An Investigation into the influence of ageing components on medium voltage network configurations in Semi-Urban areas

Nosi Mpelo

Dissertation submitted in fulfillment of the requirements for the degree:

Master of Engineering

in

Electrical Engineering

Department of Electrical, Electronics and Computer Engineering

Faculty of Engineering, Built Environment and Information Technology

Central University of Technology, Free State

Supervisor: Prof. P. Hertzog

May 2020

Declaration

I, Nosi Paul Mpelo, student number , do hereby declare that this research project, which has been submitted to the Central Univeristy of Technology, Free State, for the degree: Master of Engineering in Electrical Engineering, is my own independent work and complies with the Code of Academic Intergrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State. This research has not been submitted before by any person in fulfillment (or partial fulfillment) of the requirements for the attainment of any qualification.

Nosi Paul Mpelo

Date: 11 May 2020

Acknowledgements

First, I would like to thank Almighty God for giving me the strength to complete this journey. I would also like to thank everyone who has made it possible for me to write this dissertation I would like to express my gratitude and appreciation to my supervisor, Prof. P. Hertzog. Thank you for all the guidance you have given me throughout my study. Thank you very much. I really appreciate all your help.

Dedication

I dedicate this dissertation to my family. The support and encouragement you have given me throughout the study made it possible for me to accomplish this journey. To my wife, Palesa Mpelo and my two beautiful daughters, Neo and Letlotlo Mpelo, this is for you.

Abstract

Access to electricity for all South Africans is a goal that is still achievable. Access to electricity is not a luxury, but a need. Electricity improves all individuals' lives, including those who live in semi-urban areas. Most of the medium voltage electrical networks that supply semi-urban areas are more than 30 years old; some are beyond repair. The existing electrical network configurations can cause accelerated ageing of electrical components, which can have a negative impact on performance, quality of supply and the public. The three semi-urban areas selected for the study were located in different parts of Northern Cape. Visual inspection, components failure rate and voltage simulations were used during the investigation to shed light on the details of the selected networks and their ageing characteristics as well as how ageing components or infrastructure affect the performance of the network, the safety of personnel and equipment, and quality of supply.

Components on the electrical networks selected for the research have different deterioration characteristics in accordance with their environment and design of electrical network configuration. Ageing of electrical components on the network is mainly due to the materials used on the components, which deteriorate naturally after a certain period of service. However, some of the materials age because they have been operated beyond their design specifications. In relation to ageing, the most affected components are jumpers, pole-mounted transformers and wooden poles. Component failures lead to poor performance of the network as well as an unsafe and unreliable network. Northern Cape has one of the largest landscapes in South Africa, which makes the distribution networks much longer than they usually are. Thus, more time is needed to inspect them than any other networks in South Africa.

Ageing of components on the electrical network can result in capital loss, loss of life and high supply interruptions, which result in loss of revenue for the power utility. The results of this investigation show that safe, reliable and correctly designed or utilized electrical networks in semi-urban areas can improve the performance and quality of supply as well as reduce the maintenance costs of the network. The study shows that most of the component failures were more common in certain areas of the selected networks. Premature failures and ageing of components on MV network was one of the main causes of deteriorating performance on MV networks in semi-urban areas. In the field of electrical engineering, the focus is more on major components on the electrical network including power transformers, reactors and generally high voltage components because they are more expensive. Medium voltage components generally cost less than high voltage components; consequently, the cost of their maintenance is much lower, which is a gap that can be explored in future research.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

No.	Abbreviations	Description
1	AAAC	All Aluminium Alloy Conductor
2	AAC	All Aluminium Conductor
3	ABC	Aerial Bundle Conductor
4	ACSR	Aluminium Conductor Steel Reinforced
5	ADMD	After Diversity Maximum Demand
6	ARC	Auto- Recloser
7	AUX	Auxiliary
8	BI	Business Intelligence
9	CCA	Chromated Copper Arsenate
10	CI	Customer Interruptions
11	CIH	Customer Interruption Hours
12	CNC	Customer Network Centre
13	CT	Current Transformer
14	CVM	Current-Voltage Monitor
15	DigSILENT	Digital Simulation of Electrical Networks
16	DSLI	Distribution Supply Loss Index
17	DPM	Distribution Performance Model
18	IEC	International Electrotechnical Commission
19	IEEE	Institute of Electrical and Electronics Engineers
20	Km	Kilometre
21	KV	Kilovolt
22	LV	Low Voltage
23	MCB	Miniature Circuit Breaker
24	MD	Maximum Demand
25	MMW	Months Moving Average
26	MV	Medium Voltage
27	MVA	Mega Volt Ampere
28	NEC	Neutral Earthing Compensator
29	NER	Neutral Earthing Resistor
30	NERSA	National Energy Regulation of South Africa
31	NEPS	Network Equipment Performance System
32	NMD	Nominal Maximum Demand
33	NRS	National Rationalized Specifications
34	RSA	Republic of South Africa
35	RSLI	Reticulation Supply Loss Index
36	SAIDI	System Average Interruption Duration Index
37	SAIFI	System Average Interruption Frequent Index
38	SCADA	Supervisory Control and Data Acquisition
39	SWER	Single Wire Earth Return
40	TRFR	Transformer
41	UK	United Kingdom
42	VT	Voltage Transformer

CHAPTER 1: INTRODUCTION

1.1 Background information

For 90 years, Eskom has been supplying electricity to various customers and in particular, industrial customers who contribute considerably towards the economy of South Africa [1]. Prior to 1993, only 36% of the South African population, mainly in the urban areas, had access to electricity [2]. Prior to 1994, the electricity infrastructure was mainly built for industrial, agricultural, mining and domestic purposes. The latter was limited to certain domestic suburbs. Major electrification projects were initiated after 1994 when the new government took charge [1]. Although the expected life span of an MV line wood pole is approximately 30 years, this is dependent on the type of maintenance performed [3]. In the Northern Cape, most of the reticulation overhead lines were and are still being built by employing wood pole structures.

Wood poles are not manufactured to last indefinitely; rather, after a certain number of years, they start to deteriorate [3]. The rate at which poles deteriorate depends on the environment in which the network is built [4]. Similar to other assets in distribution networks, each component is designed to operate for a certain period [5]. Therefore, the electricity utility decides whether to employ an asset until its failure or whether it has plans to replace it after it has reached its life span. The MV/LV electrical network comprises components such as MV/LV transformers, auto-reclosers, isolators, fuses, conductors, cables and jumpers [5]. Although all these components have an expected life span, many factors can reduce this life span [5].

If the overloading is severe enough and the protection system does not operate properly to disconnect the line, severe overheating will occur and cause excessive damage to the affected components in a short period of a few minutes or hours [5]. During these periods, the conductor temperature will increase because of the heat generated by the resistive losses [5]. Excessive heating will cause annealing of the wires when they lose their elasticity and strength. Subsequently, the conducts will sag and violate clearance limits. This will require premature replacement with new conductors, which usually poses a huge electrocution risk for both humans and animals. Splice or jumpers on the line will overheat faster than the conductor itself, causing the jumpers to fail. This failure can cause the conductor to fall to the ground [5].

Depending on the area of the network, ambient temperature can have an effect on the deterioration of components [6]. The environment can also determine the rate at which the network deteriorates [7]. For example, in the Northern Cape, conditions range from extremely hot conditions to coastal conditions in Port Nolloth and cold conditions in Sutherland near the Western Cape border. In Port Nolloth, Sizamile, a semi-urban area, does not have many customers. Although the electrical network in Sizamile was built in approximately 1981, its network has deteriorated over the years as a result of ocean moisture; presently, the network is no longer safe for the community and field service employees.

Ageing of the electrical network configuration also has a huge impact economically. The older the component, the higher the cost of maintenance [8]. In order for a field service employee to replace a pole, they need an outage so that they can switch off the supply thus leaving customers without electricity for the duration of the outage. Some of the electrical network configurations that were employed in the past were built using bare conductors and pole structures, which disadvantage birds with long wings such as eagles, blue cranes and cape vultures [9]. The ageing process is ongoing and can lead to the reduced efficiency of components. If the phenomenon is left unchecked and unmitigated, ageing will increase the risk of the network's failure [10].

Assuming that during the component life period there is no preventative or corrective maintenance, the component failure will follow the bath-tub curve (Figure 1.1).

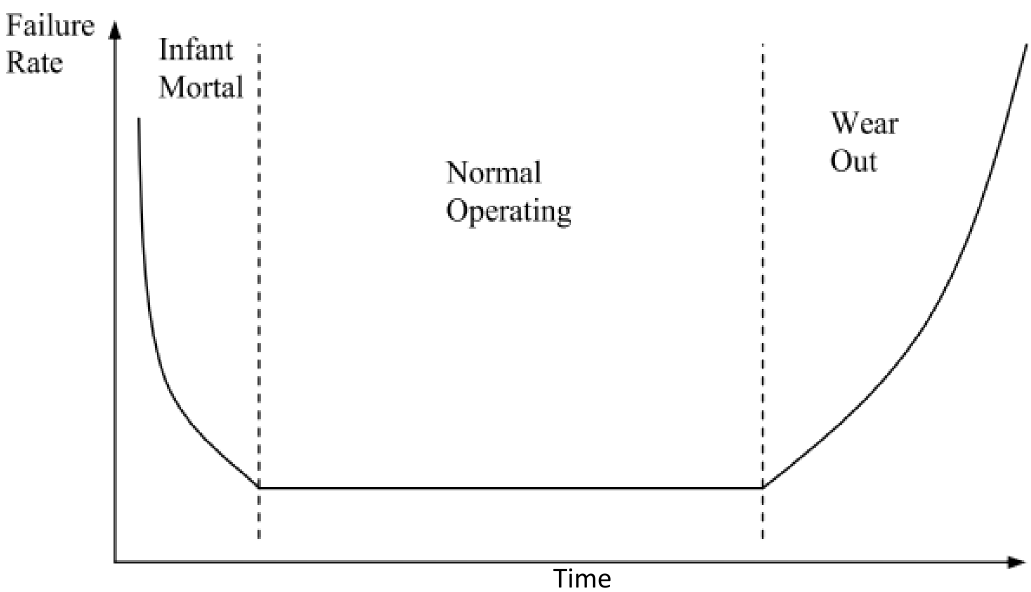


Figure 1.1: Bath-tub curve of a component's life [11]

As depicted in Figure 1.1, electrical components have a higher failure rate when they are still newly installed, this phenomenon is often refered to as Infant Mortal as indicated in Figure 1.1. Most of these early failures are due to manufacturing errors that could not be picked up during pre-commissioning testing. However, depending on whether correct maintenance has been conducted, after several months or weeks, the components tend to become more stable when operated under normal condition as shown in Figure 1.1. The normal operating period is usually constant and does not depend on the age of the component. However, after many years in operation, the failure rate increases again. Most of the time, this is caused by wear of the components as shown in Figure 1.1.

When performing an ageing analysis for components, the following can be obtained:

- ✓ Stress factors (operation and environmental conditions), which affect the performance of the components due to ageing;
- ✓ The effect induced by the ageing phenomenon on component performance; and
- ✓ Ageing contributions can be prioritized according to their risk importance [10].

1.1.1 Voltage range

Voltage ranges vary from country to country. In South Africa, the voltage range for distribution is as follows [12]:

- ✓ High Voltage: Nominal voltage levels equal to or greater than 44kV but less than 132kV;
- ✓ Medium Voltage: Nominal voltage levels equal to or greater than 1kV to 44kV; and
- ✓ Low Voltage: Nominal voltage levels from 0V to 1000V

The voltage that was used for older networks built during the 1970s and 1980s in semi-urban areas ranged from 11kV to 33kV even though 33kV networks are very rare. Most of the recent networks are 22kV with conductor ratings that are much higher than the ones used for 11kV networks [13].

