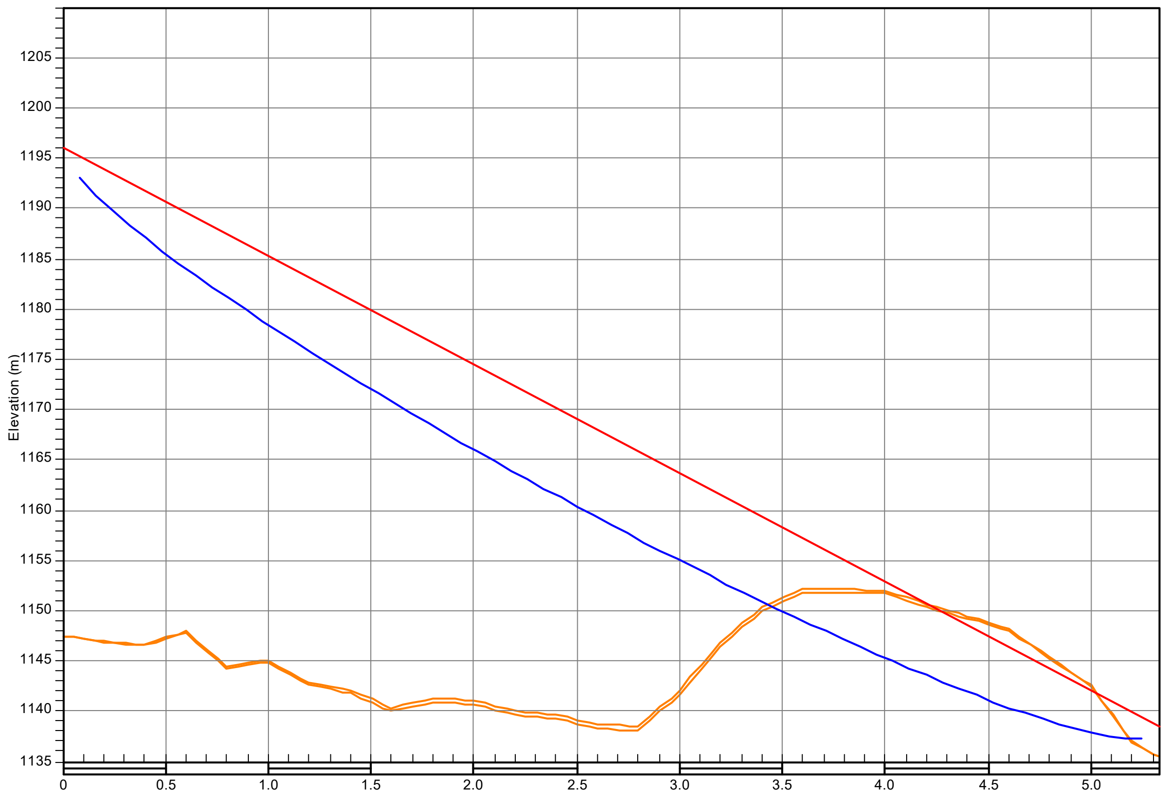

Figure 15: Pole60-2 to MTN 1 signal geographical display

As can be seen in Figure 15 above, the signal goes through a mountainous area that obscured a direct line of sight and thus decreases the signal strength to such a level that communication is not viable. Figure 16 demonstrates a geographical image of the signal strength from the modem at Pole60-2 to the repeater tower at MTN 2.

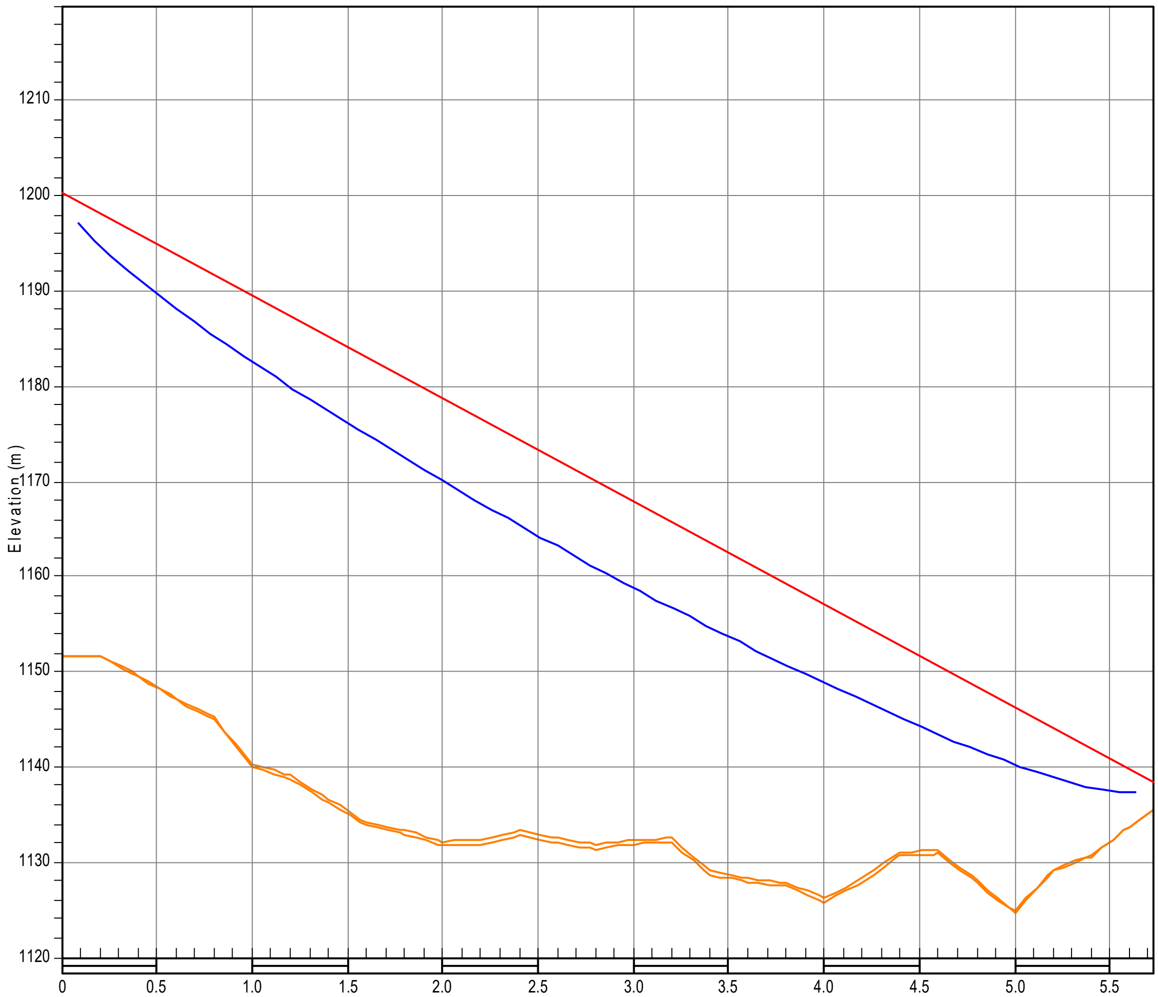

Figure 16: Pole60-2 to MTN 2 signal geographical display

As can be seen in Figure 16 above, the signal is not obscured and a direct line of sight is available and thus the signal strength is strong enough for communication to be viable. Figure 17 demonstrates a geographical image of the signal strength from the radio at Pole60-2 to the repeater tower at Eskom.

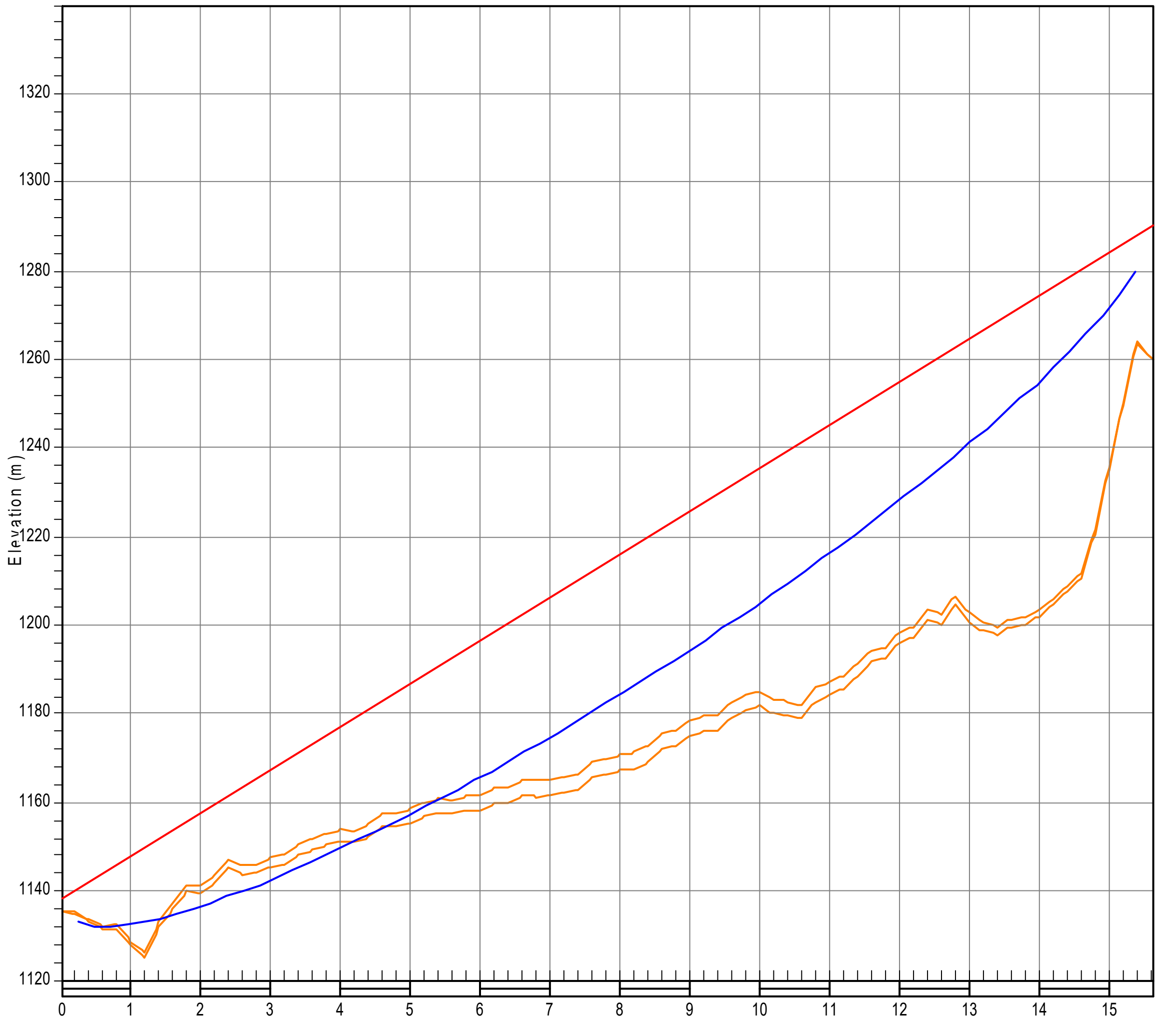

Figure 17: Pole60-2 to Eskom repeater signal geographical display

As can be seen in the figure above, the signal is not obscured and a direct line of sight is available even with a slight drop. The signal strength is strong enough for communication to be viable.

As the figures and tables indicate, there are two viable communication options for the recloser placement at pole number Pole60-2, namely MTN tower 2 and the Eskom repeater.

4.4.2 Number of failures

The number of failures were examined, and the results are displayed in Table 30. It should be noted that in cases where a recloser tripped but the fault was not found, it would be assumed that if there were a recloser to be placed further down the network, it would have tripped instead. It is important to note that the results are weighted from zero to five and are not the actual number of faults per t-off.