1.1.2 Conductors

The conductor is the principal component of distribution lines; wire or bundles of wire made of aluminium, copper or steel [5]. There are different types of conductors used for MV lines, depending on the load which they supply. The greater the load, the higher the conductor rating used and the larger the conductor size [14]. Lightning is most common leading factor of conductor failure [15]. Overloading is caused by a high current flowing through the conductor, which generates excessive heat. Other failures usually occur on the joints where the jumpers are connected to the conductor or any other component on the network that is connected to the conductor [16].

There is usually a line at the top of high voltage lines called earth wire, which is used to absorb lightning strikes to ground thereby minimizing the risk for conductor damage. However, there is no earth wire on MV electrical networks thus posing the possibility of damage by lightning [17]. Pole-mounted transformers are components equipped with earth wire. When the conductor is a certain age, its strength deteriorates and its vulnerability for failure increases [14].

1.1.3 MV transformers

MV transformers ensure that voltage is decreased to a safe voltage that can be used by the consumer [18]. A different range of transformers is utilized in semi-urban areas. The size of pole-mounted transformers is determined by the number of customers in areas that are classified as transformer zones. In the past, most people lived on farms and in rural areas where there was no electricity. Only a few people lived in semi-urban areas [19]. The majority of people who lived in rural areas or farms migrated to townships for work so that they could provide for their families back home [20].

Although the government provided electricity to the existing communities in those townships, with time most families on farms and in rural areas migrated to semi-urban areas in the hope of a better life [19]. Consequently, semi-urban areas expanded on a large scale and thus, the implementation of electrification programs became imperative. When electrification programs finally began in most semi-urban areas around Northern Cape after 1994, the electrical network designers of those electrification projects used the existing pole-mounted transformers to connect the new users. At that time, the old ADMD (After Diversity Maximum Demand) used per pole-mounted transformer was 0.2kVA. As the numbers of customers were added to some of these transformers, utilities including municipalities experienced a high number of overloaded transformers [21].

MV/LV pole-mounted transformers range between 10kVA to 500kVA (for large power users) [22]. Most of the transformers used in the townships are 32kVA, 50kVA and 100kVA. Furthermore, 16kVA transformers, which are single-phase transformers, supply farmers, schools and churches.

1.1.4 Bundle conductors

A bundle conductor is the cable used for the distribution of electricity from the MV transformer. Different sizes of bundle conductors are used in current networks ranging from 30mm^2 to 70mm^2. In townships built prior to 1994, the LV network comprised bare conductors that still exist in most of the networks that currently belong to municipalities. Several disadvantages related to bare conductors, which can compromise the safety of township residents as well as other components on the network, have been identified. Presently, it is considered non-standard to use bare conductors in Eskom due to various reasons including safety and maintenance.

1.1.5 Concentric cables and meters (Technology)

Customers are connected to the network by a concentric cable. Concentric cables are used to ensure that the supply of electricity is accessible in houses. Specifically, the connection is done through the top pole box, which is usually installed just outside houses. Depending on the size of a township, a top pole box may be shared by two to four customers. Concentric cables are made of insulated copper, which are connected to the meter in houses. The same principle is applied in townships that are supplied from an underground network with the exception of customers that are supplied from mini-substations instead of top pole boxes.

New technologies of concentric cables are currently being implemented. These new concentric cables include communication wire from the pole top box to the meter in the house. The breaker for new meters is actually in the top pole box and only the keypad is in the house. The majority of townships still use conventional meters. Meters are used to ensure that customers are able to buy electricity from retail shops. Most of the old conventional meters had circuit breakers and earth leakages installed in houses for protection.

Previously, there were several challenges related to conventional meters; the most common challenge involved tampering with meters. The new meters that are installed are called spilt meters, which are installed in the pole top box instead of the house. Most of the new electrification projects are supplied with 20A meters because of the low use of electricity in households.

1.1.6 Configuration (mid-block and street front)

There are two different types of LV electrical networks used in the current network configuration including mid-block and street-front configurations. While most of the old townships still use a mid-block electrical network configuration, only a few employ a street-front configuration. A mid-block configuration involves a bundle conductor (LV network) running between houses/yards. Mid-block configurations involve an overhead network or underground network.

A Street-front configuration involves the LV network running in front of the houses/yards. The top pole boxes are in front of houses and concentric cables run from houses to top pole boxes. Although this is the easiest configuration to maintain, it is very difficult to construct sometimes, especially in highly populated semi-urban areas. A MV and LV network configuration in a semi-urban area is depicted in Figure 1.2.

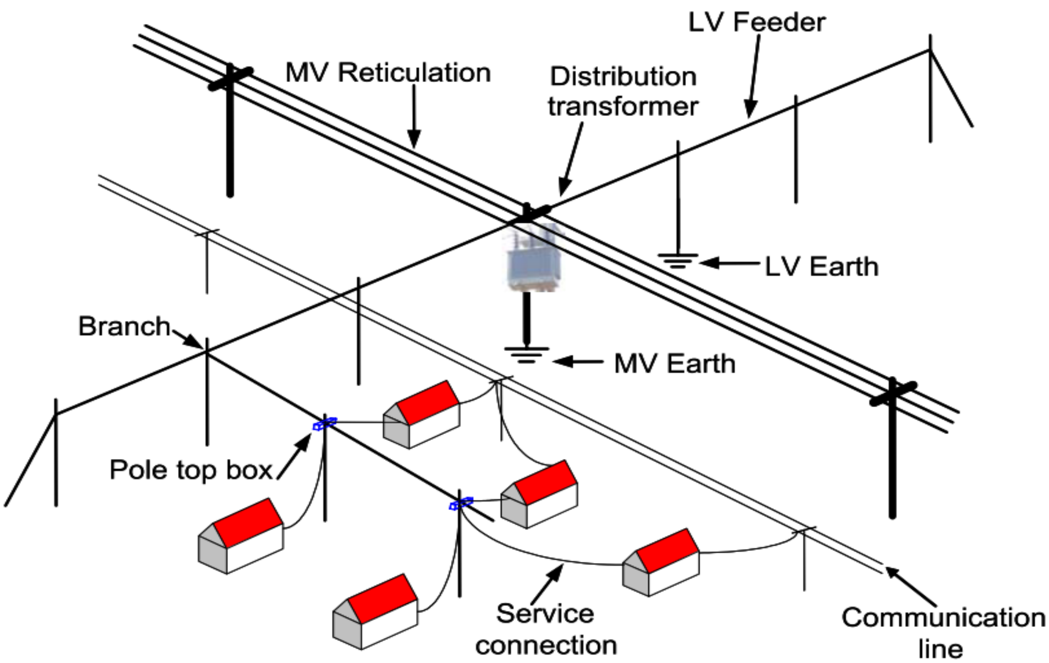


Figure 1.2: MV and LV network configuration in a semi-urban area [13]

1.1.7 Sectionalization and auto-recloser optimization

Different types of networks are employed in distribution; the most common type of network thereof is a radial and ring type network [23]. Most of the networks in semi-urban areas are radial networks while most of those in developed urban areas are ring networks. A radial network occurs when the line is supplied from a single source. However, if that source of supply is interrupted, all the customers supplied from that source will be without a supply of electricity. Utilities make use of auto-reclosers to protect the line against faults that might damage the installed equipment on the line and lightning [24].

The performance of the feeder depends on the number of interruptions the line has experienced over a certain period. The utilities are measured in accordance with the number of interruptions the customers who have been without the supply of electricity have [25]. The time taken to restore supply after the interruption is also measured. This is an immense challenge for an area such as the Northern Cape because it is the largest province in South Africa. Consequently, a great deal of time is spent driving to the site. An example of a MV radial network is depicted in Figure 1.3.

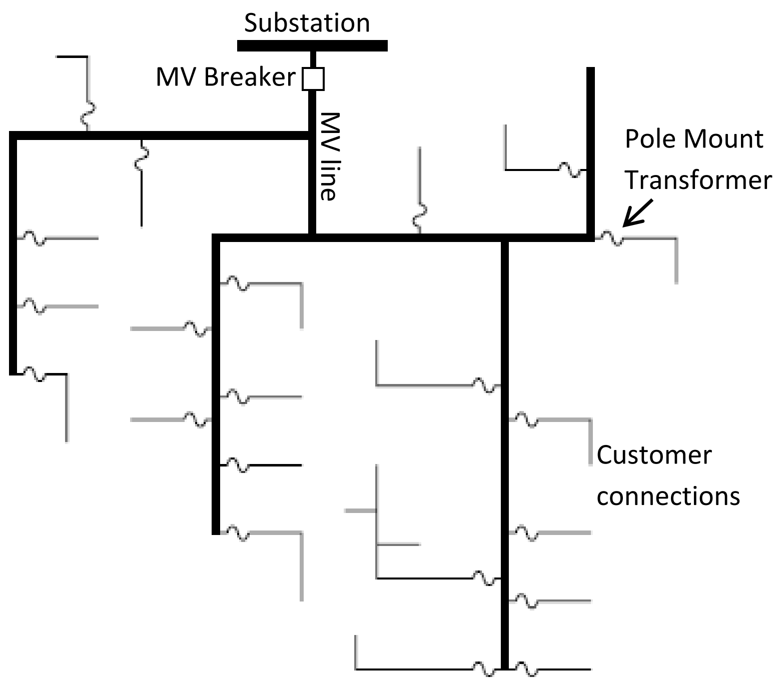


Figure 1.3: An example of a radial network in a semi-urban area [26]

The MV lines are supplied Distribution Substation through HV/MV transformers. The lines consist of MV feeder bays which include the MV breakers used for protecting the line. Along the MV feeders, there are MV\LV pole-mounted transformers used for stepping down the voltage to a safe home appliance usage.

1.2 Problem statement

Most of the electrical network configurations in townships of which some are still operational were built during the 1960s and 1970s. The common components negatively affected by age in the network include wooden structures, insulators and MV transformers. The main problem that affects the performance and quality of supply in townships is the design of the old electrical network configuration (mid-block configuration and radial network). As the network ages, some of the components wear out, especially if they were not maintained properly after their first commission. The types of network configurations used in most of the townships currently do not comply with the new standard configurations.

Previously, the transformers were designed with an ADMD of 0.2kVA. However, as the townships grew larger, the number of customers connected increased thus forcing the MV transformers to supply a high number of connections, which resulted in overloading of the MV/LV transformers. Because of the high number of connections, MV conductors supplying the transformer zone also experienced overloading because they were not designed to carry high loads. One of the disadvantages of the old network configuration is the lack of Sectionalization in townships. Most of the networks in the townships are radial networks, which affect the performance of the network (SAIDI and SAIFI).

1.3 Research question

Ageing components on the electrical network are the most substantial problem related to the performance of medium voltage networks in electrical utilities in the world. Accordingly, the following questions were formulated to guide this study so as to shed light on the effects of ageing components on medium voltage networks in Northern Cape semi-urban areas:

- ✓ What is the current condition of the network in selected areas?
- ✓ What is the current age of these electrical components?
- ✓ How does ageing and failure of these components affect the selected networks?
- ✓ How can one prevent these components from failing and accelerated ageing of components so as to increase their life span?

1.4 Aim of the study

The aim of this research is to investigate the influence of ageing infrastructure, the environment and loading on medium voltage components on the electrical network, which can affect safety, quality of supply and performance of the networks in semi-urban areas. A further aim is to investigate the rate at which each component on the network deteriorates and thus, find an enhanced way of reducing deterioration so that the components can last much longer.

1.5 Methodology

The main purpose of the study is to improve the network configuration and make it safer and more reliable. The study comprised planning, investigation, design and simulations. Data collected from the simulated networks determined whether there were any improvements discovered from the issues related to these networks. Three townships were selected based on the condition of their network. The electrical network configuration of the townships was modelled by employing the DigSILENT Power Factory 2018 SP3 with different voltage ratings and different conductor sizes. DigiSILENT is the software used widely to perform Studies on electrical networks.

The model of the MV electrical network configuration included MV transformers, auto-reclosers, links, fuses, conductors and normally open points. For the MV overhead lines from the substation to the townships that were much longer, the voltage regulators were taken into consideration because the longer the line, the lower the voltage becomes on the receiving side. The methodology employed is presented in Figure 1.4.

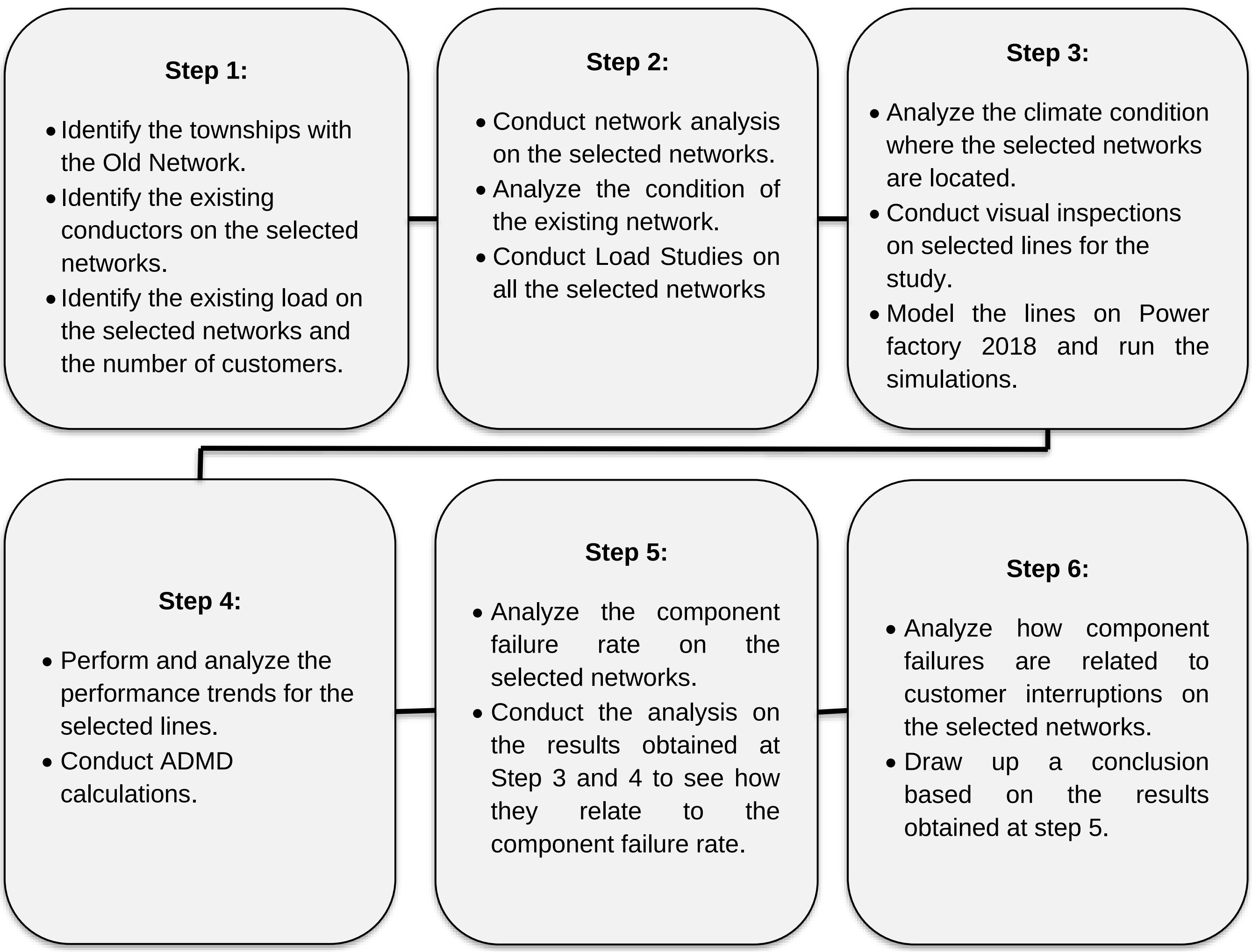


Figure 1.4: implementation of model simulation

The simulations were conducted by employing different loads in all three townships and collecting data so as to highlight how reliable the network was. The simulations were conducted on the current network configuration and after the network had been reconfigured by employing different conductors, adding extra MV transformers and sectionalizing the network on Power Factory. The simulation was also conducted to verify the effects of overloading on the network and how to improve it to ensure a longer life span and avoid overloading.

The following parameters formed part of the main focus when conducting the simulation:

- ✓ Voltage profile;
- ✓ Loading of the township;
- ✓ Type of conductors; and
- ✓ Spare capacity.

1.6 Benefits of the research

It is hoped that the outcome of the study will have an immense impact on the new designs of the network configurations in the country. These designs can be utilized by Eskom and municipalities when they conduct township normalization projects or new electrification projects. The improvement of the electrical network configuration will not only assist the performance and quality of supply but also ensure that the network is safe and protected at all times. Because electricity is dangerous, people and animals should be protected at all times. Furthermore, it is the responsibility of the planner to ensure that the designs prioritize safety.

It is expected that the study will also benefit Eskom and municipalities by ensuring that the electrical networks in semi-urban areas:

- ✓ Are reliable;
- ✓ Can minimize the faults/interruptions;
- ✓ Can create back-feed or other points of supply; and
- ✓ Have more space capacity to supply future connections.

Many people living in townships have been disadvantaged because they did not have access to electricity. However, with a steady supply in our townships, the benefit of having a continuous supply at all times with minimum interruptions can be enjoyed. During storms and heavy rains, there is always a chance that the supply will trip. However, with the improvement of the network, the chance of interruptions will be low. During the construction of the project, jobs will be created for the locals and thus, many will benefit during the project.

1.7 Delimitations of the study

This study focused on the medium voltage networks in semi-urban areas and not specifically on the entire line although the performance of the line may have a negative impact on the township. Some of the information related to the selected lines especially with regard to background information and results are not examined because of the confidentiality thereof. Furthermore, the performance results of the selected networks are not discussed in detail because this is a complex topic on its own.

1.8 Outline of the study

The dissertation comprises of five chapters:

Chapter 1: In this chapter, the study was introduced and the research question formulated. Furthermore, the background of the study and reasons for conducting the study were outlined. The objective of the study and methodology employed were also provided.

Chapter 2: In this chapter, existing literature relevant to the field of study is reviewed. The literature review includes a discussion of research that was conducted previously on the ageing of different types of components used in medium voltage networks. The ageing phenomenon, quality of supply, and the safety of the networks are also considered in this chapter. The effects of deteriorating electrical network components on the medium voltage networks are also discussed.

Chapter 3: The methodology employed in the study to obtain the required results is outlined in this chapter. The methodology includes various methods that were employed to obtain the results. Three methods were employed to obtain the results, which are compared; these include the software that was used.

Chapter 4: In this chapter, the results of the study are analyzed and discussed. Data obtained through the selected methodologies are discussed in detail.

Chapter 5: The study is concluded in this chapter. The results are discussed and recommendations are made. The software that was employed also assisted the researcher to make recommendations on how to ensure that networks are not overloaded to avoid accelerated ageing of components. The importance of having a reliable electrical network in townships to ensure that every South African has access to a reliable and safe electrical supply is emphasized in this chapter.

1.9 Summary

Access to electricity remains a dream for many South Africans. Electricity improves one's way of life, even for those who live in townships and rural areas. The focus of this study is on the electrical networks in semi-urban areas or townships. The majorities of electrical networks in the townships are old and are beyond their life expectancy. Each component on distribution networks has a life span or life expectancy. Furthermore, each component does not deteriorate in the same way. Some of the electrical components like CTs, VTs and MV/LV transformers have a longer life expectancy than the wood poles, control components and cables. Most of the electrical networks in townships comprise overhead lines and only a few townships possess an underground network.

Wood poles are the most affected component on the networks in townships. The environment can have an impact on the rate at which poles deteriorate. In most townships, MV and LV electrical network maintenance has not been considered to be as important as that of the substations and HV networks. Although the new electrical networks have improved, there are still challenges and concerns on how they are configured. The electrical configurations that were used in the past differ from the configurations that are currently employed. Most of the townships in the Northern Cape still use the old electrical network configurations, which affect the supply negatively.

Most of the electrical network configurations in the semi-urban areas in Northern Cape are radial networks. The electrical distribution utilities in South Africa, that is, the municipalities and Eskom are measured based on the performance of the network, which includes key performance indicators such as SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index). The aim of this study was to investigate the influence of ageing electrical components, the environment and loading on medium voltage components on the electrical network, which can affect safety, quality of supply and performance of the networks in semi-urban areas. The deterioration of components on the electrical network can have a negative impact in semi-urban areas.

CHAPTER 2- LITERATURE REVIEW

2.1 Introduction

The deterioration of electrical components on networks has been widely discussed in different countries. Various studies have been conducted to develop models and formulas that can estimate the life expectancy of components on the network [27]. The most widely studied component on the network is the insulation of material used on the electrical network [6]. The ageing process of electrical components is mainly the result of electrical stress, thermal stress and mechanical stress. Studies have revealed that there is a relationship between the ageing process of the components on the network and the performance of the network. The probability failure rate of the components can be classified by the rate at which the components age [6].

Depending on the conditions they are exposed to, electrical components age differently from one another. Circuit breakers age much quicker than power transformers when subjected to a great deal of stress and cables age much quicker than overhead conductors when exposed to the same stress [6]. Although components are widely considered to have a life span of 30-40 years, some components can last for more than 60 years if maintained properly. The most common effect that causes electrical components to age much quicker is the heat to which they are exposed. When the components are operated at full load or more than the rated values, at some point they experience overheating, which is the main factor involved in accelerating the rate at which components age [5].

2.2 Wood poles

Wood poles are the most widely used components on distribution networks for carrying the conductors to different areas. In comparison to other materials used in distribution networks, wood poles are considered to be cost effective. Wood pole networks are widely used throughout the world for distribution networks. However, wood poles need intensive care and should be well maintained if they are to last [28]. Wood poles that have been treated with creosote are more durable than poles that have not been treated [28]. The deterioration of the mechanical stress of poles can be weakened by many factors including the decay of the wood due to moisture, insects and woodpeckers [28]. Failure of poles can have a negative impact on performance and primarily on the safety of personnel and individuals in distribution networks [29].

Wood poles may have different ageing or deterioration characteristics due to the varying climates throughout the world. For example, wood poles that are located in tropical areas may have different ageing characteristics to wood poles in deserts. Employing other material in some areas may be a better option than wood poles.

The following study which was conducted by R. Vidor, M. Pires, B. Dedavid, B. Montani and A. Gabiatti focused on the inspection of approximately 10 000 wood poles in 23 cities in Southern

Brazil. The results of the inspection of wood poles in various Brazilian cities are displayed In Table 2.1.

Table 2.1: Location and number of inspected service poles in five AES SUL regions [29]

Region	Number of Cities	Inspection	
		Number of Poles	%
Central	2	976	9.1
North Frontier	2	859	8.0
South Frontier	3	1583	14.8
Metropolitan	11	5.54	51.8
Valleys	5	1734	16.2
Total	**23**	**10692**	**100**

Most of the inspections were conducted in the metropolitan cities where a total of 1734 poles were inspected in 11 cities. South Frontier followed with the inspection of 1583 wood poles in over three cities. In metropolitan areas, wood poles amounted to 51% of all the poles inspected in 23 cities [29]. Several methods are employed to inspect the poles. While visual assessment is employed to assess the cracks, holes, and burned and rotten points on the poles, the hummer is used to assess if the pole has a hollow core because of decay [29]. Another method involves digging a hole around the pole to check if there is any decay possibly due to moisture around the pole. A method used globally involves drilling a hole on the base of the pole to measure the internal decay of thereof.

The conditions of the wood poles are classified into different classes in relation to their conditions (Table 2.2). After the inspections on the wood poles are completed, the wood poles are classified according to the criteria in Table 2.2. Whether the inspection was conducted internally and/or externally and what procedure should take place after the classification is also displayed in the table.