Table 30: Failures on t-offs

Ranking	Recloser location	Failures on t-off (2014-2015)	Failures on t-off (2015-2016)	Failures on t-off (2016-2017)	Total
1	Pole387	2	3	2	2,33
2	Pole61	2	2	2	2
3	Pole266	1	2	2	1,67
4	Pole15-2	2	1	2	1,67
5	Pole183	1	1	2	1,33
6	Pole84-32-1	1	1	2	1,33
7	Pole60-1	1	1	2	1,33
8	Pole181-47	1	0	2	1
9	Pole84-53-1	0	1	2	1
10	Pole84-51-1	1	0	2	1
11	Pole84-86-31	0	1	1	0,67
12	Pole84-1	1	0	1	0,67
13	Pole60-12-1	1	1	0	0,67
14	Pole84-76-1	0	1	0	0,33
15	Pole84-53-46	1	0	0	0,33
16	Pole60-16	0	0	1	0,33
17	Pole60-13-1	0	1	0	0,33
18	Pole84-85	0	0	0	0

19	Pole15-44	0	0	0	0
20	Pole15-18-24	0	0	0	0
21	Pole15-18-1	0	0	0	0
22	Pole15-15	0	0	0	0

As can be seen in Table 30, most faults occurred at pole Pole387 and further down towards the end of the network. As mentioned before, the inaccurate feedback from the faults makes it nearly impossible to determine the exact location of faults. According to the data received, no faults occurred in the pole numbers ranked from 18–22.

4.4.3 Sensitive customers

The number of sensitive customers were examined, and the results are shown in Table 31. It should be noted that the number of sensitive customers does not change over the 3-year period. This could be true or false as some customers could have gone off-grid or have been added to the network. The reason the numbers remain the same is because the programme used to analyse the network is a "live" system and has no history of customers. It is important to note that the results are ranked from zero to five and do not indicate the actual number of customers.

Table 31: Sensitive customers on t-offs

Ranking	Recloser location	Sensitive customers
1	Pole61	5
2	Pole15-18-24	5
3	Pole15-18-1	5
4	Pole15-15	5
5	Pole266	4
6	Pole84-1	4
7	Pole15-2	4
8	Pole387	3
9	Pole183	3

10	Pole84-86-31	3
11	Pole84-85	3
12	Pole84-53-46	3
13	Pole84-32-1	3
14	Pole15-44	3
15	Pole181-47	2
16	Pole84-76-1	2
17	Pole84-53-1	2
18	Pole84-51-1	2
19	Pole60-16	1
20	Pole60-13-1	1
21	Pole60-12-1	1
22	Pole60-1	1

The sensitive customers are SPU and LPU customers. They are customers that could possibly have businesses that are dependent on power, so without it they suffer major losses on their side which could possibly be claimed back from the utility. As can be seen in Table 31, the most sensitive customers occur at the pole numbers ranked 1-4. The least number of sensitive customers occur at pole numbers ranked 19-22.

4.4.4 T-off length

The networks t-off lengths were determined and displayed in Table 32 using the Geoviewer system. The lengths of the t-offs are important as finding faults can prove to take longer during fault conditions, which means customers are going to be without electricity for longer periods of times and thereby increasing CENS, SAIDI and SAIFI figures. It is important to note that the results are ranked from zero to five and do not indicate the actual t-off lengths.

Table 32: T-off lengths

Ranking	Recloser location	T-off length
1	Pole387	5
2	Pole266	5
3	Pole183	5
4	Pole181-47	5
5	Pole61	5
6	Pole84-32-1	3
7	Pole84-1	3
8	Pole84-86-31	2
9	Pole84-85	2
10	Pole84-53-46	2
11	Pole84-53-1	2
12	Pole84-51-1	2
13	Pole84-76-1	1
14	Pole60-16	1
15	Pole60-13-1	1
16	Pole60-12-1	1
17	Pole60-1	1
18	Pole15-44	1
19	Pole15-18-24	1
20	Pole15-18-1	1
21	Pole15-15	1
22	Pole15-2	1

As can be seen above, the longest t-offs occur at pole numbers ranked 1-5 and the shortest t-off lengths occur at pole numbers ranked 13-22. This finding or driving to a fault will be quickest at pole numbers ranked from 13 to 22. Finding faults and driving to rectify them will take longest for the pole number ranked one to five.

4.4.5 Lightning density

The results of the Lightning Density on Network B can be seen in Table 33. Lightning on a network will result in more faults occurring on the network. In the 2014-2015 year, there were more lightning strikes over Network B than the other two years. It is important to note that the results are ranked from zero to five and do not indicate the actual number of lightning strikes at the pole numbers.

Table 33: Overall Lightning Density results

Ranking	Recloser location	Lightning density 2014-2015	Lightning density 2015-2016	Lightning density 2016-2017	Average
1	Pole15-15	3	2	2	2,33
2	Pole183	2	2	2	2,00
3	Pole84-53-46	2	2	2	2,00
4	Pole84-51-1	2	2	2	2,00
5	Pole60-16	3	1	2	2,00
6	Pole60-13-1	3	1	2	2,00
7	Pole60-12-1	3	1	2	2,00
8	Pole60-1	3	1	2	2,00
9	Pole15-18-24	3	1	2	2,00
10	Pole15-18-1	3	1	2	2,00
11	Pole15-2	3	1	2	2,00
12	Pole266	2	1	2	1,67
13	Pole181-47	3	1	1	1,67
14	Pole61	3	1	1	1,67
15	Pole387	2	1	1	1,33
16	Pole84-86-31	2	1	1	1,33
17	Pole84-85	2	1	1	1,33
18	Pole84-76-1	2	1	1	1,33

19	Pole84-53-1	2	1	1	1,33
20	Pole84-32-1	3	0	1	1,33
21	Pole84-1	2	1	1	1,33
22	Pole15-44	2	1	1	1,33

As can be seen in Table 33, the most active area of lightning strikes with the most density was seen around Pole15-15 and the lowest lightning strikes density can be seen ranked from 15 to 22, as they are the same.

4.4.6 Matrix overall ranking results

Table 34 includes all the results of the matrix and thus the overall ranking can be determined. This will hopefully result in installing the reclosers in the sequence as the ranking indicates.

Table 34: Matrix recloser ranking results

Ranking	Matrix Pole numbers	Ranking 2016-2017	Ranking 2015-2016	Ranking 2014-2015	Rankings overall
1	Pole387	2,24	2,5	2,68	2,47
2	Pole183	2,53	2,53	2,16	2,41
3	Pole61	2,13	2,13	2,82	2,36
4	Pole266	2,42	2,24	2,27	2,31
5	Pole181-47	2,5	1,72	2,23	2,15
6	Pole15-2	1,88	1,44	1,95	1,76
7	Pole84-32-1	1,75	1,31	1,96	1,67
8	Pole84-86-31	1,89	1,63	1,33	1,62
9	Pole84-1	1,6	1,34	1,89	1,61
10	Pole84-51-1	1,74	1,22	1,48	1,48
11	Pole84-53-1	1,67	1,41	1,22	1,43
12	Pole84-53-46	1,22	1,22	1,85	1,43

13	Pole15-15	1,36	1,36	1,54	1,42
14	Pole15-18-24	1,14	1,22	1,8	1,39
15	Pole84-85	1,41	1,41	1,33	1,38
16	Pole15-18-1	1,36	1,18	1,54	1,36
17	Pole60-1	1,44	1	1,36	1,27
18	Pole60-16	1,51	1,07	1,1	1,23
19	Pole60-13-1	0,92	1,26	1,36	1,18
20	Pole84-76-1	1,22	1,22	1,03	1,16
21	Pole60-12-1	0,92	1	1,36	1,09
22	Pole15-44	0,74	0,74	1,14	0,87

As can be seen in Table 34, the first recloser should be installed at Pole387 and the last recloser should be installed at Pole15-44. This is in a perfect world where the money will be available and where all the installations can occur as soon as possible. There are always criteria to consider, i.e., getting outages approved, material not always arriving as scheduled and having a team or teams available to install and commission them. The teams available to install the reclosers can either be a dead work team or a live work team (outages will not be required).

4.5 Summary

In this chapter, a detailed description of the data analysis and results was given, as retrieved and interpreted from the methodology. Firstly, the tariff comparisons were given and explained. This was followed by the demographic comparisons in the area of interest. Then followed a discussion on the validity of the methodologies that were used to measure the number of reclosers to be placed on a network, the CBA being the methodology utilised for this current study. Furthermore, recloser placement rankings were reviewed, which measure the order in which the reclosers should be placed in accordance with their importance on the specified network.

The next chapter entails a discussion of the results as produced by the CBA. The findings, contributions, implications, limitations, and conclusions of the study are also presented in this chapter.

CHAPTER 5: DISCUSSIONS, IMPLICATIONS AND CONCLUSION

5.1 Introduction

The previous chapter covered the data analysis and the results of the study. The tariff comparisons, Free State Operating Unit customer demographics, case study, and general results were compiled using different methodologies and recloser placement rankings were determined using a matrix table. This chapter will provide a summarised overview of the previous chapters, address the research questions and objectives, and elaborate on final recommendations.

5.2 Reflection of the previous chapters

Chapter 1: The background presented the importance of the reliability program of the distribution business of Eskom, whereby underinvesting will have long term implications. The reliability plan focuses on five interventions, of which adding reclosers to isolate upstream networks from faults is the main theme of this study. Eskom wants to be one of the top five utilities in the world and to do this, Eskom Distribution focused on improving SAIDI. Eskom's standard focuses on two criteria (length of network and number of customers), but should focusing on three more according to this study, namely the type of customers, tariff per customers, and the load of customers. This will determine the financial viability of the recloser installations.

The six research questions that were posed are answered, and the four research objectives are addressed in the following sections of Chapter 5. The brief methodology section incorporated criteria to be used when determining the number of reclosers for a network, namely the network length, number of customers, type of customers, tariff of customers, number of faults, and type of fault. This will be used in the CBA methodology to determine the ROI for each recloser to be installed. Once the number of reclosers and the pole numbers have been determined, a matrix table will be used to rank them according to importance. The benefit of this study will have a positive impact on the reliability and performance of the networks. The delimitations of the study were also covered, including three financial aspects.

Chapter 2: The literature study was done looking at the history of recloser placements. To define the importance of recloser placements in the distribution networks, a performance target model was created. This technique is measured by relevant KPIs namely the SAIDI and SAIFI targets. The CBA methodology was later used to place reclosers on electrical networks and focuses more on the financial aspect than the performance aspect.

Constant improvements are required by utilities for performance enhancement as well as cost saving. Reaching the targets gets more difficult with each passing year. A vast number of recloser placement methodologies are analysed globally and locally. Measurement indicators are used to show if changes are making progress towards achieving goals. These indicators are measured either by performance or financial impact.

NERSA's intention for Eskom distribution is to lower the impact of electricity interruptions by minimising the number of customers interrupted and the duration of interruptions. NERSA uses a MYPD model to determine the electricity price increases towards Eskom. Reliability improvement funds are given to Eskom based on them reaching the targets set by NERSA. Eskom can be incentivised or penalised depending on how well they reach (or fail to reach) their objectives.

Chapter 3: The methodology looks at using CBA to determine the placement of reclosers on distribution networks. There are three expected results that are found using this specific methodology. The numerous data inputs required to achieve these results are also mentioned. Actual networks were used in the Free State region. Financial benefits were determined using CENS calculations. The payback period will be used to determine the ROI.

The research approach assisted in determining if installing a recloser is financially viable, as well as the number of reclosers to be installed and their position on the distribution network. The benefits as well as the costs to install reclosers are discussed. All factors needed to calculate the CBA are discussed in detail. An example of the front page of the calculation tool is shown, displaying all the inputs with all its relevant results.

The placing of reclosers is helped by using a system called Geoviewer which has a geographical display to assist when tracing parts of the network. This is done to determine the number and type of customers on the traced part of the network until a CBA of more than one is found, making the recloser installation financially viable.