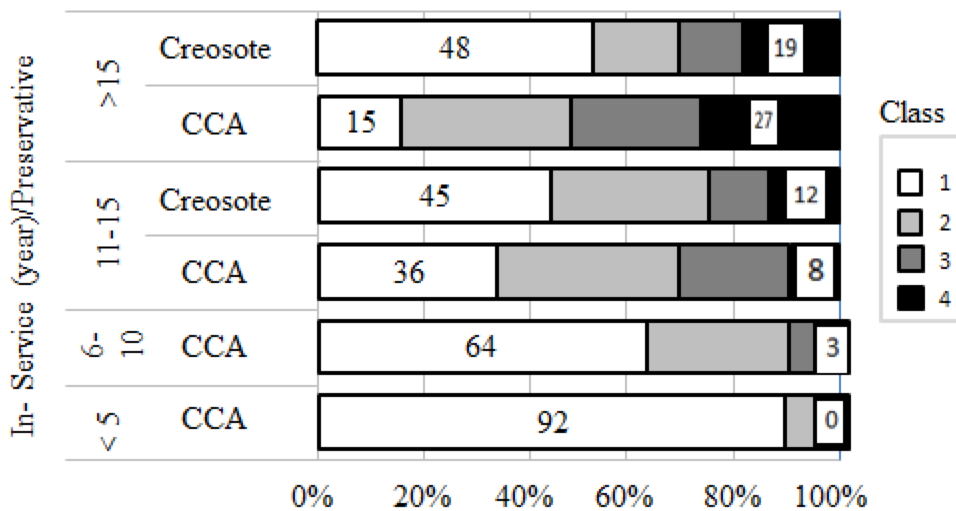
Table 2.2: Classification of poles after they have been inspected [29]

Inspection		Class	Procedure	
Internal	External		Evaluation	Action
Healthy wood	Rotten wood			
>0.10m	without	1	Good	None
0.07 to 0.10m	Max. 0.01m	2	Initial decay	Retreat int./ext.
0.03 to 0.70m	Max. 0.02m	3	Advance decay	Retreat Int./Ext.
<0.03m	total	4	Failure	Replace

Different methods are employed to conduct external and internal inspections on wood poles. Such evaluations reveal whether the wood is healthy or rotten and what action should be taken depending on the classification of the wood poles after the inspections. For a wood pole to be classified as class 1, the health of the wood should be >0.10m internally and without any signs of deterioration externally [29]. On the contrary, for a wood pole to be classified as class 4, the internal health of the wood should be <0.03m and the exterior of the wood should show signs of total deterioration. The evaluation table indicates whether the wood pole is good or has initial signs of decay or advanced decay and if the wood pole is almost a total failure. According to the information in Table 2.2, all wood poles that are classified in class 4 should be replaced.

The percentage at which in-service poles deteriorate when using different treatment [29] is indicated in Table 2.3. It has been observed that poles that are treated more frequently have a much longer life span than poles with no treatment [29].

Table 2.3: The influence of preservatives on pole decay classification at different in-service lifetime ranges [29]



It has been noted that in Europe and America, the lifetime of poles range between 25 and 50 years depending on the treatment used [29]. In Europe and America, they use a different treatment to that employed in Brazil. In Australia, they use different types of wood to that used in Brazil, which are treated mostly with CCA. They use eucalyptus timber whose durability ranges from 35-45 years [29]. It has also been noted that there are several factors that affect the durability of poles in service including the quality of poles used and environmental factors including the climate of the particular area, insects and nature of soil [29]. It is noteworthy that all poles that are less than 30 years of age in service should be inspected visually and hammer tested. Furthermore, the results should be recorded [29]. All poles that are more than 30 years old should be inspected by either ultra-sound or drilled. The results thereof should also be recorded and the classes of the poles should be clearly labelled on them [30].

2.3 Conductors

Different types of conductors are used around the world to distribute electricity. This is also the case with Eskom. Different types of conductors are used on overhead lines. This is mainly based on the load and the length of the line. The most common conductors used in distribution networks are aluminium conductors, which include ACC, AAAC and ACSR [30]. Aluminium conductors have advantages and disadvantages. In contrast to copper conductors, which are resistant to corrosion and can easily be repaired, aluminium conductors are affected by corrosion especially near coastal areas [30]. Although the deterioration of the components on the network can be predicted, other failures on the network due to weather conditions and manufacturing errors can occur [30].

Temperature can affect overhead line conductors in several ways:

- ✓ High ambient temperature reduces the cooling effect of conductors and can result in overloaded conductors exceeding the design temperature; and
- ✓ The electrical load can also result in the conductor temperature being above the design load [30].

These factors can have a negative impact on the characteristics of the conductor. The temperature can cause the conductor to sag below the minimum clearance value. High temperatures can cause the material used on the conductor to become soft, which will result in the conductor stretching beyond its elastic limit, exceeding the clearance limit and posing a safety risk to the public [31]. Conductor sag is illustrated in Figure 2.1.

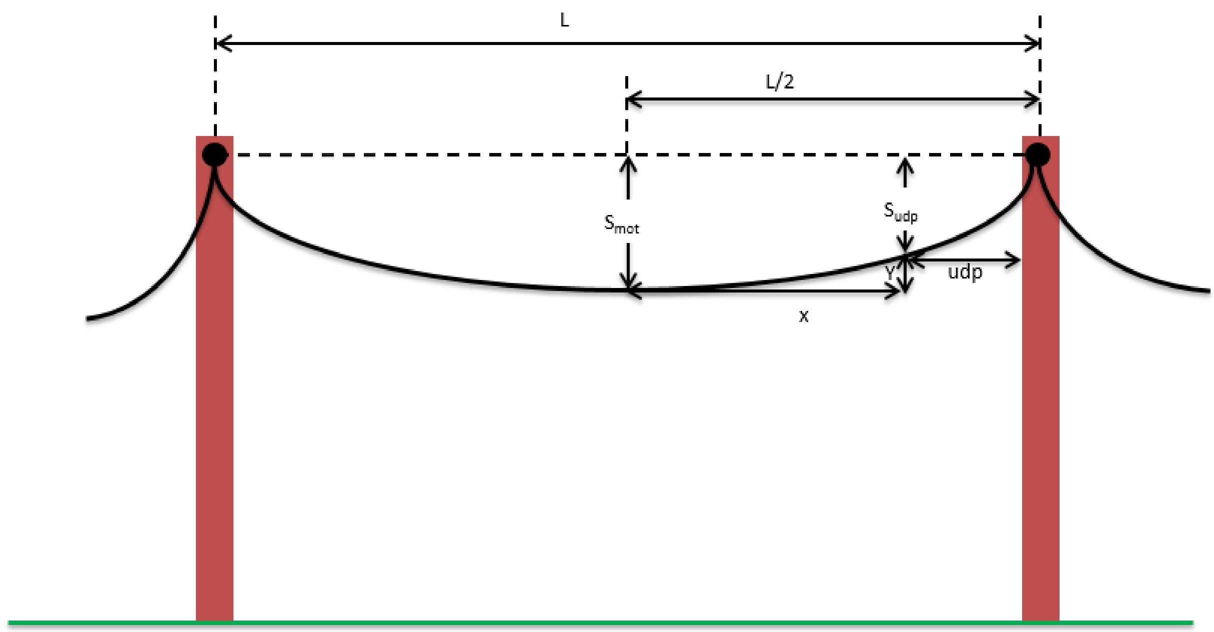


Figure 2.1: Conductor sag at any point along span length [32]

Conductors can withstand high temperatures for a certain period during high current faults without losing their strength. The maximum temperature can rise as high as 340ºC during the fault in aluminum conductors [33].

For a wide range of temperature, the resistance rises almost linearly with temperature for both aluminum and copper. The effects of temperature are simplified as a linear equation (2.1):

$$R_{t2} = R_{t1}[1 + \alpha(t_2 - t_1)] \tag{2.1}$$

Where

R_{t2} = resistance at temperature t_2 given in ºC

R_{t1} = resistance at temperature t_2 given in ºC

α= a temperature coefficient of resistance

= 0.00404 for 61.2% IACS aluminum at 20°C

= 0.00347 for 6201-T81 aluminum alloy at 20°C

= 0.00383 for hard-drawn copper at 20°C

= 0.0036 for aluminum-clad steel at 20°C

Thus, the resistance of aluminum with 61.2% conductivity increases by 4% for every 10°C rise in temperature. The equation can subsequently be interpolated using the resistance at two different temperatures [33]:

$$R(T_c) = R(T_{low}) + \frac{\left(R(T_{high}) - R(T_{low})\right)}{(T_{high} - T_{low})}(T_c - T_{low}) \tag{2.2}$$

Where

$R(T_c)$ = conductor resistance at temperature T_c

$R(T_{high})$ = resistance at the higher temperature T_{high}

$R(T_{low})$ = resistance at the lower temperature T_{low}

The thermal rating of conductors depends on the load they carry before reaching their thermal limits. The thermal rating depends on the size of the conductor used to carry the load. Conductors with a small cross-sectional area reach their thermal limit as the load increases. The thermal rating limits also increase as the size of conductors increase.

2.4 Jumpers

Thermal limits are considered on the jumpers to prevent them from burning and by selecting the right size of the conductor to be used as a jumper. Vibration and poor compression joints can all cause jumper failures if the sizes of conductors are too small. Poor installation and the use of inappropriate connections can also lead to fault conditions. Stays are frequently broken at pole connections especially if eyebolts are used. Stays rarely break due to overloading. Fatigue failures and corrosion are usually the major problems related to the failure of jumpers [30]. The connection of jumpers on a medium voltage overhead line is depicted in Figure 2.2.

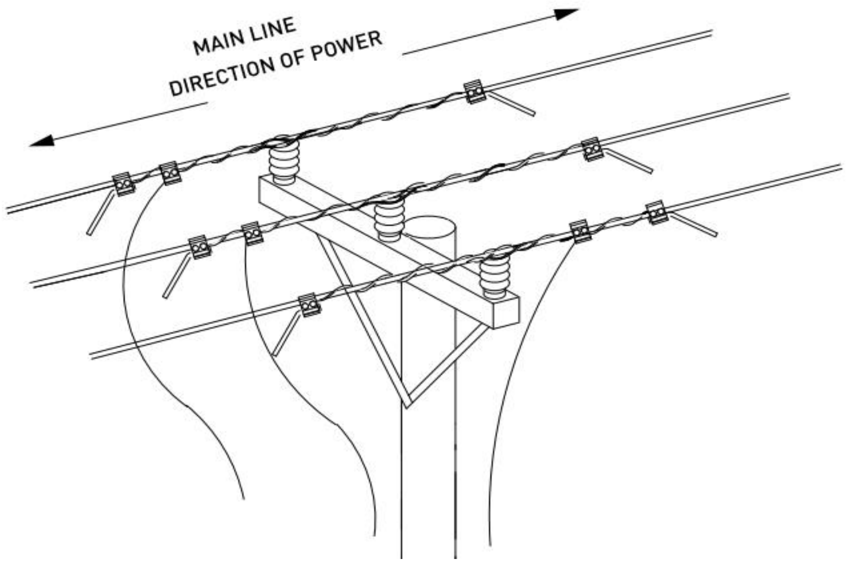


Figure 2.2: Connection of the jumpers on a medium voltage overhead line [34]

Most studies have revealed that jumpers usually fail because of the loose connection between the jumpers and the main line. When the termination is connected to the overhead jumpers, overheating on the conductor results and the jumper is burned [35]. Loose connections increase resistance at the point of the connection, which the generated heat causes to escalate until the thermal failure occurs [36]. The following formula is generally used to calculate the heat [81]:

$$E = Pt \tag{2.3}$$

Where

E= Heat, J

P= Power, A (where $P = \sqrt{3}VI\cos\emptyset$ for three-phase network)

t= time, s

2.5 Pole-mounted transformers

Pole-mounted transformers form part of the medium voltage network in the distribution system. Pole-mounted transformers step down the medium voltage to low voltage that is usable by the consumer and in order to distribute the power to several customers [18]. The area supplied from an MV/LV transformer is known as the transformer zone. Transformers include different ratings, which are selected based on the load they are supplying [22]. The medium voltage network in the townships cannot be used without medium voltage transformers [37].