The sequence in which reclosers are installed are determined by certain factors. A questionnaire was formed to determine these important factors which included communication, number of failures on t-offs, geographical obstacles, sensitive customers, t-off length, and lightning density area. The weight of each factor was determined based on these results and was used in a matrix table. The delimitation of the study discussed the boundaries and limitations of the study.

Chapter 4: Data analysis and results were discussed in this chapter. Customers are charged depending on their tariffs and for this reason, nine different tariffs were compared and ranked according to their income towards the utility.

The study was done in the Free State and the customers on the networks can be categorised into three categories namely PPU, SPU, and LPU. The number of customers is compared to the loads of the customers. Results show that using a CBA methodology that looks at the customer loads instead of the number of customers makes financial sense.

The case study and general results were done on two networks in the Free State. Network A was simple as it was a short network with only PPU customers. During the 2014-2017 (3 year) period, the utility's recloser placement method showed that only 2 reclosers are to be installed. The CBA methodology showed that a total of eleven reclosers can be installed that will have a ROI of one year, but because of the layout of the network, only 9 could be installed. The improvement for SAIDI can range from 11,45%-38,39%. The CENS was found to be in the range of an 8,4%-34,34% improvement.

Network B was a longer network with multiple different customers in all three categories PPU, SPU, and LPU. During the 2014-2017 (three-year) period, the utility's recloser placement method showed that only ten reclosers are to be installed even though nine were installed. The CBA methodology showed that a total of 43 reclosers can be installed that will have a ROI of one year but because of the layout of the network, only 22 could be installed. The improvement for SAIDI was 24,42%. The CENS was found to have a 24,51% improvement.

After the number of reclosers are determined, the placement and sequence of installation will be determined by using a matrix table. The matrix table consisted of six categories, each with their own weights attached to them. The determined number of reclosers are ranked according to the results obtained from the matrix table. The pole number with the highest overall ranking should be installed first and the lowest ranked recloser last.

5.3 Research Questions

The research questions, as stated in Chapter 1, can now be answered as follows:

The first question was: "What benefits will be achieved by using a cost-benefit analysis (CBA) methodology to place reclosers on distribution networks?"
Firstly, the user will know that they will have a ROI of one year. Secondly, it was found that on two different networks, a SAIDI and CENS improvement was obtained. The SAIDI improvement on Network A ranged between 11,45%-38,39% and on Network B it was 24,42%. The CENS improvement on Network A ranged between 8,4%-34,34% and on Network B it was 24,51%. Lastly, this methodology removes guessing or assuming where the recloser should be installed.

The second question was: "Will placing reclosers using the CBA method improve the technical performance of the distribution network?"

Yes, as can be seen by the results in Chapter 4. The technical performance improvements can be seen in Table 22, 23 and 27, where the studies were based on actual networks in the Free State region.

The third question was: “In what order should reclosers be placed if not all can be placed at once, and which recloser will be the most crucial to install compared to others on the distribution network?”

To determine this, a questionnaire was formed and sent to staff members within the company. From this questionnaire, six categories or factors were determined, each with their own weighting shown in Table 18. The ranking ranges from zero to five and depending on all six categories’ final ranking, the most crucial to least crucial recloser placements are determined.

The fourth question was: “What criteria should be used when placing reclosers on our distribution networks?”

All six factors mentioned in the matrix table as well as the type of customers and their tariffs should be considered when placing reclosers. To determine the CENS, you also need to know what events happened and determine which customers were affected during the fault/outage.

The fifth question was: “Will the placing of reclosers for larger power users have benefits?” Placing reclosers for LPU customers has benefits as explained in Chapter 4.2. The benefit is significant when looking at the financial aspect of the methodology but will also have performance benefits for the network. Figure 12 shows that 80% of the Free State region’s load is based on LPU customers. When it comes to losing your LPU customers, the loss of income is much greater compared to a PPU customer only being 7% of the load in the Free State operating unit. Making a decision based on CENS using a CBA methodology will help determine the most feasible way to set recloser placements.

The sixth question was: “Is SAIDI the correct indicator when it comes to recloser placements?”

Depending on the chosen KPIs and the finances available, using a methodology for placing reclosers that focuses on improving SAIDI is a good method. If the utility is having financial problems, it is recommended to base KPIs on income achieved or income lost. A CBA methodology can assist with this. Basing your recloser placements on using CENS as the KPI is recommended as it improves the CENS and SAIDI at the same time. The better recloser placement method is thus a CBA methodology.

5.4 Objectives

In Chapter 1, the following objectives were stated that are now addressed:

- To use a CBA methodology to place reclosers.

A complete working model was built including all necessary parameters to formulate and determine the viability for placing of reclosers. The CBA methodology was compared with a standard methodology used by Eskom and proved to achieve improved results, financially and with performance by improving the KPI's.

- To do a payback period calculation.

A payback period was used to motivate for the viability of installing a specific recloser at a specific point on the electrical networks. The aim was to prove that placing of a specific recloser will have a payback period or ROI of one year. This was achieved in both networks that was used during the investigation.

- To prove the financial viability of recloser placements.

The financial viability of recloser placements were shown by the results achieved. In both electrical networks that were used in the Free State it was proven that using the CBA methodology not only improved the financial savings but also improved the performance figures. The different types of customers and different types of tariffs were compared to the costs involved to purchase, commission and maintain such equipment. Each recloser was carefully formulated and calculated to prove its viability that will ultimately have a ROI of one year. On Network A the improvement for the CENS made during the three-year period (2014-2017) can be reduced between 8,4% - 34,34%. On Network B the improvement for the CENS made during the three-year period (2014-2017) was 24,51% average per annum.

- To improve technical performance (SAIDI) figures.

The technical performance figures most specifically SAIDI was indeed improved using the CBA methodology. The CBA methodology was indeed justified by a payback period that proved, that by placing reclosers using this methodology will have a payback period of one year. Not only did the methodology prove to pay itself back within one year, but it also improved the most important KPI the SAIDI. On Network A the improvement for SAIDI made during the 2014-2017 (3 year) period can range from 11,45% - 38,39%. On Network B the improvement for SAIDI made during the 2014-2017 (3 year) period was an average of 24,42% per annum.

5.5 Recommendations

Recloser placements is an important factor when improving your network's reliability. The vast number of methods makes it difficult to choose the best for the utility. With this in mind, here are some recommendations for future studies that may affect the outcome of this study:

- Combine the recloser placement methodology with other protection-sensing equipment i.e., fault path indicators or current voltage monitor devices.
- Evaluate more/other recloser placement methodologies.

References

[1] Hadebe Phakamani, “Eskom Factor 2.0,” 2018. Accessed: May 10, 2022. [Online]. Available: https://www.eskom.co.za/wp-content/uploads/2021/02/Eskom_Factor_2.0.pdf

[2] C. C. Michelle Warricke, Ntshafa Mononyane, “MYPD4 Reliability substream.” Eskom, South Africa, pp. 5–6, 2016. Accessed: May 10, 2019. [Online]. Available: http://dx.eskom.co.za/sites/dho/bipmh/_layouts/WordViewer.aspx?id=/sites/dho/bipmh/MYPD4/MYPD4 Reliability substream revkd.docx&DefaultItemOpen=1

[3] T. Kleynhans and D. Gütschow, “Planning standard for distribution network reliability,” vol. 1, no. 240–76613395, pp. 35–36, 92, 2015.

[4] L. Bruno, “History of reclosers,” *Journal of Chemical Information and Modeling*, 2019. https://www.eaton.com/us/en-us/company/about-us/our-heritage/cooper-power-series.html (accessed Jan. 16, 2020).

[5] I. Hristov and A. Chirico, “The role of sustainability key performance indicators (KPIs) in implementing sustainable strategies,” *Sustainability*, vol. 11, no. 20, p. 5742, 2019.

[6] W. Jiang and R. Marggraf, “The origin of cost–benefit analysis: a comparative view of France and the United States,” *Cost Effectiveness and Resource Allocation*, vol. 19, no. 1, p. 74, 2021, doi: 10.1186/s12962-021-00330-3.

[7] H. F. Campbell and R. P. C. Brown, *Cost Benefit Analysis*, Second. Queensland, Auatralia: Routledge, 2015.

[8] Hasan *et al.*, “A Methodology for Planning and Prioritisation of Rural Roads in Bangladesh,” *Sustainability*, vol. 14, no. 4, p. 2337, 2022.

[9] H. Sultan, S. J. Ansari, A. Alam, S. Khan, M. Sarwar, and M. Zaid, “Reliability improvement of a radial distribution system with recloser placement,” in *2019 International Conference on Computing, Power and Communication Technologies (GUCON)*, 2019, pp. 736–741.

[10] M. Z. Ghorbani-Juybari, H. Gholizade-Narm, and Y. Damchi, “Optimal Recloser Placement in Distribution System Considering Maneuver Points, Practical Limitations, and Recloser Malfunction,” *International Transactions on Electrical*

Energy Systems, vol. 2022, 2022.

[11] B. Zhang and P. Crossley, "Reliability improvement using ant colony optimization applied to placement of sectionalizing switches," 2017. doi: 10.1016/j.egypro.2017.12.199.

[12] A. Alam, V. Pant, and B. Das, "Switch and recloser placement in distribution system considering uncertainties in loads, failure rates and repair rates," *Electric Power Systems Research*, 2016, doi: 10.1016/j.epsr.2016.05.012.

[13] F. da R. Leite *et al.*, "Efficient Switch Placement for Power Distribution Systems using Pareto Optimality Multiobjective Function," 2019. doi: 10.1109/isgt-la.2019.8895472.

[14] V. Brilliantova and T. W. Thurner, "Blockchain and the future of energy," *Technology in Society*, vol. 57, pp. 38–45, 2019.

[15] A. Abyad, "The Pareto Principle: Applying the 80/20 Rule to Your Business," *Middle East Journal of*, 2020.

[16] *Electricity supply - Quality of supply Part 2 : Voltage characteristics, compatibility levels, limits and assessment methods*. 2003.

[17] L. E. Weldemariam, V. Cuk, and J. F. G. Cobben, "A proposal on voltage dip regulation for the Dutch MV distribution networks," *International Transactions on Electrical Energy Systems*, vol. 29, no. 2, pp. 1–18, 2019, doi: 10.1002/etep.2734.

[18] "Benefit-Cost Analysis for Transportation Projects," *Minnesota Department of Transportation*, 2020. https://www.dot.state.mn.us/planning/program/benefitcost.html (accessed Feb. 04, 2020).

[19] G. H. Volden, "Assessing public projects' value for money: An empirical study of the usefulness of cost–benefit analyses in decision-making," *International Journal of Project Management*, vol. 37, no. 4, pp. 549–564, 2019.

[20] "NERSA our profile." http://nersa.org.za/ (accessed Feb. 04, 2020).

[21] NERSA (National Energy Regulator of South Africa), "Multi Year Price Determination (MYPD)," pp. 1–24, 2009.

[22] NERSA, "Design of Eskom Distribution Service Incentive Scheme for MYPD2," vol. 2, 2010, [Online]. Available:

http://www.nersa.org.za/Admin/Document/Editor/file/Electricity/Compliance Monitoring/Design of Eskom Distribution Incentive Scheme For MYPD2.pdf

[23] E. Performance, "Eskom Performance for the year-ended 31 March 2017," no. March, 2017.

[24] T. South, A. Grid, and N. C. Rev, "The South African Grid Code The Network Code," no. March, pp. 1–59, 2008.

[25] "research methodology definition." http://www.businessdictionary.com/definition/research-methodology.html (accessed Dec. 28, 2019).

[26] H. Snyder, "Literature review as a research methodology: An overview and guidelines," *J Bus Res*, vol. 104, pp. 333–339, 2019.

[27] D. Conradie and A. Jaykaran, "Maintenance reqiurements for protection systems," 2021.

[28] Dr. Tao Hong, "Load Factor Definition." http://blog.drhongtao.com/2014/11/load-factor-coincidence-factor-diversity-factor-responsibility-factor.html

[29] M. A. Koondhar, "Impact of Load Factor on Distinct Feeders of 132/11 kV Grid Station in Distribution Network," *Sir Syed University Research Journal of Engineering & Technology*, vol. 10, no. 2, 2020.

[30] "Schedule of standard prices for Eskom tariffs 1 April 2017 to 31 March 2018 for non-local authority supplies, and 1 July 2017 to 30 June 2018 for local authority supplies," vol. 0207, no. JUNE, pp. 1–46, 2018.

[31] "Tariffs & Charges Booklet," no. April, p. 27, 2016.

[32] "Power Factor." https://en.wikipedia.org/wiki/Power_factor (accessed Nov. 17, 2020).

[33] A. Power, "Topic Refresher: The Power Triangle," Jan. 2021.

[34] K. Subramanian and S. Tandon, "Power factor correction using capacitors & filters," *International Journal of Engineering & Technology*, vol. 7, p. 234, Apr. 2018, doi: 10.14419/ijet.v7i2.12.11288.

[35] "Grid Electricity - ADMD." https://www.csir.co.za/sites/default/files/Documents/Chapter_012_Vol_II3Gridelectricity.pdf (accessed Mar. 03, 2020).

[36] J. Li, "Optimal sizing of grid-connected photovoltaic battery systems for residential houses in Australia," *Renew Energy*, vol. 136, pp. 1245–1254, 2019.

[37] "GeoViewer." https://cdn2.hubspot.net/hubfs/1740477/LT/LT-Site/Resources/geoviewer_user_manual.pdf (accessed Mar. 06, 2020).

[38] V. Yarosh, S. Oskin, A. Efanov, and V. Shemyakin, "Integration of graphic and semantic information in geographic information systems of distribution electric networks," in *Engineering for Rural Development*, 2020, pp. 1494–1499.

[39] M. Grzanic, M. G. Flammini, and G. Prettico, "Distribution network model platform: A first case study," *Energies (Basel)*, vol. 12, no. 21, p. 4079, 2019.

[40] R. van Zyl, Stuart; Groenewald, Philip; McCurrach, "Protection settings philosophy for MV distribution networks," 2017.

[41] J. A. Krosnick, "Questionnaire design," in *The Palgrave handbook of survey research*, Springer, 2018, pp. 439–455.

[42] "Trio Data Radio." https://isurplus.com.au/manuals/Trio ER450 User Manual.pdf (accessed Mar. 06, 2020).

[43] C. Naidoo, T. Telecoms, S. Coe, and R. Mccurrach, "Telecommunication guideline: Design guide for cellular modem," 2019.

[44] "Pathloss Telecommunication Engineering." http://www.pathloss.com/pwiki/index.php?title=Pathloss_5_-_Basic_program_information (accessed Mar. 03, 2020).

[45] Y. A. Zakaria, E. K. I. Hamad, A. S. Abd Elhamid, and K. M. El-Khatib, "Developed channel propagation models and path loss measurements for wireless communication systems using regression analysis techniques," *Bull Natl Res Cent*, vol. 45, no. 1, pp. 1–11, 2021.

[46] J. Isabona, A. L. Imoize, S. Ojo, C.-C. Lee, and C.-T. Li, "Atmospheric Propagation Modelling for Terrestrial Radio Frequency Communication Links in a Tropical Wet and Dry Savanna Climate," *Information*, vol. 13, no. 3, p. 141, 2022.

[47] "Smallworld." https://en.wikipedia.org/wiki/Smallworld (accessed Mar. 05, 2020).

[48] X. Wei, S. Gao, and T. Huang, "Analysis of electrical network vulnerability using segmented cascading faults graph," *Computers & Electrical Engineering*, vol. 81, p. 106519, 2020.

[49] "FALLS." https://www.vaisala.com/en/products/software/falls (accessed Mar. 05, 2020).

[50] R. P. de S. Barradas, G. V. S. Rocha, J. R. S. Muniz, U. H. Bezerra, M. V. A. Nunes, and J. S. e Silva, "Methodology for analysis of electric distribution network criticality due to direct lightning discharges," *Energies (Basel)*, vol. 13, no. 7, p. 1580, 2020.

[51] Nunes Nelson, "240-96794270 - QA standard - Rev4 new 2019." p. 54, 2019.

Annexure A: Network A CBA calculations

Tee Off	Customers Type	Customer Numbers	Tariff (2016/2017)R/kWh Gross	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT	PPU	3171	1.2459	0.67791	R 1,801.10	0.230255459	R 414.71			11.56
	SPU	25	1.9181	0.67791	R 31.00	0.230255459	R 7.14			
	LPU	2	1.9181	0.67791	R 2.48	0.230255459	R 0.57			
							R 422.42	R 10,138.14	R 3,700,420.10	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						11.56			
	Recloser PBP months						1.04			
Tee Off1	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT50-1	PPU	310	1.2459	0.67791	R 176.08	0.230255459	R 40.54			1.11
	SPU	0	1.9181	0.67791	R 0.00	0.230255459	R 0.00			
	LPU	0								
							R 40.54	R 973.02	R 355,153.77	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.11	1.11		
	Recloser PBP months						10.81	10.81		
Tee Off2	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT51	PPU	291	1.2459	0.67791	R 165.29	0.230255459	R 38.06			1.06
	SPU	2	1.9181	0.67791	R 2.48	0.230255459	R 0.57			
	LPU	0								
							R 38.63	R 927.09	R 338,389.30	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.06	1.06		
	Recloser PBP months						11.35	11.35		
Tee Off3	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT54-3A	PPU	430	1.2459	0.67791	R 244.24	0.230255459	R 56.24			1.54
	SPU	0	1.9181	0.67791	R 0.00	0.230255459	R 0.00			
	LPU	0								
							R 56.24	R 1,349.68	R 492,632.64	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.54	1.54		
	Recloser PBP months						7.79	7.79		
Tee Off4	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT49-1	PPU	485	1.2459	0.67791	R 275.48	0.230255459	R 63.43			1.75
	SPU	2	1.9181	0.67791	R 2.48	0.230255459	R 0.57			
	LPU	0								
							R 64.00	R 1,536.02	R 560,646.82	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.75	1.75		
	Recloser PBP months						6.85	6.85		
Tee Off5	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT49-26A	PPU	340	1.2459	0.67791	R 193.12	0.230255459	R 44.47			1.23
	SPU	2	1.9181	0.67791	R 2.48	0.230255459	R 0.57			
	LPU	0								
							R 45.04	R 1,080.89	R 394,526.51	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.23	1.23		
	Recloser PBP months						9.73	9.73		
Tee Off6	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT49-26-19	PPU	313	1.2459	0.67791	R 177.78	0.230255459	R 40.94			1.14
	SPU	3	1.9181	0.67791	R 3.72	0.230255459	R 0.86			
	LPU	0								
							R 41.79	R 1,003.00	R 366,095.27	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.14	1.14		
	Recloser PBP months						10.49	10.49		
Tee Off7	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT49-32	PPU	322	1.2459	0.67791	R 182.89	0.230255459	R 42.11			1.17
	SPU	2	1.9181	0.67791	R 2.48	0.230255459	R 0.57			
	LPU	0								
							R 42.68	R 1,024.40	R 373,904.67	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.17	1.17		
	Recloser PBP months						10.27	10.27		
Tee Off8	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT49-56	PPU	286	1.2459	0.67791	R 162.45	0.230255459	R 37.40			1.06
	SPU	5	1.9181	0.67791	R 6.20	0.230255459	R 1.43			
	LPU	0								
							R 38.83	R 931.96	R 340,165.54	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.06	1.06		
	Recloser PBP months						11.29	11.29		
Tee Off9	Customers Type	Customer Numbers	**Tariff (2016/2017)R/kWh Gross**	Operating cost R/kWh	Tariff Turnover	C.F. (Actual MVA used per customer)	Actual Turnover R/kWh	Turnover per Day	Turnoff p.a.	CBA
SBT49-101-1	PPU	394	1.2459	0.67791	R 223.79	0.230255459	R 51.53			1.45
	SPU	5	1.9181	0.67791	R 6.20	0.230255459	R 1.43			
	LPU	0								
							R 52.96	R 1,270.95	R 463,896.53	
	Recloser cost R/kWh						R 36.53	R 876.71	R 320,000.00	
	Recloser vs Income ratio						1.45	1.45		
	Recloser PBP months						8.28	8.28		

Annexure B: Network B CBA calculations

Number of reclosers	Pole numbers	Eskom turnover	EskomProfit	Recloser (Equipment plus installation)	CBA	Payback period	Payback period in days
1	Pole387	R1,817,921.64	R804,870.76	R300,000.00	2.682902519	0.37	136
2	Pole266	R1,047,485.22	R626,085.14	R300,000.00	2.08695047	0.48	175
3	Pole183	R852,356.59	R511,574.44	R300,000.00	1.705248143	0.59	214
4	Pole181-47	R550,583.46	R360,467.90	R300,000.00	1.201559654	0.83	304
5	Pole61	R1,442,054.23	R864,102.92	R300,000.00	2.88034307	0.35	127
6	Pole84-86-31	R929,532.72	R569,495.26	R300,000.00	1.898317543	0.53	192
7	Pole84-85	R873,935.47	R536,787.82	R300,000.00	1.789292731	0.56	204
8	Pole84-76-1	R485,823.50	R299,367.02	R300,000.00	0.997890068	1.00	366
9	Pole84-53-46	R1,083,245.41	R610,395.01	R300,000.00	2.034650022	0.49	179
10	Pole84-53-1	R906,792.35	R531,563.51	R300,000.00	1.771878372	0.56	206
11	Pole84-51-1	R694,917.39	R335,061.71	R300,000.00	1.116872383	0.90	327
12	Pole84-32-1	R780,650.16	R477,974.15	R300,000.00	1.593247172	0.63	229
13	Pole84-1	R1,196,112.64	R686,474.71	R300,000.00	2.288249033	0.44	160
14	Pole60-16	R2,030,226.73	R732,911.90	R300,000.00	2.44303965	0.41	149
15	Pole60-13-1	R2,235,844.25	R793,929.17	R300,000.00	2.646430581	0.38	138
16	Pole60-12-1	R2,310,754.18	R797,063.15	R300,000.00	2.656877155	0.38	137
17	Pole60-1	R1,709,416.47	R583,986.99	R300,000.00	1.946623299	0.51	188
18	Pole15-44	R523,489.24	R317,481.05	R300,000.00	1.058270182	0.94	345
19	Pole15-18-24	R944,469.62	R450,301.90	R300,000.00	1.501006335	0.67	243
20	Pole15-18-1	R1,943,786.74	R846,265.09	R300,000.00	2.820883638	0.35	129
21	Pole15-15	R1,300,043.50	R558,245.34	R300,000.00	1.860817799	0.54	196
22	Pole15-2	R1,339,020.34	R598,310.41	R300,000.00	1.994368038	0.50	183
					42.97571786	0.56	206