The maintenance and monitoring of MV/LV transformers are not as important as high voltage power transformers because of the low capital costs [38]. The transformer comprises different parts like power transformers. Transformers comprise windings, tank, bushings and surge arrestors for surge protection. Due to a lack of maintenance, pole-mount transformers have experienced various problems over the years, which have caused the transformers to fail. Pre-mature failure is very common in pole-mount transformers [37]. Known transformer failures that have been studied are thus listed:

- ✓ Winding failure
- ✓ Bushing failure
- ✓ Core failure
- ✓ Tank failure
- ✓ Protection system failure

Ageing of electrical equipment should be managed in relation to a comprehensive maintenance plan and procedures. The objective of maintenance of electrical equipment is to achieve a maximum lifecycle while still effectively protecting it [39]. A study conducted in mainly remote areas in Saudi Arabia where temperatures exceed 50ºC, revealed that pole-mounted transformers are the most affected thus causing pre-mature failure of pole-mounted transformers [40]. Depending on the area of the installation, pole-mounted transformers can be classified into four types:

- ✓ Single-phase transformers;
- ✓ Three-phase transformers;
- ✓ Single wire earth return (SWER) transformers; and
- ✓ Isolating transformers (rarely used in South Africa) [41].

Most of the transformers installed in distribution networks are step down transformers [41]. Depending on the country, transformers can step down the voltage from 44kV, 33kV, 22kV and 11kV to a low voltage of 400V or 230V to supply domestic customers [41]. Transformers mostly fail because of the insulation breakdowns, which are caused by heat (pyrolysis), oxidation, acidity, moisture, design of manufacturing errors, loose blocking, poor brazing, inadequate core insulation, inferior short circuit strength, foreign objects left in the tank, oil contamination, corrosive sulfur, carbon tracking, overloading, fire and explosions, line surges, maintenance/operation, floods and loose connections [27].

Depending on the size of the transformers, pole-mounted transformers are usually mounted on H-pole structures or even single-pole structures. The maximum size of a transformer that can be mounted on a pole is 500kVA [41]. Transformers are usually connected with surge arresters to protect them against sudden surges. As depicted in Figure 2.3, pole-mounted transformers can be protected by using fuses on the primary side against faults that may occur on the line.

Figure 2.3: An example of a pole-mounted transformer [42]

The most studied component on the network is the transformer. Many researchers have designed various models to estimate the remaining life of the transformer insulation. The insulation life can be estimated using the IEEE standard, which applies different temperatures the transformer is exposed to in order to obtain per unit life [27]. With a transformer that was constructed using IEC 60076, the relative ageing rate can be expressed in the following equation [27]:

$$V = 2^{\frac{\theta HS-98}{6}} \tag{2.4}$$

Where θ_{HS} is the hot spot temperature and V is the relative loss of life.

The relation between insulation deterioration to time and temperature can be explained by employing Arrhenius reaction rate theory in which the following equation is used [43]:

$$Per\ Unit\ life = Ae^{\left(\frac{B}{\theta h+273}\right)} \quad (2.5)$$

Where A and B are constants.

Both distribution transformers and power transformers can employ the same equations because they are both manufactured using the same cellulose conductor insulation. The use of this expression also shows that temperature plays a major role in the thermal life of electrical components. The expression further reveals the rate at which ageing is accelerated beyond normal for temperatures above a reference of 110ºC and less than 1 for temperatures below 110ºC [43].

2.6 Network configurations

Different countries make use of different medium voltage network configurations. The reliability of distribution systems not only depends on the reliability of the distribution technology, but is also dependent on the network configuration. Two major models are distinguished [44]. A radial/fishbone network configuration and a loop network configuration are depicted in Figure 2.4 and Figure 2.5, respectively.

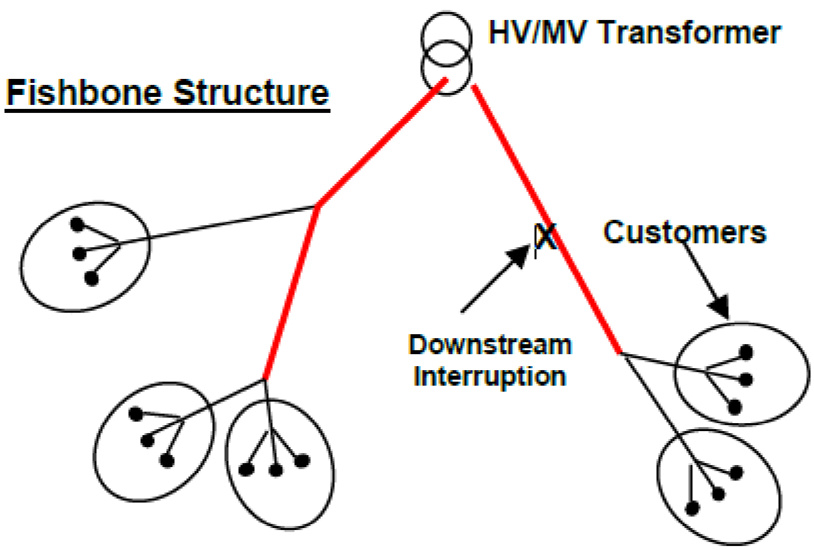


Figure 2.4: Radial/Fishbone network configuration [37]

In a fishbone network configuration, customers may lose energy only in the event of a breakdown on a circuit below the HV/MV transformer. Most of the overhead MV networks are based on this principle and may be subject to failures; in particular, rural areas with forests. France employed this configuration during the 1999 storm [44].

On the contrary, underground MV network configurations are well interconnected in loops. In the event of a breakdown on one branch, low voltage customers can be supplied through another branch from another transformer with very little interruption of the service. Most utilities are working in this direction thus increasing the lengths of underground lines [44]. Researchers have indicated that 13% of the total power generated is in the form of line loss at distribution networks [45].

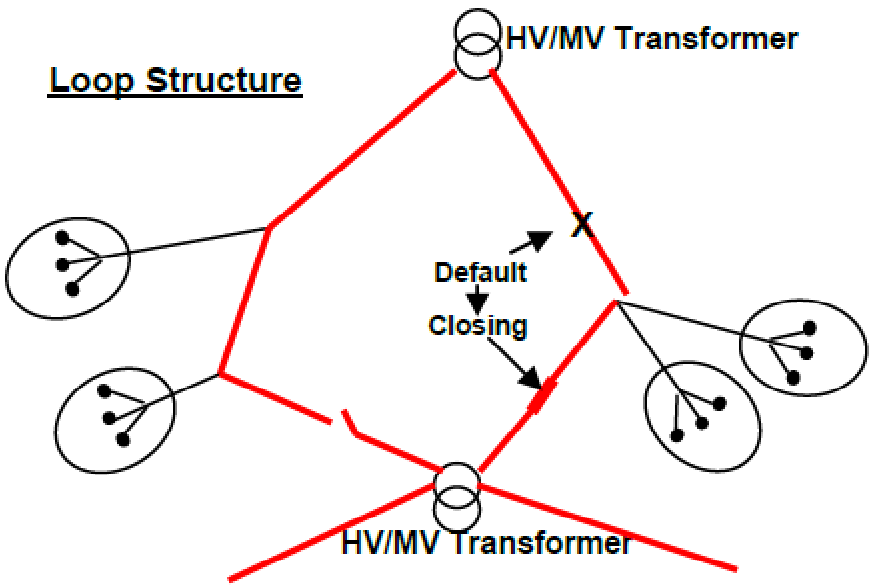


Figure 2.5: Loop network configuration [44]

Network reconfigurations can be implemented to decrease the losses on the system and improve the reliability of the network. Even though many studies have investigated network reconfigurations, they are problematic [45]. In accordance with a study or simulation conducted by S.A. Nagy [45] , load flow was used to calculate the feeder current, network node voltage and network losses. The results of the simulation revealed that the reconfiguration of the network demonstrated high efficiency in power loss reduction [45]. By adding Sectionalization to the network configuration, the reduction of losses can be significant.

2.7 Quality of supply

The supply of South African electricity is regulated by NERSA. The second edition of the NRS 048 covers the voltage parameters that might affect the normal operation of the electrical process to customers. The NRS 048 was compiled by representatives of the South African Electricity Supply Industrial that was appointed by the Electricity Suppliers Liaison Committee. The document takes into consideration the measurements of the quality of supply parameters on South African power networks [46].

The NRS 048-2 focuses on specific voltage characteristics, compatibility levels, limits and assessment methods for the quality of electricity supplied by South African licensees to customers. The purpose of the document is to provide the following [46]:

- ✓ The national regulation with a mean of evaluating and regulating the quality of supply provided by the licensee;
- ✓ Licensee and customers with a reference for establishing the appropriate quality of supply contracts;
- ✓ A licensee with quality of supply standards and criteria for planning, designing, operating and managing the networks;
- ✓ Customer standards and criteria for evaluating the quality of supply delivered by the utilities; and
- ✓ Customers and equipment suppliers with standards and criteria to take into consideration when designing a plant and specifying equipment.

According to the regulations, the LV network has a standard voltage of 230/400V. In the case of HV and MV, the reference voltage is the nominal voltage or declared voltage (a fixed voltage agreed between the customer and the utility) [46]. It is then recommended that the declared voltage is within the limit of 5% of the nominal voltage. The regulation also states that all the phases of the supply voltage should be monitored.

The highest 10 minute r.m.s value is not exceeded for more than 95% of the week and retains the value for comparison with the compatibility level. One should determine the highest 10 minute r.m.s value of the week and retain the value for comparison with limits. For long- term statistical measurements, the assessed values are based on the data remaining after excluding flagged and missing data providing that no more than 95% of the 10 minute value has been excluded [46]. Unless otherwise agreed in a contract between the customer and utility, the compatibility levels for the magnitude of supply voltage are as specified in Table 2.4 [46]:

Table 2.4: Deviation from the standard or declared voltage

1	2
Voltage Level (V)	Compatibility Level (%)
<500	±10
≥500	±5

Eskom and the municipalities are regulated according to NRS 048 in terms of the quality of supply provided to customers. Should they violate the regulation, they could lose their license to supply the electricity. Consequently, it is important to always ensure that regulations are followed at all times.

2.8 Safety

Electricity can be very dangerous because it cannot be touched or smelled and it is invisible. Unsafe distribution electrical networks can pose high safety risks for members of the public. Voltage as low as 230V can kill a person [47]. Ageing wood poles are the highest risk because they carry the conductors that distribute power on the network. During heavy storms, lines may sag and fall if the poles are not strong enough. Sometimes when the line has fallen down, the auto-recloser will eventually trip the line and lock-out. However, at other times, the line remains live and this is when most fatalities occur. Children playing outside are usually at high risk because of their lack of knowledge about electricity.

The survey depicted in Figure 2.6 [47] highlights the fatalities that occurred in the United Kingdom from 1997 to 2006. The survey only included members of public and third party contractors.