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole395-4 22kV/230V Trfr	16	1	0	0	1	R1,817,921.64	R804,870.76
Pole389-5 22kV/400V Trfr	25	0	1	0	1		
Pole435 22kV/400V Trfr	50	0	1	0	1	**Pole 387 - end**	
Pole427-2 22kV/400V Trfr	300	6	1	1	8		
Pole476-1 22kV/230V Trfr	16	0	1	0	1		
Pole405-10 22kV/230V Trfr	16	0	1	0	1		
Pole432-12 22kV/400V Trfr	100	101	1	0	102		
Pole430-1 22kV/400V Trfr	100	63	4	0	67		
Pole427-1-6 22kV/400V Trfr	100	93	0	0	93		
Pole437-26-1 22kV/230V Trfr	16	1	0	0	1		
Pole432-18 22kV/400V Trfr	25	0	1	0	1		
Pole437-8 22kV/230V Trfr	16	1	0	0	1		
Total		266	11	1	278		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole312-30 22kV/400V Trfr	50	0	1	0	1	R1,047,485.22	R626,085.14
Pole297-25-9-2 22kV/400V Trfr	25	0	1	0	1		
Pole273-2 22kV/400V Trfr	25	0	1	0	1	**Pole 266 - Pole 387**	
Pole385-23-1 22kV/230V Trfr	16	1	0	0	1		
Pole281-2 22kV/400V Trfr	50	0	0	1	1		
Pole342-5 22kV/400V Trfr	50	0	1	0	1		
Pole385-11 22kV/400V Trfr	25	1	0	0	1		
Pole385-19-2 22kV/230V Trfr	16	1	0	0	1		
Pole268-3 22kV/400V Trfr	25	0	1	0	1		
Pole382-39 22kV/400V Trfr	200	0	0	1	1		
Pole385-4 22kV/400V Trfr	50	0	1	0	1		
Pole297-10-2 22kV/400V Trfr	25	0	1	0	1		
Pole297-16 22kV/400V Trfr	25	0	1	0	1		
Pole297-25-17 22kV/400V Trfr	50	0	0	1	1		
Pole312-14-1 22kV/400V Trfr	100	0	1	0	1		
Pole297-48 22kV/400V Trfr	25	0	1	0	1		
Pole329-24 22kV/400V Trfr	200	0	0	1	1		
Pole292 22kV/400V Trfr	25	0	1	0	1		
Pole308-1 22kV/400V Trfr	25	0	1	0	1		
Pole329-15-1 22kV/400V Trfr	50	0	1	0	1		
Pole267-30 22kV/400V Trfr	100	0	1	0	1		
Total		3	14	4	21		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole241-1 22kV/400V Trfr	100	0	1	0	1	R852,356.59	R511,574.44
Pole232-24-5 22kV/230V Trfr	10	0	1	0	1		
Pole232-3-1 22kV/400V Trfr	100	0	1	0	1	**Pole 183 - Pole 266**	
Pole213-3 22kV/400V Trfr	25	0	1	0	1		
Pole185-3 22kV/400V Trfr	100	0	0	1	1		
Pole232-24-15 22kV/230V Trfr	16	0	1	0	1		
Pole197-5 22kV/400V Trfr	200	0	0	1	1		
Pole232-41 22kV/400V Trfr	100	0	1	0	1		
Pole230-1 22kV/230V Trfr	10	0	1	0	1		
Pole241-6 22kV/400V Trfr	100	0	1	0	1		
Pole208-7 22kV/400V Trfr	100	0	0	1	1		
Pole249-18 22kV/460V Trfr	32	0	1	0	1		
Total		0	9	3	12		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole181-115-8 22kV/400V Trfr	100	0	1	0	1	R550,583.46	R360,467.90
Pole181-103-5 22kV/400V Trfr	25	0	1	0	1		
Pole181-156-1 22kV/400V Trfr	50	0	1	0	1	**Pole 181/47 - end**	
Pole181-77-58 22kV/400V Trfr	25	0	1	0	1		
Pole181-77-31-2 22kV/400V Trfr	25	0	1	0	1		
Pole181-47-14-3 22kV/400V Trfr	100	0	1	0	1		
Pole181-127-2 22kV/400V Trfr	50	0	1	0	1		
Pole181-47-50-2 22kV/400V Trfr	25	0	1	0	1		
Pole181-47-35-3 22kV/400V Trfr	25	0	1	0	1		
Pole181-77-1-1 22kV/400V Trfr	50	0	1	0	1		
Total		0	10	0	10		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole127-2 22kV/400V Trfr	100	0	1	0	1	R1,442,054.23	R864,102.92
Pole159-11-7 22kV/400V Trfr	50	0	1	0	1		
Pole181-4-40 22kV/400V Trfr	50	0	1	0	1	**Pole 61 - Pole181/47**	
Pole161-1 22kV/400V Trfr	100	0	0	1	1		
Pole137-21 22kV/400V Trfr	100	0	0	1	1		
Pole180-3 22kV/400V Trfr	50	0	1	0	1		
Pole159-15 22kV/400V Trfr	25	0	1	0	1		
Pole181-4-50 22kV/400V Trfr	100	0	1	0	1		
Pole137-18 22kV/400V Trfr	100	0	0	1	1		
Pole181-4-5 22kV/230V Trfr	15	0	1	0	1		
Pole176-3 22kV/400V Trfr	100	0	0	1	1		
Pole124-3 22kV/400V Trfr	25	0	1	0	1		
Pole119-2 22kV/400V Trfr	50	0	1	0	1		
Pole164 22kV/400V Trfr	25	0	1	0	1		
Pole88-3 22kV/400V Trfr	25	0	1	0	1		
Pole176-6 22kV/400V Trfr	100	0	0	1	1		
Pole181-4-12-2 22kV/400V Trfr	25	0	1	0	1		
Pole67-6 22kV/400V Trfr	50	0	1	0	1		
Pole70-7 22kV/400V Trfr	100	0	1	0	1		
Pole80-1 22kV/400V Trfr	25	0	1	0	1		
Total		0	15	5	20		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole84-86-66-6 22kV/400V Trfr	50	0	1	0	1	R929,532.72	R569,495.26
Pole84-86-60 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-31-5 22kV/400V Trfr	50	0	1	0	1	**Pole 84/86/31 - end**	
Pole84-86-38-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-31-8 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-32-3 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-38-7-1 22kV/400V Trfr	100	0	1	0	1		
Pole84-86-52-3-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-64-2 22kV/400V Trfr	100	0	1	0	1		
Pole84-86-38-10-2 22kV/400V Trfr	100	0	1	0	1		
Pole84-86-56 22kV/230V Trfr	15	0	1	0	1		
Pole84-86-71 22kV/230V Trfr	16	0	1	0	1		
Pole84-86-.50 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-52-16 22kV/400V Trfr	50	0	1	0	1		
Total		0	14	0	14		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole84-86-15-8-2 22kV/400V Trfr	50	0	1	0	1	R873,935.47	R536,787.82
Pole84-86-16-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-11 22kV/400V Trfr	25	0	1	0	1	**Pole 84/85 - Pole84/86/31**	
Pole84-86-15-10 22kV/400V Trfr	25	0	1	0	1		
Pole84-89-1 22kV/400V Trfr	25	0	1	0	1		
Pole84-86-25-1 22kV/400V Trfr	25	0	1	0	1		
Pole84-86-24-12 22kV/400V Trfr	100	0	1	0	1		
Pole84-86-12-1 22kV/400V Trfr	100	0	1	0	1		
Pole84-86-18-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-24-7 22kV/400V Trfr	100	0	2	0	2		
Pole84-86-20-2 22kV/400V Trfr	50	0	1	0	1		
Pole84-86-19-1 22kV/230V Trfr	16	0	1	0	1		
Pole84-86-5 22kV/400V Trfr	100	0	1	0	1		
Pole84-86-15-5-1 22kV/400V Trfr	25	0	1	0	1		
Total		0	15	0	15		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole84-76-13 22kV/400V Trfr	50	0	1	0	1	R485,823.50	R299,367.02
Pole84-76-9-1 22kV/230V Trfr	10	0	1	0	1		
Pole84-76-18-1 22kV/400V Trfr	50	0	1	0	1	**Pole 84/76/1 - end**	
Pole84-76-21-1 22kV/400V Trfr	50	0	2	0	2		
Pole84-76-9-3T-2 22kV/400V Trfr	50	0	1	0	1		
Pole84-76-8-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-76-5 22kV/400V Trfr	25	0	1	0	1		
Pole84-76-9-3-3 22kV/400V Trfr	50	0	1	0	1		
Total		0	9	0	9		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole84-53-55-4 22kV/230V Trfr	16	1	0	0	1	R1,083,245.41	R610,395.01
Pole84-53-48-8 22kV/400V Trfr	100	0	2	0	2		
Pole84-53-58-1 22kV/400V Trfr	100	0	1	0	1	**Pole 84/53/46 - end**	
Pole84-53-64 22kV/400V Trfr	100	0	0	1	1		
Pole84-53-50-5 22kV/400V Trfr	50	0	1	0	1		
Pole84-53-66 22kV/400V Trfr	100	0	1	0	1		
Pole84-53-61-11 22kV/230V Trfr	16	1	1	0	2		
Pole84-53-53-1 22kV/400V Trfr	100	0	0	1	1		
Pole84-53-71 22kV/400V Trfr	200	0	0	1	1		
Pole84-53-61-3-2 22kV/230V Trfr	16	1	0	0	1		
Pole84-53-59-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-53-50-2 22kV/400V Trfr	50	0	1	0	1		
Total		3	8	3	14		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole84-53-36-2 22kV/400V Trfr	50	0	1	0	1	R906,792.35	R531,563.51
Pole84-53-27-2 22kV/400V Trfr	25	0	1	0	1		
Pole84-53-44-2 22kV/400V Trfr	50	0	1	0	1	**Pole 84/53/1 - Pole84/53/46**	
Pole84-53-19-1 22kV/400V Trfr	200	0	1	0	1		
Pole84-53-23-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-53-22-4 22kV/400V Trfr	50	0	1	0	1		
Pole84-53-9-1 22kV/400V Trfr	100	0	1	0	1		
Pole84-53-45-1 22kV/230V Trfr	16	1	0	0	1		
Pole84-53-15-2 22kV/400V Trfr	50	0	1	0	1		
Pole84-53-43 22kV/400V Trfr	100	0	1	0	1		
Pole84-53-39 22kV/230V Trfr	16	1	0	0	1		
Pole84-53-44-15 22kV/400V Trfr	100	0	1	0	1		
Total		2	10	0	12		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole84-51-27 22kV/400V Trfr	50	0	0	1	1	R694,917.39	R335,061.71
Pole84-51-8-14-2 22kV/230V Trfr	16	1	0	0	1		
Pole84-51-8-5-1 22kV/400V Trfr	100	0	1	0	1	**Pole 84/51/1 - end**	
Pole84-51-8-15 22kV/400V Trfr	50	0	1	0	1		
Pole84-51-8-2-5 22kV/400V Trfr	100	0	0	1	1		
Pole84-51-14-5 22kV/400V Trfr	100	0	0	1	1		
Pole84-51-15-5 11kV/400V Trfr	500	0	0	1	1		
Total		2	2	4	7		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole84-32-8-21 22kV/400V Trfr	200	0	0	1	1	R780,650.16	R477,974.15
Pole84-32-8-8-3-1 22kV/400V Trfr	500	0	0	1	1		
Pole84-32-8-8-2 22kV/400V Trfr	25	0	1	0	1	**Pole 84/32/1 - end**	
Pole84-32-15 22kV/400V Trfr	100	0	1	0	1		
Pole84-32-12-1 22kV/400V Trfr	100	0	0	1	1		
Pole84-32-30-5 22kV/400V Trfr	50	0	1	0	1		
Pole84-32-49 22kV/230V Trfr	16	0	1	0	1		
Pole84-32-75 22kV/230V Trfr	15	0	1	0	1		
Pole84-32-12-T1 22kV/400V Trfr	100	0	1	0	1		
Pole84-32-13 22kV/230V Trfr	16	1	0	0	1		
Pole84-32-8-19T1 22kV/400V Trfr	50	0	1	0	1		
Pole84-32-8-8-7 22kV/230V Trfr	16	1	0	0	1		
Pole84-32-8-7-1 22kV/400V Trfr	100	0	1	0	1		
Pole84-32-8-11 22kV/400V Trfr	100	0	1	0	1		
Total		2	9	3	14		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole84-67 22kV/230V Trfr	16	1	1	0	2	R1,196,112.64	R686,474.71
Pole84-66-12-1 22kV/400V Trfr	25	0	1	0	1		
Pole84-66-16 22kV/400V Trfr	100	0	1	0	1	**Pole 84/1 - Pole 84/85**	
Pole84-14-1 22kV/400V Trfr	50	0	0	1	1		
Pole84-43-2-2 22kV/400V Trfr	100	0	1	0	1		
Pole84-66-5-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-85 22kV/230V Trfr	16	1	0	0	1		
Pole84-43-3-1 22kV/400V Trfr	50	0	0	1	1		
Pole84-80-2 22kV/400V Trfr	50	0	1	0	1		
Pole84-43-13 22kV/400V Trfr	100	0	1	0	1		
Pole84-43-11-1 22kV/400V Trfr	50	0	1	0	1		
Pole84-9-1 22kV/400V Trfr	50	0	0	1	1		
Pole84-29-1 22kV/400V Trfr	100	0	0	1	1		
Pole84-16 22kV/400V Trfr	200	0	0	1	1		
Pole84-43-4-1 22kV/400V Trfr	100	0	1	0	1		
Pole84-84-1 22kV/230V Trfr	16	0	1	0	1		
Total		2	10	5	17		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole60-16-1 22kV/400V Trfr	100	63	0	0	63	R2,030,226.73	R732,911.90
Pole60-25 22kV/400V Trfr	100	52	0	0	52		
Pole60-16-3 22kV/400V Trfr	100	75	2	0	77	**Pole 60/16 - end**	
Pole60-25-2 22kV/400V Trfr	100	94	0	0	94		
Pole60-27 22kV/400V Trfr	100	66	0	0	66		
Total		350	2	0	352		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole60-13-3 22kV/400V Trfr	100	59	1	0	60	R2,235,844.25	R793,929.17
Pole60-15-4 22kV/400V Trfr	100	85	0	0	85		
Pole60-13-1 22kV/400V Trfr	100	73	0	0	73	**Pole 60/13/1 - Pole 60/16**	
Pole60-13-2 22kV/400V Trfr	100	53	0	0	53		
Pole60-15-11 22kV/400V Trfr	100	109	0	0	109		
Total		379	1	0	380		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole60-12-5 22kV/400V Trfr	200	127	0	1	128	R2,310,754.18	R797,063.15
Pole60-12-1 22kV/400V Trfr	100	77	0	0	77		
Pole60-12-6 22kV/400V Trfr	50	59	0	0	59	**Pole 60/12/1 - end**	
Pole60-12-3 22kV/400V Trfr	100	84	0	0	84		
Pole60-12-6-8 22kV/400V Trfr	50	40	0	0	40		
Pole60-12-6-6-2 22kV/400V Trfr	50	67	0	0	67		
Total		454	0	1	455		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole60-9 22kV/400V Trfr	200	0	0	1	1	R1,709,416.47	R583,986.99
Pole60-8-3 22kV/230V Trfr	16	0	1	0	1		
Pole60-10-3-14 22kV/400V Trfr	100	104	0	0	104	**Pole 60/1 - Pole 60/16**	
Pole60-10-3-7-2 22kV/400V Trfr	100	114	0	0	114		
Pole60-10-10 22kV/400V Trfr	100	101	0	0	101		
Pole60-10-3-5-2 22kV/400V Trfr	100	79	0	0	79		
Pole60-10-4 22kV/400V Trfr	100	35	1	0	36		
Pole60-10-8 22kV/400V Trfr	50	1	1	0	2		
Total		434	3	1	438		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole15-61 22kV/400V Trfr	50	0	1	0	1	R523,489.24	R317,481.05
Pole15-57 22kV/400V Trfr	50	0	1	0	1		
Pole15-59 22kV/230V Trfr	10	0	1	0	1	**Pole 15/44 - end**	
Pole15-55 22kV/230V Trfr	15	0	1	0	1		
Pole15-45-4-2 11kV/400V Trfr	100	0	0	1	1		
Pole15-47 22kV/400V Trfr	25	0	1	0	1		
Pole15-53 22kV/400V Trfr	50	0	1	0	1		
Pole15-49-3 22kV/400V Trfr	100	0	1	0	1		
Pole15-45-6 22kV/230V Trfr	16	0	1	0	1		
Pole15-45-1 22kV/230V Trfr	10	0	1	0	1		
Pole15-50 22kV/230V Trfr	16	0	1	0	1		
Pole15-45-7 22kV/400V Trfr	50	0	1	0	1		
Total		0	11	1	12		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole15-18-25-1 22kV/230V Trfr	10	1	0	0	1	R944,469.62	R450,301.90
Pole15-18-25-18 22kV/400V Trfr	200	1	1	0	2		
Pole15-18-25-6T-2 22kV/400V Trfr	315	20	19	1	40	**Pole 15/18/24 - end**	
Pole15-18-25-6-4 22kV/400V Trfr	100	1	3	0	4		
Total		23	23	1	47		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole15-18-7 22kV/400V Trfr	200	34	23	0	57	R1,943,786.74	R846,265.09
Pole15-18-4 22kV/400V Trfr	200	19	15	0	34		
Pole15-18-21 22kV/400V Trfr	50	13	9	0	22	**Pole 15/18/1 - Pole 15/24**	
Pole15-18-17 22kV/400V Trfr	100	1	0	0	1		
Pole15-18-23 22kV/400V Trfr	50	9	5	0	14		
Pole15-18-12-3 22kV/400V Trfr	25	0	1	0	1		
Pole15-18-19-6 22kV/400V Trfr	100	13	6	0	19		
Total		89	59	0	148		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole15-20-1 22kV/400V Trfr	100	5	8	0	13	R1,300,043.50	R558,245.34
Pole15-28-2 22kV/400V Trfr	50	0	3	0	3		
Pole15-16-8 22kV/400V Trfr	200	0	2	0	2	**Pole 15/15 - Pole 15/16/11 - Pole 41/2**	
Pole15-16-11 22kV/400V Trfr	200	0	3	0	3		
Pole15-16-6 22kV/400V Trfr	100	0	1	0	1		
Pole15-31 22kV/400V Trfr	50	0	1	0	1		
Pole15-28-1 22kV/230V Trfr	16	1	1	0	2		
Pole15-16-3 22kV/400V Trfr	200	18	10	0	28		
Pole15-26 22kV/230V Trfr	16	0	1	0	1		
Pole15-41-2 22kV/400V Trfr	500	0	0	1	1		
Total		24	30	1	55		

Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	Eskom Turnover	Eskom Profit
Pole15-6-2 22kV/400V Trfr	315	0	0	1	1	R1,339,020.34	R598,310.41
Pole15-6-4 22kV/400V Trfr	200	10	5	0	15		
Pole15-13-1 22kV/400V Trfr	50	0	1	0	1	**Pole 15/2 - Pole 15/16**	
Pole15-6-3-1 22kV/400V Trfr	500	9	10	1	20		
Pole15-11-1 22kV/400V Trfr	200	0	0	1	1		
Total		19	16	3	38		

Annexure C: Network B Matrix calculations

2014-2015

Ranking	Recloser location	Network Voltage	Communication	Number of failures on T-off 2014-2015	Geographical obstacles	Sensitive customers	T-off length	Lightning density area	Total weight
	Weights example		Yes continue, No stop	15	20	15	20	30	100
1	Pole387	22kV	Yes	5	1	12	25.27	19.77	63.05
2	Pole266	22kV	Yes	4	1	22	45.06	17.54	89.60
3	Pole183	22kV	Yes	2	1	15	22.01	19.49	59.50
4	Pole181-47	22kV	Yes	3	2	10	33.64	31.96	80.59
5	Pole61	22kV	Yes	7	1	25	30.61	28.49	92.10
6	Pole84-86-31	22kV	Yes	0	2	14	9.25	23.03	48.28
7	Pole84-85	22kV	Yes	0	2	15	5.99	23.91	46.90
8	Pole84-76-1	22kV	Yes	0	2	9	3.09	12.60	26.69
9	Pole84-53-46	22kV	Yes	4	1	14	5.61	18.13	42.74
10	Pole84-53-1	22kV	Yes	0	1	10	6.66	18.63	36.29
11	Pole84-51-1	22kV	Yes	1	1	10	5.31	16.36	33.67
12	Pole84-32-1	22kV	Yes	2	1	15	13.23	25.12	56.36
13	Pole84-1	22kV	Yes	1	1	20	11.33	18.80	52.13
14	Pole60-16	22kV	Yes	0	1	2	1.39	24.16	28.55
15	Pole60-13-1	22kV	Yes	0	1	1	1.69	24.16	27.85
16	Pole60-12-1	22kV	Yes	1	1	2	0.97	24.16	29.13
17	Pole60-1	22kV	Yes	2	1	5	3.78	24.16	35.94
18	Pole15-44	22kV	Yes	0	1	13	2.66	16.36	33.02
19	Pole15-18-24	22kV	Yes	0	1	25	1.37	30.00	57.37
20	Pole15-18-1	22kV	Yes	0	1	59	1.83	30.00	91.83
21	Pole15-15	22kV	Yes	0	1	32	3.48	30.00	66.48
22	Pole15-2	22kV	Yes	6	1	22	1.62	30.00	60.62

Recloser location	Failure of t-off	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	7		2				2	Failures Column	
Pole266	7	1					1	Number of faults/events	Weighting
Pole183	5	1					1	0 - 4	1
Pole181-47	6	1					1	5 - 8	2
Pole61	6		2				2	9 - 12	3
Pole84-86-31	2						0	13 - 16	4
Pole84-85	0						0	>16	5
Pole84-76-1	0						0		
Pole84-53-46	0	1					1		
Pole84-53-1	6						0		
Pole84-51-1	5	1					1		
Pole84-32-1	5	1					1		
Pole84-1	4	1					1		
Pole60-16	2						0		
Pole60-13-1	0						0		
Pole60-12-1	0	1					1		
Pole60-1	5	1					1		
Pole15-44	0						0		
Pole15-18-24	0						0		
Pole15-18-1	0						0		
Pole15-15	0						0		
Pole15-2	5		2				2		

Recloser location	Sensitive Customers	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	15			3			3	Sensitive customers	
Pole266	12				4		4	Number of customers	Weighting
Pole183	22			3			3	0 - 5	1
Pole181-47	15		2				2	6 - 11	2
Pole61	10					5	5	12 - 17	3
Pole84-86-31	25			3			3	18 - 23	4
Pole84-85	14			3			3	>23	5
Pole84-76-1	15		2				2		
Pole84-53-46	9			3			3		
Pole84-53-1	14		2				2		
Pole84-51-1	10		2				2		
Pole84-32-1	10			3			3		
Pole84-1	15				4		4		
Pole60-16	20	1					1		
Pole60-13-1	2	1					1		
Pole60-12-1	1	1					1		
Pole60-1	2	1					1		
Pole15-44	5			3			3		
Pole15-18-24	13					5	5		
Pole15-18-1	25					5	5		
Pole15-15	59					5	5		
Pole15-2	32				4		4		

Recloser location	T-off length	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	25.274					5	5	Sensitive customers Column	
Pole266	45.055					5	5	Number of customers	Weighting
Pole183	22.011					5	5	0 - 5	1
Pole181-47	33.638					5	5	5 < length < 10	2
Pole61	30.613					5	5	10 < length < 15	3
Pole84-86-31	9.254		2				2	15 < length < 20	4
Pole84-85	5.992		2				2	>20	5
Pole84-76-1	3.088	1					1		
Pole84-53-46	5.614		2				2		
Pole84-53-1	6.66		2				2		
Pole84-51-1	5.305		2				2		
Pole84-32-1	13.231			3			3		
Pole84-1	11.329			3			3		
Pole60-16	1.385	1					1		
Pole60-13-1	1.685	1					1		
Pole60-12-1	0.974	1					1		
Pole60-1	3.777	1					1		
Pole15-44	2.66	1					1		
Pole15-18-24	1.374	1					1		
Pole15-18-1	1.83	1					1		
Pole15-15	3.477	1					1		
Pole15-2	1.618	1					1		