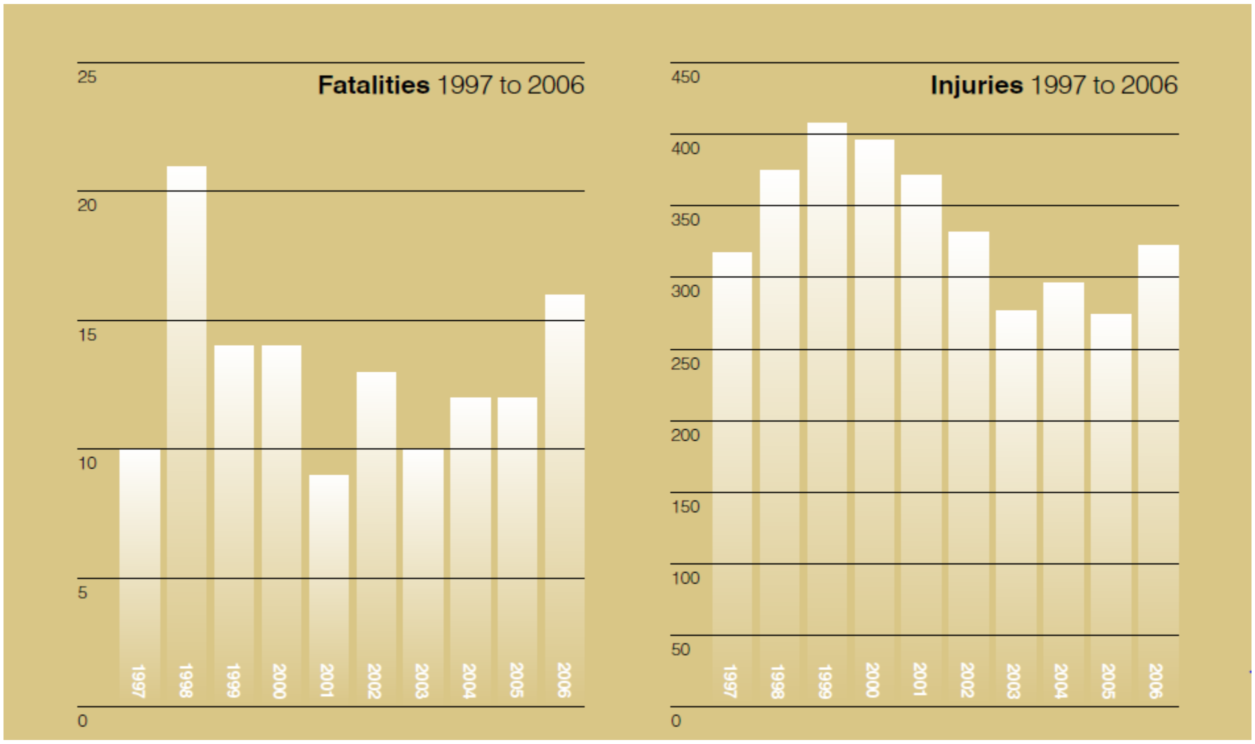


Figure 2.6: Incidents which include members of public and third party contractors [47]

An examination of Figure 2.6 reveals that during the nine-year period of the survey, most of the fatalities occurred in 1998 and most of the injuries in 1999 when there was over 400 injuries. A study conducted in Ankara, Turkey revealed that most of the injuries and fatalities occurred in the workplace [48]. It is suggested that most electrocution injuries and fatalities happen because of a lack of knowledge about electrical equipment and/or lack of programs to warn workers and members of the public about the dangers of electricity.

Broken and fallen poles can pose safety risks for the public and field service workers if they are not reported on time. A broken pole that has fallen down because of severe deterioration is shown in Figure 2.7[49].

Figure 2.7: Broken utility wood pole [49]

A wood pole deteriorates after being in service for a long period of time [4]. The deterioration of poles depends on the location or area of service. In some areas, wood poles take much longer to show signs of deterioration while in other areas; they only last for a short period. Most of the poles begin to deteriorate from the inside. This is very difficult to detect until it is too late unless necessary maintenance is performed on these poles. Wood poles that have deteriorated to the extent in Figure 2.7 affect the safety and performance of the electrical network when they fail. Deteriorated wood poles not only pose a risk to the members of the public, but also to field service workers who are doing maintenance on the poles. As noted previously, most of the incidents related to electrocution occurred in the workplace in Ankara, Turkey [48].

Deteriorated poles such as that depicted in Figure 2.7 are classified as class 4 poles and should be replaced as soon as possible after inspection. However, in most cases, due to the financial constraints electrical utilities around the world encounter, these class 4 poles remain in the network and compromise the safety of animals, members of the public and workers. Deteriorated wood poles lead to pre-mature failures, which have an adverse effect on electrical utilities if there are no plans in place.

2.9 Performance of the network

The performance of the network is measured according to the number of interruptions that affects customers. Different systems are used to measure these interruptions throughout the world. The most common systems that are used widely around the world include the SAIDI and SAIFI key performance indicators (KPIs). Various other new indicators are being implemented in other countries to monitor the performances of networks. Operation indicators form part of other KPIs that govern the world of electrical utilities [50].

The performance of an electrical network is monitored by employing different KPIs, which are based on the regulations of the specific country. Some of the common KPIs that are employed throughout the world are depicted in Figure 2.8.

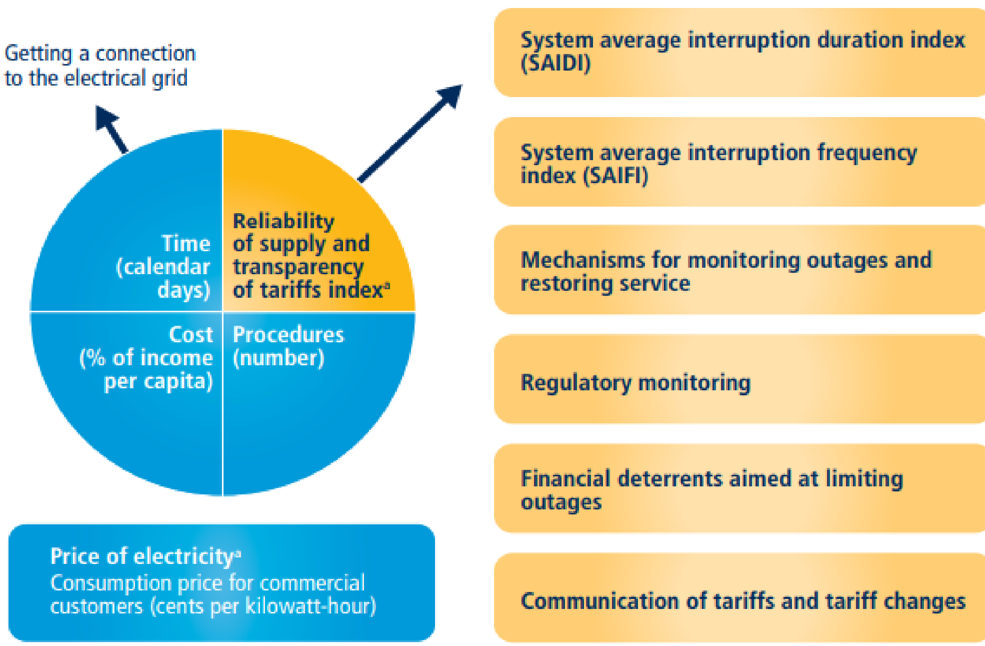


Figure 2.8: Some indicators that have been implemented [50]

The performance of an electrical network does not only affect the customers, but also the revenue of the particular utility. An unreliable network can have negative impacts on the business and economy. Studies have indicated that outages have contributed to very unreliable networks around the world, which involve planned and unplanned outages [50]. In Figure 2.8, how the reliability of a network affect tariffs is illustrated. The better the performance of the electrical network, the higher the income capital will be for the utilities. In most countries, the number of customers connected to the grid is also monitored.

The number of outages on the electrical network determines the performance of the network. In Figure 2.9, the total duration of power outages that occurred in different countries for a period of one year (year 2013) is shown.

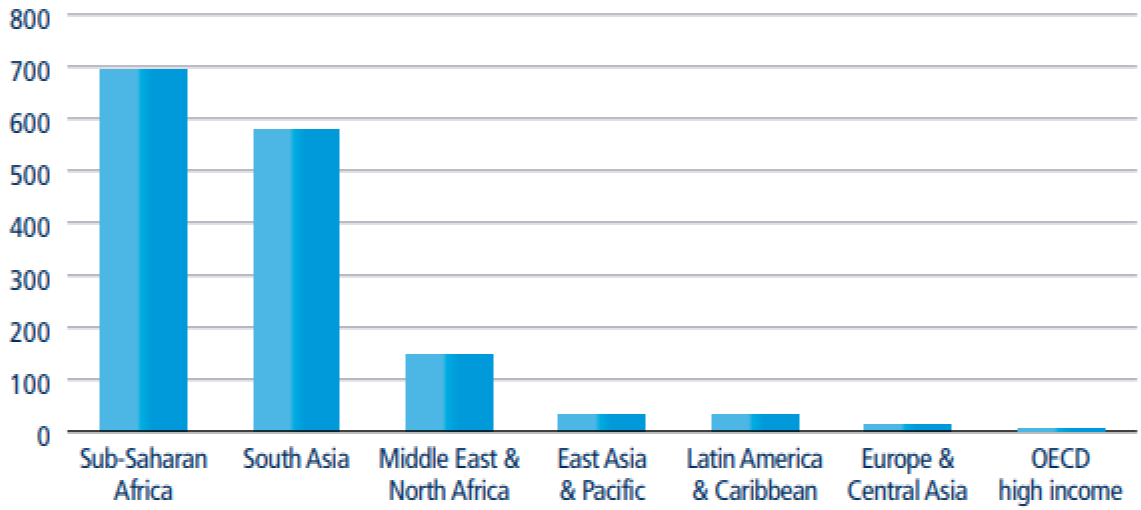


Figure 2.9: Average total duration of power outages in a year around the world [50]

Figure 2.9 reveals that Sub-Saharan Africa had the most duration power outages for customers for a year in 147 economies throughout the world. This basically means that customers were without electrical supply for an average of 700 hours during a year [50].

The number of outages that occurred over a period of one year (year 2013) in different parts of the world is depicted in Figure 2.10. South Asia had more than 200 outages for a year. This is higher than other parts of the world.

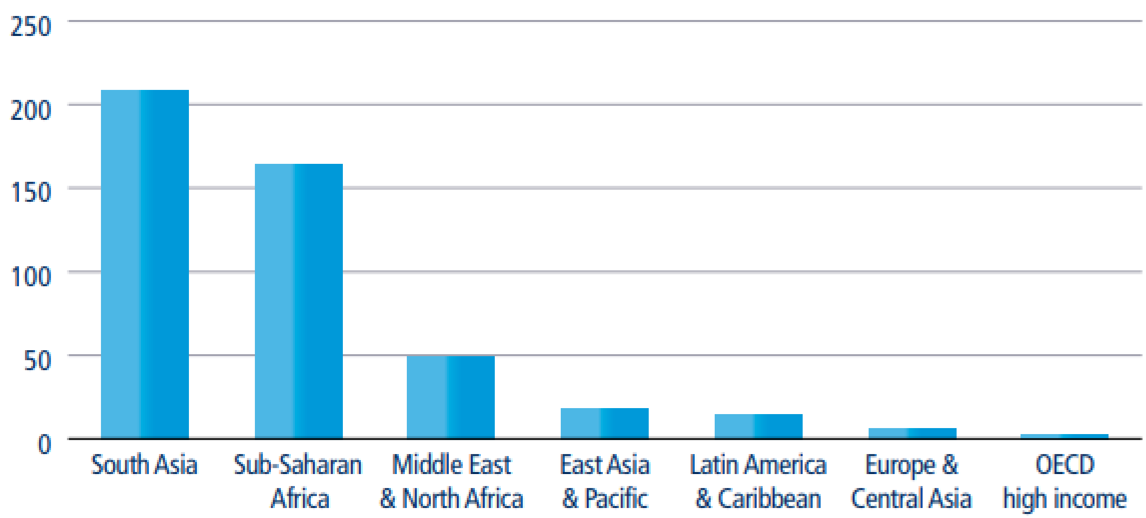


Figure 2.10: Electricity customer average frequency of power outages

Figure 2.10 reveals that South Asia has the highest number of power outages in a year with an average of over 200 outages a year. This is followed by Sub-Saharan Africa with an average of over 150 outages a year [50]. Outages can have a negative impact on an individual's quality of life. Small businesses are also affected by the outages or interruptions if the restoration time is too long. Schoeman [51] emphasized the disadvantages of long outages and how they affect small businesses around Johannesburg. Because of these outages, small businesses are forced to reduce their labour force because of insufficient income [51]. SAIDI and SAIFI can also be employed on medium voltage networks to measure their performance. Various studies have been conducted to identify which sections of the MV lines can contribute to the value of SAIDI and SAIFI [52].

Interruptions occur because of different reasons depending on the location of the network. The benchmark for the performance of the network depends on the regulatory body of the specific country. In some countries, trees that fall on the network or clash with the network contribute the most to interruptions [53]. Benchmarking of electric network performance is very important because it assists the utilities to locate where the issues are on the network and how they should be resolved so as to realize reliable networks that have minimum planned and unplanned outages [53].