Recloser location	Lightning strikes	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	9.6542		2				2	Lightning strikes	
Pole266	12.84722154		2				2	Number of strikes	Weighting
Pole183	15.58591		2				2	0 - 12	1
Pole181-47	7.212151818			3			3	12 < strikes < 24	2
Pole61	9.15949375			3			3	24 < strikes < 36	3
Pole84-86-31	10.8204		2				2	36 < strikes < 48	4
Pole84-85	9.06		2				2	>48	5
Pole84-76-1	11.0759		2				2		
Pole84-53-46	12.3295		2				2		
Pole84-53-1	7.55265		2				2		
Pole84-51-1	20		2				2		
Pole84-32-1	4.155755			3			3		
Pole84-1	11.3283		2				2		
Pole60-16	20.135			3			3		
Pole60-13-1	20.135			3			3		
Pole60-12-1	20.135			3			3		
Pole60-1	20.135			3			3		
Pole15-44	9.81844		2				2		
Pole15-18-24	20.135			3			3		
Pole15-18-1	20.135			3			3		
Pole15-15	15.3537			3			3		
Pole15-2	20.135			3			3		

Pole number	Recloser location	Network Voltage	Communication	Number of failures on T-off 2014-2015	Geographical obstacles	Sensitive customers	T-off length	Lightning density area	Total weight
	Weighting		Yes continue, No stop	26	26	11	19	18	100
1	Pole61	22kV	Yes	2	1	5	5	3	**2.82**
2	Pole387	22kV	Yes	2	2	3	5	2	**2.68**
3	Pole266	22kV	Yes	1	1	4	5	2	**2.27**
4	Pole181-47	22kV	Yes	1	1	2	5	3	**2.23**
5	Pole183	22kV	Yes	1	1	3	5	2	**2.16**
6	Pole84-32-1	22kV	Yes	1	1	3	3	3	**1.96**
8	Pole15-2	22kV	Yes	2	1	4	1	3	**1.95**
9	Pole84-1	22kV	Yes	1	1	4	3	2	**1.89**
12	Pole84-53-46	22kV	Yes	1	2	3	2	2	**1.85**
7	Pole15-18-24	22kV	Yes	0	2	5	1	3	**1.8**
10	Pole15-18-1	22kV	Yes	0	1	5	1	3	**1.54**
11	Pole15-15	22kV	Yes	0	1	5	1	3	**1.54**
15	Pole84-51-1	22kV	Yes	1	1	2	2	2	**1.48**
16	Pole60-13-1	22kV	Yes	0	2	1	1	3	**1.36**
17	Pole60-12-1	22kV	Yes	1	1	1	1	3	**1.36**
18	Pole60-1	22kV	Yes	1	1	1	1	3	**1.36**
13	Pole84-86-31	22kV	Yes	0	1	3	2	2	**1.33**
14	Pole84-85	22kV	Yes	0	1	3	2	2	**1.33**
19	Pole84-53-1	22kV	Yes	0	1	2	2	2	**1.22**
21	Pole15-44	22kV	Yes	0	1	3	1	2	**1.14**
20	Pole60-16	22kV	Yes	0	1	1	1	3	**1.1**
22	Pole84-76-1	22kV	Yes	0	1	2	1	2	**1.03**

2015-2016

Ranking	Recloser location	Network Voltage	Communication	Number of failures on tee-off 2015-2016	Geographical obstacles	Sensitive customers	T-off length	Lightning density area	Total weight
	Weights		Yes continue, No stop	26	26	11	19	18	100
1	Pole387	22kV	Yes	9	1	15	25.27	6.23	56.50
2	Pole266	22kV	Yes	6	1	12	45.06	8.97	73.03
3	Pole183	22kV	Yes	4	1	22	22.01	15.59	64.60
4	Pole181-47	22kV	Yes	0	2	15	33.64	9.98	60.62
5	Pole61	22kV	Yes	5	1	10	30.61	9.16	55.77
6	Pole84-86-31	22kV	Yes	4	2	25	9.25	11.32	51.58
7	Pole84-85	22kV	Yes	0	2	14	5.99	10.82	32.81
8	Pole84-76-1	22kV	Yes	1	2	15	3.09	5.54	26.63
9	Pole84-53-46	22kV	Yes	0	1	9	5.61	14.10	29.71
10	Pole84-53-1	22kV	Yes	2	1	14	6.66	10.83	34.49
11	Pole84-51-1	22kV	Yes	0	1	10	5.31	12.08	28.39
12	Pole84-32-1	22kV	Yes	3	1	10	13.23	11.27	38.50
13	Pole84-1	22kV	Yes	0	1	15	11.33	7.38	34.71
14	Pole60-16	22kV	Yes	0	1	20	1.39	9.82	32.20
15	Pole60-13-1	22kV	Yes	1	1	2	1.69	9.82	15.50
16	Pole60-12-1	22kV	Yes	3	1	1	0.97	9.82	15.79
17	Pole60-1	22kV	Yes	2	1	2	3.78	9.82	18.59
18	Pole15-44	22kV	Yes	0	1	5	2.66	8.06	16.72
19	Pole15-18-24	22kV	Yes	0	1	13	1.37	9.82	25.19
20	Pole15-18-1	22kV	Yes	0	1	25	1.83	9.82	37.65
21	Pole15-15	22kV	Yes	0	1	59	3.48	12.08	75.56
22	Pole15-2	22kV	Yes	2	1	32	1.62	9.82	46.43

Recloser location	Failure of t-off	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	7			3			3	Failures Column	
Pole266	7		2				2	Number of failts/events	Weighting
Pole183	5	1					1	0 - 4	1
Pole181-47	6						0	5 - 8	2
Pole61	6		2				2	9 - 12	3
Pole84-86-31	2	1					1	13 - 16	4
Pole84-85	0						0	>16	5
Pole84-76-1	0	1					1		
Pole84-53-46	0						0		
Pole84-53-1	6	1					1		
Pole84-51-1	5						0		
Pole84-32-1	5	1					1		
Pole84-1	4						0		
Pole60-16	2						0		
Pole60-13-1	0	1					1		
Pole60-12-1	0	1					1		
Pole60-1	5	1					1		
Pole15-44	0						0		
Pole15-18-24	0						0		
Pole15-18-1	0						0		
Pole15-15	0						0		
Pole15-2	5	1					1		

Recloser location	Sensitive customers	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	15			3			3	Sensitive customers	
Pole266	12			3			3	Number of customers	Weighting
Pole183	22				4		4	0 - 5	1
Pole181-47	15			3			3	6 - 11	2
Pole61	10		2				2	12 - 17	3
Pole84-86-31	25					5	5	18 - 23	4
Pole84-85	14			3			3	>23	5
Pole84-76-1	15			3			3		
Pole84-53-46	9		2				2		
Pole84-53-1	14			3			3		
Pole84-51-1	10		2				2		
Pole84-32-1	10		2				2		
Pole84-1	15			3			3		
Pole60-16	20				4		4		
Pole60-13-1	2	1					1		
Pole60-12-1	1	1					1		
Pole60-1	2	1					1		
Pole15-44	5	1					1		
Pole15-18-24	13			3			3		
Pole15-18-1	25					5	5		
Pole15-15	59					5	5		
Pole15-2	32					5	5		

Recloser location	T-off length	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	25.274					5	5	T-off length	
Pole266	45.055					5	5	Length in kilometers	Weighting
Pole183	22.011					5	5	0 - 5	1
Pole181-47	33.638					5	5	5 < length < 10	2
Pole61	30.613					5	5	10 < length < 15	3
Pole84-86-31	9.254		2				2	15 < length < 20	4
Pole84-85	5.992		2				2	>20	5
Pole84-76-1	3.088	1					1		
Pole84-53-46	5.614		2				2		
Pole84-53-1	6.66		2				2		
Pole84-51-1	5.305		2				2		
Pole84-32-1	13.231			3			3		
Pole84-1	11.329			3			3		
Pole60-16	1.385	1					1		
Pole60-13-1	1.685	1					1		
Pole60-12-1	0.974	1					1		
Pole60-1	3.777	1					1		
Pole15-44	2.66	1					1		
Pole15-18-24	1.374	1					1		
Pole15-18-1	1.83	1					1		
Pole15-15	3.477	1					1		
Pole15-2	1.618	1					1		

Recloser location	Lightning strikes	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	9.6542	1					1	Lightning strikes	
Pole266	12.84722154	1					1	Number of strikes	Weighting
Pole183	15.58591		2				2	0 - 12	1
Pole181-47	7.212151818	1					1	12 < strikes < 24	2
Pole61	9.15949375	1					1	24 < strikes < 36	3
Pole84-86-31	10.8204	1					1	36 < strikes < 48	4
Pole84-85	9.06	1					1	>48	5
Pole84-76-1	11.0759	1					1		
Pole84-53-46	12.3295		2				2		
Pole84-53-1	7.55265	1					1		
Pole84-51-1	20		2				2		
Pole84-32-1	4.155755						0		
Pole84-1	11.3283	1					1		
Pole60-16	20.135	1					1		
Pole60-13-1	20.135	1					1		
Pole60-12-1	20.135	1					1		
Pole60-1	20.135	1					1		
Pole15-44	9.81844	1					1		
Pole15-18-24	20.135	1					1		
Pole15-18-1	20.135	1					1		
Pole15-15	15.3537		2				2		
Pole15-2	20.135	1					1		

Pole number	Recloser location	Network Voltage	Communication	Number of failures on T-off 2015-2016	Geographical obstacles	Sensitive customers	T-off length	Lightning density area.	Total weight
	Weighting		Yes continue, No stop	26	26	11	19	18	100
1	Pole183	22kV	Yes	1	2	4	5	2	**2.53**
2	Pole387	22kV	Yes	3	1	3	5	1	**2.5**
3	Pole266	22kV	Yes	2	1	3	5	1	**2.24**
4	Pole61	22kV	Yes	2	1	2	5	1	**2.13**
5	Pole181-47	22kV	Yes	0	1	3	5	1	**1.72**
6	Pole84-86-31	22kV	Yes	1	1	5	2	1	**1.63**
8	Pole15-2	22kV	Yes	1	1	5	1	1	**1.44**
9	Pole84-85	22kV	Yes	0	2	3	2	1	**1.41**
12	Pole84-53-1	22kV	Yes	1	1	3	2	1	**1.41**
7	Pole15-15	22kV	Yes	0	1	5	1	2	**1.36**
10	Pole84-1	22kV	Yes	0	1	3	3	1	**1.34**
18	Pole84-32-1	22kV	Yes	1	1	2	3	1	**1.49**
19	Pole60-13-1	22kV	Yes	1	2	1	1	1	**1.26**
11	Pole84-53-46	22kV	Yes	0	1	2	2	2	**1.22**
13	Pole84-51-1	22kV	Yes	0	1	2	2	2	**1.22**
15	Pole15-18-24	22kV	Yes	0	2	3	1	1	**1.22**
16	Pole84-76-1	22kV	Yes	1	1	3	1	1	**1.22**
14	Pole15-18-1	22kV	Yes	0	1	5	1	1	**1.18**
17	Pole60-16	22kV	Yes	0	1	4	1	1	**1.07**
20	Pole60-12-1	22kV	Yes	1	1	1	1	1	**1**
21	Pole60-1	22kV	Yes	1	1	1	1	1	**1**
22	Pole15-44	22kV	Yes	0	1	1	1	1	**0.74**