2.10 Financial implications

The cost of medium voltage electrical network infrastructure can be very costly if not planned correctly. There have been numerous developments in most countries throughout the world to ensure that each household has access to electricity [54]. Most semi-urban areas that were electrified prior to 1990 in South Africa were designed using low-cost material available at the time. Previously, there was a perception that customers who live in rural areas and semi-urban areas do not utilize electricity as much as predicted; consequently, the network was designed according to their utilization. Load limitations are displayed in Table 2.5.

Table 2.5: Load limitations [46]

Supply Option	Connection fee	Level of Service
2.5Amp (some cases directly upgradable to 20 Amp)	0	Four lights, monochrome TV, small radio. Unmetered supply
20 Amp	R150	Lights, colour TV, radio and additional small appliances. The most common option for rural homes in South Africa is a prepaidmeter
40 Amp	R500	All normal electricity requirements in high income households or small businesses. Credit or prepaid meter
60 Amp	R1000	All normal electricity requirements in high income households or small businesses. Credit or prepaid meter

In recent years, the use of low ADMD in semi-urban areas and rural areas has proven to be a problem for pole-mounted transformers due to overloading. Therefore, electrical utilities and municipalities spend more money trying to normalize electrical networks in semi-urban areas [54]. Normalizing old electrical networks or refurbishing the old medium voltage electrical network does not increase revenue for the utility. Nor does it extend the lifespan of the existing network, ensure a reliable network and guarantee the safety of community members. In most cases, the maintenance of electrical networks in townships is not a high priority. The cost of re-configuring electrical networks escalates every year as a result of declining economies in most countries.

Using low quality material can have a negative impact on the finances of the electrical utility because such material is likely to deteriorate long before its designed lifespan. Thus, if the network was planned to last for 40 years, it may only last for 20 years and the utility will be forced to refurbish the infrastructure that was not planned.

2.11 Summary

The ageing of electrical components, especially important electrical network components has been widely studied throughout the world. Literature related to medium voltage components on an electrical network was reviewed in this chapter. The performance of electrical networks depends mostly on utilization, the environment and its lifespan. Studies have revealed that the deterioration of most electrical components depends on the material used during manufacturing. As noted in this chapter, electrical components that include pole-mounted transformers, wood poles, jumpers and conductors have different ageing characteristics. These components are used differently on the network; hence, their failure rate varies.

When electrical components reach a certain level of deterioration, they have a high probability of failure, which can compromise the safety of the employees and members of the public. Electricity is invisible and thus, very dangerous. Consequently, if safety is compromised, severe injuries or fatality will result. The performance of electrical networks is measured according to certain KPIs depending on the particular country. KPIs, which include the SAIDI and SAIFI, are widely used by many electrical utilities around the world. These KPIs are set by the regulators of those countries. Pre-mature failures on the network result in financial implications for the electrical utilities if they were not planned. The cost of re-configuring the electrical network or refurbishing ageing infrastructure continually increases.

The literature review in this chapter has shown that ageing of electrical infrastructures not only affect the performance of the electrical components and networks, but pose safety concerns for humans and animals.

CHAPTER 3- METHODOLOGY

3.1 Introduction

The ageing of electrical infrastructures was examined extensively in Chapter 2. The purpose of Chapter 3 is to explain the research methodology that was employed in the present study. This chapter comprises the research approach, flow chart and methods that were used to collect data that were analyzed. The aim of this study was to investigate the influence of ageing infrastructure, the environment and loading on medium-voltage components on the electrical network, which can affect the safety, quality of supply and performance of the networks in semi-urban areas. The lifespan of most of the electrical networks that were specifically designed for supplying the semi-urban areas in the Northern Cape has been reached. Most recent studies have focused mainly on suburbs and urban areas. This study focused on semi-urban areas (townships) because this is where most of the customers in South Africa live [49].

The medium voltage electrical networks in the Northern Cape, in particular, in the semi-urban areas are mostly overhead lines and consist of only a few underground networks. Several data collection methods including visual inspection, load studies and performance trends are provided in this chapter.

3.2 Research approach

The research approach is the plan employed in research studies to achieve specific results to support a study [55]. The approach comprises three main components, which guide the researcher throughout the study to obtain the results that can be analyzed and interpreted. The three main components include the philosophical worldview, research design and research methods [55]. Each component consists of various options, which can be followed to achieve the results. The options included within the three main components are presented in Table 3.1.

Table 3.1: Three main components in research approach

Philosophical Worldview	**Strategies of inquiry**	**Research Methods**
Post positivist	Quantitative strategies	Questions
Constructivist	Qualitative strategies	Data collection
Transformative	Mixed method strategies	Data analysis
Pragmatic		Interpretation
		Validation

3.3 Strategies of enquiry

The research design comprises three main sources of collecting data, namely, qualitative methods, quantitative methods and mixed methods [56]. Qualitative sources include interviews, field observations and informal discussions while quantitative sources incorporate questionnaires and interviews [56]. Due to the nature of this study, the qualitative approach was utilized to collect relevant data. This study employed observations for specific locations selected as means of collecting data. Software simulations were also employed as one of the methods to collect data. It was envisaged that those approached would assist the researcher to collect enough data to support the investigation on the ageing of electrical components and how they affect the performance of the network on MV lines that supply the townships.

3.4 Criteria

The aim of this study was to investigate the influence of ageing electrical components, the environment and loading on medium voltage components on the electrical network, which can affect safety, quality of supply and performance of the networks in semi-urban areas. There are many townships that are located in the Northern Cape, making this province different to other provinces because of the province's size. The criteria used to select the townships with ageing MV electrical networks are presented in Table 3.2.

Table 3.2: The criteria used to select the semi-urban areas to be studied

Criteria for Selecting the Townships for this study				
Name of the Township	**Age**	**Configuration**	**Number of Customers**	**Location**
1. Sizamile	27	Overhead Line	±520	Port Nolloth
2. Newtown	31	Overhead Line	±1000	Postmasburg
3. Kuyasa	46	Overhead Line	±2603	Colesberg

3.5 Selected semi-urban areas

Each of the selected networks had a different number of customers, which ranged from approximately 520 to 2 603. Furthermore, they were located in different areas in the Northern Cape. While towns in mostly urban areas are normally supplied by municipalities, most of the semi-urban areas are supplied directly from Eskom. The overhead lines that supply the selected semi-urban areas are presented in Table 3.3.

Table 3.3: Selected semi-urban areas

Overhead Line	Township Name	Area
Muisvlakte- Port Nolloth 11kV OHL	Sizamile Township	Port Nolloth- Springbok Area
Colesberg- Coleskop 11kV OHL	Kuyasa Township	Colesberg Area
Postmasburg- Boichoko 11kV OHL	Newtown Township	Postmasburg Area

All the selected networks had overhead lines thus making it easy to analyze their physical condition with the aid of a camera. Some of the ageing components could easily be detected by mere visual inspection although some had to be tested. Although the corrosion on some of the components could easily be detected, it was challenging to detect the decay inside wood poles unless tested with special testing equipment.

3.6 Methodology flow chart

The effects of ageing electrical components on the medium voltage network could be observed in various ways and the results obtained by employing different types of methods. This is depicted in the methodology flow chat in Figure 3.1.

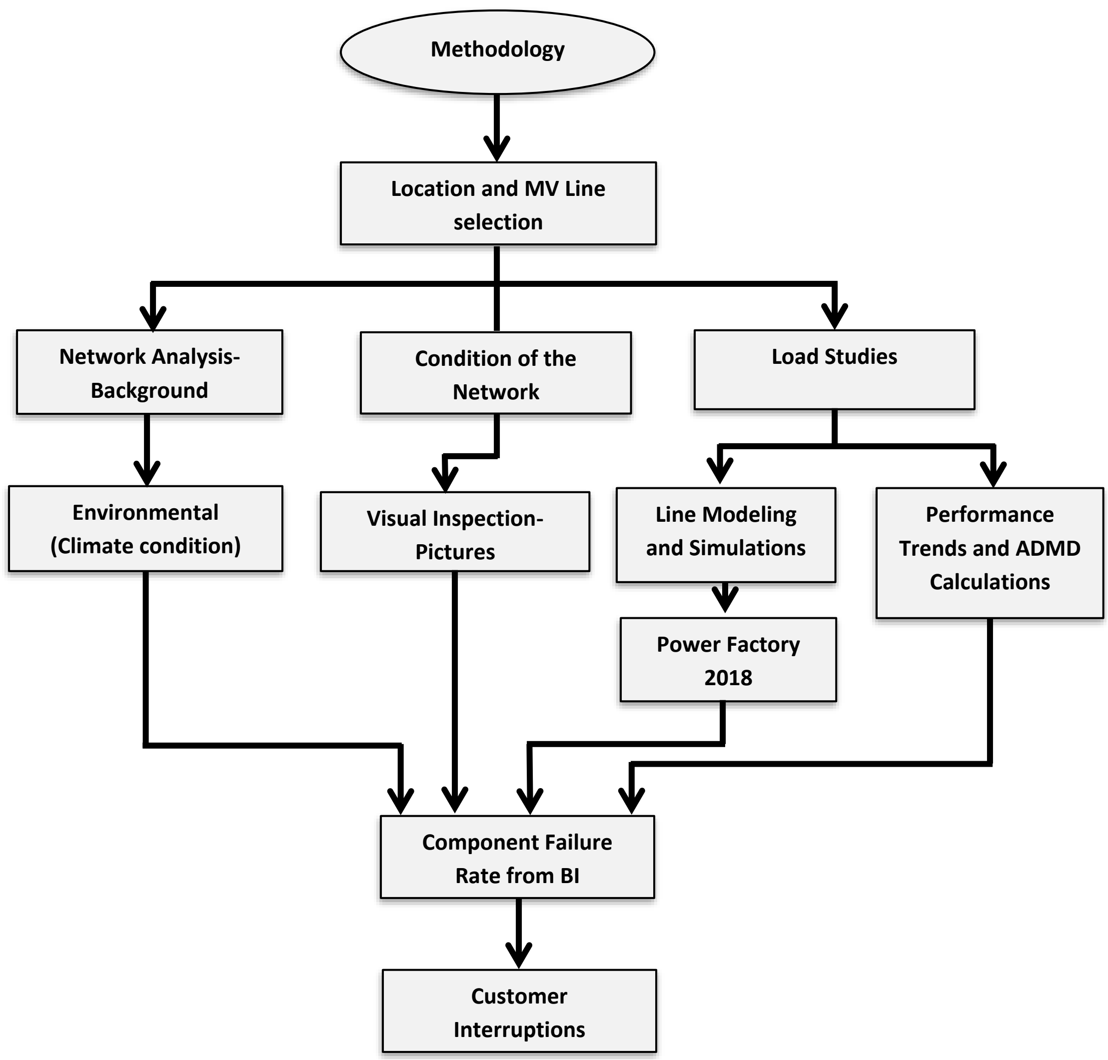


Figure 3.1: Methodology flow chart

The methodology comprised three sections: background information of the selected networks, condition of the network in terms of physical appearance and load studies of the lines selected. The network condition includes a detailed discussion of climate. The climate can affect the rate at which the network deteriorates [7]. While some of the components on the network are designed for certain types of environment, others are generic and can be installed anywhere.

The physical condition of the network was observed through site visits and photographing the defects on the network. The main methods included background checks of the selected networks and their age profile, that is, when were they first installed and commissioned. The climate of areas in the Northern Cape varies, ranging from desert to coastal conditions [57]. Capturing the defects on the line assisted the researcher to define the type of defects that were experienced at the different networks. The expected defects in coastal areas were not the same as the inland areas, particularly if the metallic surfaces were not galvanized [58].