2016-2017

Ranking	Recloser location	Network Voltage	Communication	Number of failures on T-off	Geographical obstacles	Sensitive customers	T-off length	Lightning density area.	Total weight
	Weights		Yes continue, No stop	15	20	15	20	30.00	100.00
1	Pole387	22kV	Yes	7	1	15	25.27	9.65	57.93
2	Pole266	22kV	Yes	7	1	12	45.06	12.85	77.90
3	Pole183	22kV	Yes	5	1	22	22.01	15.59	65.60
4	Pole181-47	22kV	Yes	6	2	15	33.64	7.21	63.85
5	Pole61	22kV	Yes	6	1	10	30.61	9.16	56.77
6	Pole84-86-31	22kV	Yes	2	2	25	9.25	10.82	49.07
7	Pole84-85	22kV	Yes	0	2	14	5.99	9.06	31.05
8	Pole84-76-1	22kV	Yes	0	2	15	3.09	11.08	31.16
9	Pole84-53-46	22kV	Yes	0	1	9	5.61	12.33	27.94
10	Pole84-53-1	22kV	Yes	6	1	14	6.66	7.55	35.21
11	Pole84-51-1	22kV	Yes	5	1	10	5.31	20.00	41.31
12	Pole84-32-1	22kV	Yes	5	1	10	13.23	4.16	33.39
13	Pole84-1	22kV	Yes	4	1	15	11.33	11.33	42.66
14	Pole60-16	22kV	Yes	2	1	20	1.39	20.14	44.52
15	Pole60-13-1	22kV	Yes	0	1	2	1.69	20.14	24.82
16	Pole60-12-1	22kV	Yes	0	1	1	0.97	20.14	23.11
17	Pole60-1	22kV	Yes	5	1	2	3.78	20.14	31.91
18	Pole15-44	22kV	Yes	0	1	5	2.66	9.82	18.48
19	Pole15-18-24	22kV	Yes	0	1	13	1.37	20.14	35.51
20	Pole15-18-1	22kV	Yes	0	1	25	1.83	20.14	47.97
21	Pole15-15	22kV	Yes	0	1	59	3.48	15.35	78.83
22	Pole15-2	22kV	Yes	5	1	32	1.62	20.14	59.75

Recloser location	Failure of t-off	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	7		2				2	Failures Column	
Pole266	7		2				2	Number of failts/events	Weighting
Pole183	5		2				2	0 - 4	1
Pole181-47	6		2				2	5 - 8	2
Pole61	6		2				2	9 - 12	3
Pole84-86-31	2	1					1	13 - 16	4
Pole84-85	0						0	>16	5
Pole84-76-1	0						0		
Pole84-53-46	0						0		
Pole84-53-1	6		2				2		
Pole84-51-1	5		2				2		
Pole84-32-1	5		2				2		
Pole84-1	4	1					1		
Pole60-16	2	1					1		
Pole60-13-1	0						0		
Pole60-12-1	0						0		
Pole60-1	5		2				2		
Pole15-44	0						0		
Pole15-18-24	0						0		
Pole15-18-1	0						0		
Pole15-15	0						0		
Pole15-2	5		2				2		

Recloser location	Sensitive Cust	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	15			3			3	Sensitive customers	
Pole266	12			3			3	Number of customers	Weighting
Pole183	22				4		4	0 - 5	1
Pole181-47	15			3			3	6 - 11	2
Pole61	10		2				2	12 - 17	3
Pole84-86-31	25					5	5	18 - 23	4
Pole84-85	14			3			3	>23	5
Pole84-76-1	15			3			3		
Pole84-53-46	9		2				2		
Pole84-53-1	14			3			3		
Pole84-51-1	10		2				2		
Pole84-32-1	10		2				2		
Pole84-1	15			3			3		
Pole60-16	20				4		4		
Pole60-13-1	2	1					1		
Pole60-12-1	1	1					1		
Pole60-1	2	1					1		
Pole15-44	5	1					1		
Pole15-18-24	13			3			3		
Pole15-18-1	25					5	5		
Pole15-15	59					5	5		
Pole15-2	32					5	5		

Recloser location	T-off length	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	25.274					5	5	T-off length	
Pole266	45.055					5	5	Number of customers	Weighting
Pole183	22.011					5	5	0 - 5	1
Pole181-47	33.638					5	5	5 < length < 10	2
Pole61	30.613					5	5	10 < length < 15	3
Pole84-86-31	9.254		2				2	15 < length < 20	4
Pole84-85	5.992		2				2	>20	5
Pole84-76-1	3.088	1					1		
Pole84-53-46	5.614		2				2		
Pole84-53-1	6.66		2				2		
Pole84-51-1	5.305		2				2		
Pole84-32-1	13.231			3			3		
Pole84-1	11.329			3			3		
Pole60-16	1.385	1					1		
Pole60-13-1	1.685	1					1		
Pole60-12-1	0.974	1					1		
Pole60-1	3.777	1					1		
Pole15-44	2.66	1					1		
Pole15-18-24	1.374	1					1		
Pole15-18-1	1.83	1					1		
Pole15-15	3.477	1					1		
Pole15-2	1.618	1					1		

Recloser location	Lightning strikes	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight	Matrix criterias	
Pole387	9.6542	1					1	Lightning strikes	
Pole266	12.84722154		2				2	Number of strikes	Weighting
Pole183	15.58591		2				2	0 - 12	1
Pole181-47	7.212151818	1					1	12 < strikes < 24	2
Pole61	9.15949375	1					1	24 < strikes < 36	3
Pole84-86-31	10.8204	1					1	36 < strikes < 48	4
Pole84-85	9.06	1					1	>48	5
Pole84-76-1	11.0759	1					1		
Pole84-53-46	12.3295		2				2		
Pole84-53-1	7.55265	1					1		
Pole84-51-1	20		2				2		
Pole84-32-1	4.155755	1					1		
Pole84-1	11.3283	1					1		
Pole60-16	20.135		2				2		
Pole60-13-1	20.135		2				2		
Pole60-12-1	20.135		2				2		
Pole60-1	20.135		2				2		
Pole15-44	9.81844	1					1		
Pole15-18-24	20.135		2				2		
Pole15-18-1	20.135		2				2		
Pole15-15	15.3537		2				2		
Pole15-2	20.135		2				2		

Pole number	Recloser location	Network Voltage	Communication	Number of failures on T-off 2016-2017	Geographical obstacles	Sensitive customers	T-off length	Lightning density area	Total weight
	Weighting		Yes continue, No stop	26	26	11	19	18	100
1	Pole183	22kV	Yes	2	1	4	5	2	**2.53**
3	Pole181-47	22kV	Yes	2	2	3	5	1	**2.5**
2	Pole266	22kV	Yes	2	1	3	5	2	**2.42**
4	Pole387	22kV	Yes	2	1	3	5	1	**2.24**
5	Pole61	22kV	Yes	2	1	2	5	1	**2.13**
7	Pole84-86-31	22kV	Yes	1	2	5	2	1	**1.89**
6	Pole15-2	22kV	Yes	2	1	5	1	2	**1.88**
8	Pole84-32-1	22kV	Yes	2	1	2	3	1	**1.75**
13	Pole84-51-1	22kV	Yes	2	1	2	2	2	**1.74**
14	Pole84-53-1	22kV	Yes	2	1	3	2	1	**1.67**
9	Pole84-1	22kV	Yes	1	1	3	3	1	**1.6**
10	Pole60-16	22kV	Yes	1	1	4	1	2	**1.51**
15	Pole60-1	22kV	Yes	2	1	1	1	2	**1.44**
17	Pole84-85	22kV	Yes	0	2	3	2	1	**1.41**
11	Pole15-18-1	22kV	Yes	0	1	5	1	2	**1.36**
12	Pole15-15	22kV	Yes	0	1	5	1	2	**1.36**
19	Pole84-53-46	22kV	Yes	0	1	2	2	2	**1.22**
18	Pole84-76-1	22kV	Yes	0	2	3	1	1	**1.22**
16	Pole15-18-24	22kV	Yes	0	1	3	1	2	**1.14**
20	Pole60-13-1	22kV	Yes	0	1	1	1	2	**0.92**
21	Pole60-12-1	22kV	Yes	0	1	1	1	2	**0.92**
22	Pole15-44	22kV	Yes	0	1	1	1	1	**0.74**

Matrix2014-2015 Ranking		Matrix 2015-2016 ranked		Matrix 2016-2017 Ranked			Ranking	Matrix Pole numbers	Ranking 2016-2017	Ranking 2015-2016	Ranking 2014-2015	Rankings overall
Pole61	2.82	Pole183	2.53	Pole183	2.53		1	Pole387	2.24	2.5	2.68	2.47
Pole387	2.68	Pole387	2.5	Pole181-47	2.5		2	Pole183	2.53	2.53	2.16	2.41
Pole266	2.27	Pole266	2.24	Pole266	2.42		3	Pole61	2.13	2.13	2.82	2.36
Pole181-47	2.23	Pole61	2.13	Pole387	2.24		4	Pole266	2.42	2.24	2.27	2.31
Pole183	2.16	Pole181-47	1.72	Pole61	2.13		5	Pole181-47	2.5	1.72	2.23	2.15
Pole84-32-1	1.96	Pole84-86-31	1.63	Pole84-86-31	1.89		6	Pole15-2	1.88	1.44	1.95	1.76
Pole15-2	1.95	Pole15-2	1.44	Pole15-2	1.88		7	Pole84-32-1	1.75	1.31	1.96	1.67
Pole84-1	1.89	Pole84-85	1.41	Pole84-32-1	1.75		8	Pole84-86-31	1.89	1.63	1.33	1.62
Pole84-53-46	1.85	Pole84-53-1	1.41	Pole84-51-1	1.74		9	Pole84-1	1.6	1.34	1.89	1.61
Pole15-18-24	1.8	Pole15-15	1.36	Pole84-53-1	1.67		10	Pole84-51-1	1.74	1.22	1.48	1.48
Pole15-18-1	1.54	Pole84-1	1.34	Pole84-1	1.6		11	Pole84-53-1	1.67	1.41	1.22	1.43
Pole15-15	1.54	Pole84-32-1	1.31	Pole60-16	1.51		12	Pole84-53-46	1.22	1.22	1.85	1.43
Pole84-51-1	1.48	Pole60-13-1	1.26	Pole60-1	1.44		13	Pole15-15	1.36	1.36	1.54	1.42
Pole60-13-1	1.36	Pole84-53-46	1.22	Pole84-85	1.41		14	Pole15-18-24	1.14	1.22	1.8	1.39
Pole60-12-1	1.36	Pole84-51-1	1.22	Pole15-18-1	1.36		15	Pole84-85	1.41	1.41	1.33	1.38
Pole60-1	1.36	Pole15-18-24	1.22	Pole15-15	1.36		16	Pole15-18-1	1.36	1.18	1.54	1.36
Pole84-86-31	1.33	Pole84-76-1	1.22	Pole84-53-46	1.22		17	Pole60-1	1.44	1	1.36	1.27
Pole84-85	1.33	Pole15-18-1	1.18	Pole84-76-1	1.22		18	Pole60-16	1.51	1.07	1.1	1.23
Pole84-53-1	1.22	Pole60-16	1.07	Pole15-18-24	1.14		19	Pole60-13-1	0.92	1.26	1.36	1.18
Pole15-44	1.14	Pole60-12-1	1	Pole60-13-1	0.92		20	Pole84-76-1	1.22	1.22	1.03	1.16
Pole60-16	1.1	Pole60-1	1	Pole60-12-1	0.92		21	Pole60-12-1	0.92	1	1.36	1.09
Pole84-76-1	1.03	Pole15-44	0.74	Pole15-44	0.74		22	Pole15-44	0.74	0.74	1.14	0.87

Annexure D: Publications

1. Strydom, R. and Hertzog, P.E., 2019, January. Recloser placement on medium voltage distribution networks. In *2019 Southern African Universities Power Engineering Conference/Robotics and Mechatronics/Pattern Recognition Association of South Africa (SAUPEC/RobMech/PRASA)* (pp. 305-309). IEEE.
2. Strydom, R. and Hertzog, P.E., 2021. Optimization of recloser methods on medium voltage distribution networks. *3C Tecnologia*, *10*(3), p.57.