Heat plays a significant role in the acceleration of the ageing of components [59]. Ambient temperature has a deleterious effect on the ageing of components, especially pole-mounted transformers [60]. The results or the effects of ambient temperature are evident through the leaking of pole-mounted transformers [60]. When the number of customers i on the network increases, the load connected also increases, which leads to high temperatures in the conductors, jumpers and transformers. Wood poles are widely used throughout the world for overhead lines. Depending on the type of treatment they underwent during manufacturing, they can have a long lifespan [61]. Climatic conditions can have a negative impact on the lifespan of wood poles [4]. Ageing wood poles can break easily during bad weather conditions and can lead to many unplanned outages, which result in customer interruptions.

Thermal loading studies include modelling the network in software to determine how much load is connected per transformer zone. To model the network, software such as DigSILENT Power Factory 2018 SP3 was employed. MV lines are much longer than normal in the Northern Cape because of its size. Consequently, voltage drops are experienced on a regular basis in long networks. ADMD calculations determine how much load is connected per transformer zone as well as how many customers should be connected per transformer zone.

3.7 Climate conditions

The climate in South Africa includes coastal, desert and semi-arid (Highveld) regions. The selected areas were located in areas with different climates [57]. The various climate conditions in South Africa are depicted in Figure 3.2. Northern Cape is the largest province in South Africa and the climate of its areas varies. Selected townships or MV lines supplying the selected townships are also depicted in Figure 3.2. The selected areas included Sizamile Township, which is supplied from the Muisvlakte-Port Nolloth 11kV overhead line, Newtown Township, which is supplied from the Postmasburg-Boichoko 11kV feeder, and Kuyasa Township, which is supplied from Colesberg-Coleskop 11kV overhead line.

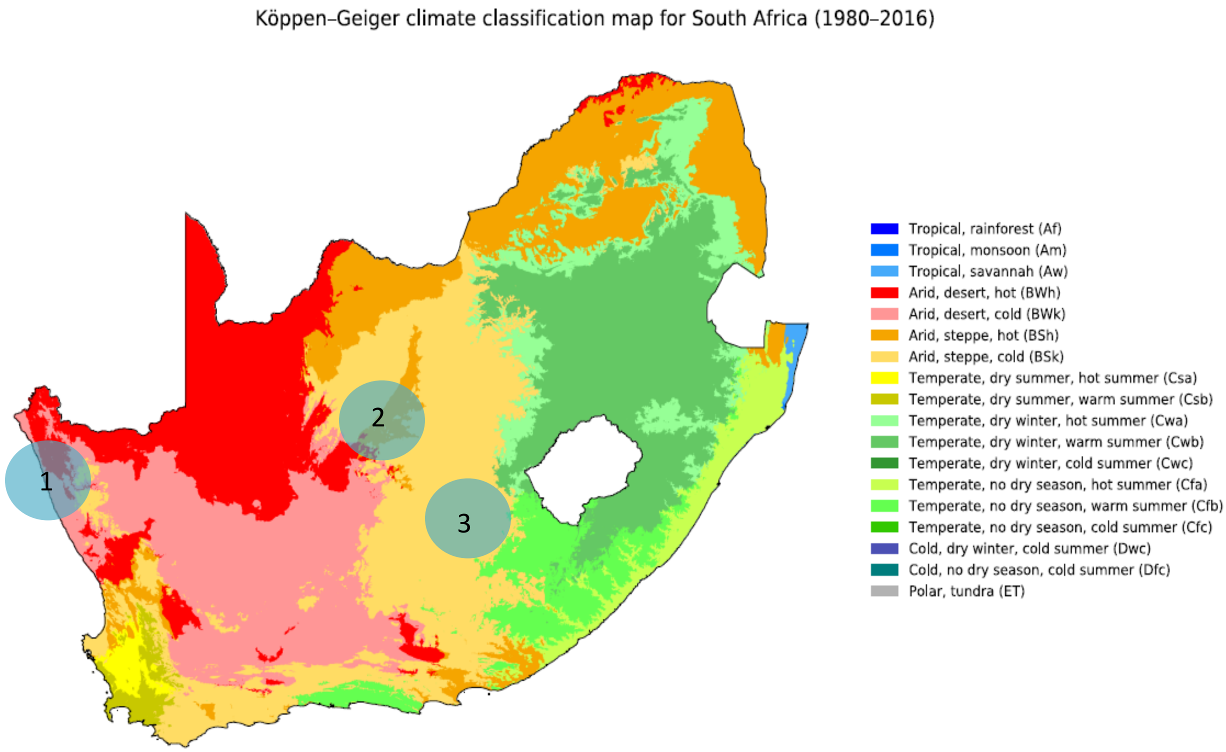


Figure 3.2: South African climatic zones [62]

The electrical network ageing characteristics of the different areas varied from one another. The networks in the areas with high humidity deteriorated more quickly than the networks located in low humidity areas [63]. The three selected areas of study were in various areas in the province. Sizamile is located in an arid, desert and coastal region that has extremes in temperature. Newtown is located in the Postmasburg area and is characterized by an arid hot climate. Kuyasa is located in Colesberg area and is marked by an arid cold climate.

3.8 Methods

3.8.1 Method 1: Visual inspection

The period during which an area was electrified is very important because it indicates where the components on the line were first commissioned and if it remains operational. Components such as the conductor, transformers and insulators are designed to operate for a long period, but only if they are maintained according to their routine maintenance and design specifications [5]. Weather plays an important role in the ageing of the components on the line [7]. Exposed components including overhead lines are more exposed to the changing environment. The impact of weather on the electrical components cannot be determined over a short period of time. However, severe damage can occur over many years as well as during severe storms, which are rare in South Africa.

The condition of the line could only be determined by visiting the site and taking photographs to check for the following signs:

- ✓ Deterioration from poles including cracks on both the poles and cross-arms;
- ✓ Corrosions on stays and jumpers;
- ✓ Oil leakages from the pole-mounted transformers;
- ✓ Sagging on the conductors, which might pose risks of electrocution for members of the public and animals;
- ✓ High tension on the conductors;
- ✓ Damage on the insulators; and
- ✓ The configuration of the network to determine whether it is a radial or ring network.

The general observation assisted in highlighting the high-risk areas based on the photographs taken. The process, which was followed to collect the data, is shown in Figure 3.3.

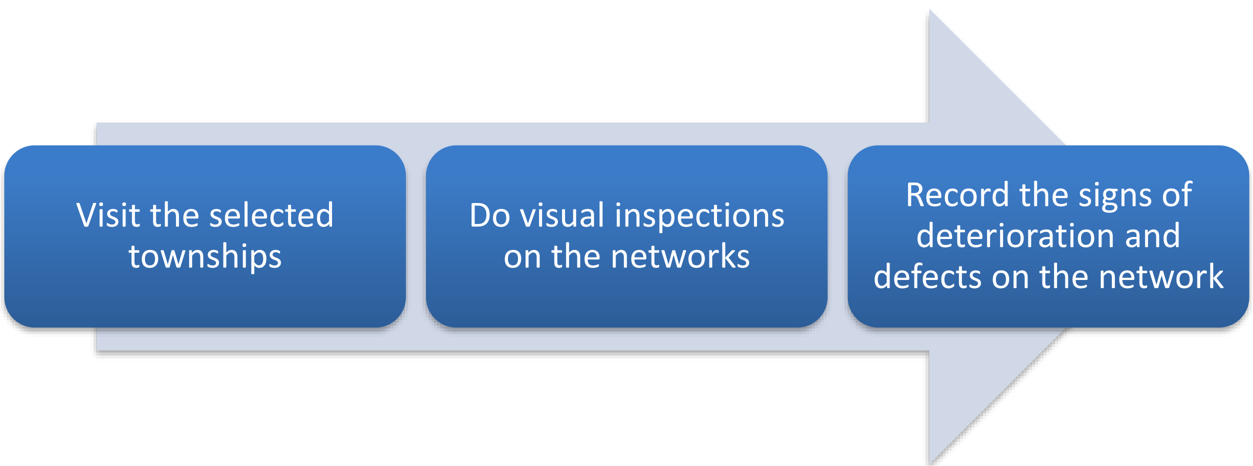


Figure 3.3: Visual inspection flow diagram

3.8.2 Method 2: Loading studies

3.8.2.1 DigSILENT Power Factory 18

DigSILENT Power Factory is the software that most utilities employ to conduct studies on generation, transmission and distribution networks. The main focus in this study was the medium voltage networks, which are classified as distribution. Power Factory allows one to model any network to conduct performance, reliability and loading studies. The correct information must be used and scaled accordingly to ensure the software works correctly.

Many functions can be obtained once the network has been modelled. The results can be obtained from the software and the results for different models compared. The block diagram shown in Figure 3.4 illustrates the process of running a load flow on Power Factory in order to obtain the voltage profile [64].

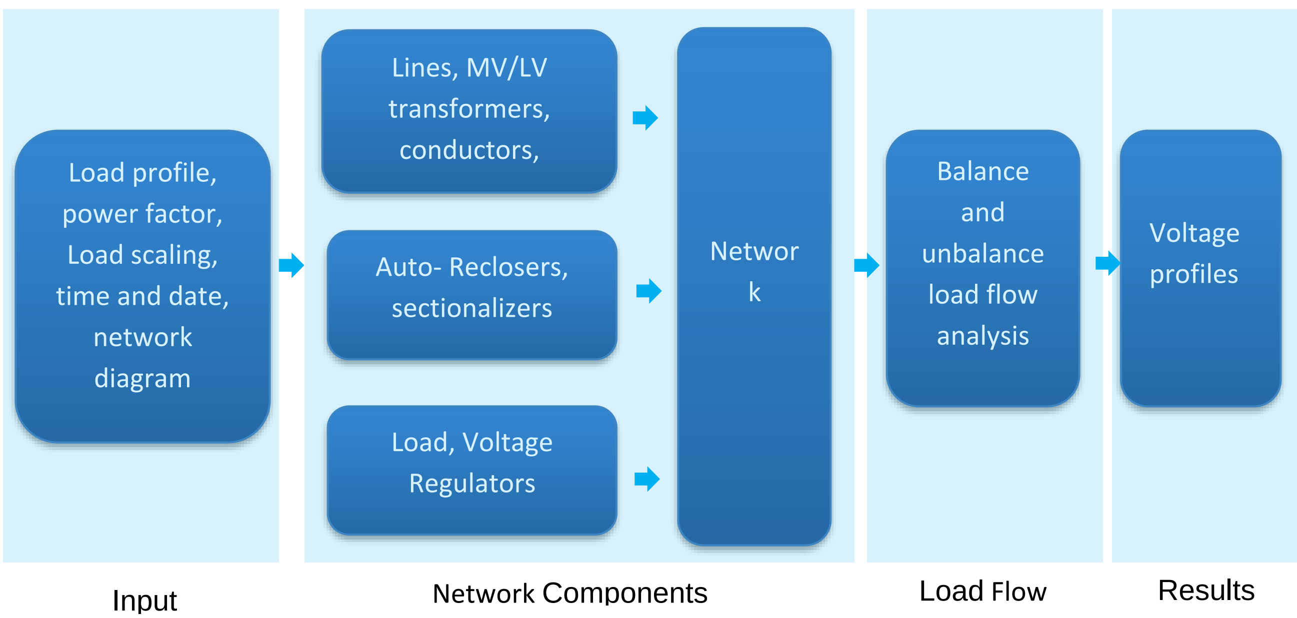


Figure 3.4: DigSILENT Power Factory

Power Factory is an effective software employed to conduct simulations for electrical networks throughout the world. In order to model the electrical network within Power Factory, correct specifications, which include load profiles, load scaling, data and time together with the correct power factor, should be included in the model. In this study, the inputs which included the load profile, detailed characteristics of the line and all relevant information regarding the MV overhead line were imported into Power Factory. Once the relevant data are imported into Power Factory, components can be defined to show results that are similar to the real time results.

3.8.3 Method 3: Calculations

3.8.3.1 After Diversity Maximum Demand (ADMD) calculations

The load on the electrical network was determined by the number of customers connected. Each transformer zone was determined by the number of customers connected per phase. To determine how many customers should be connected per transformer, the ADMD calculations were performed. The design of the network was applied by employing NRS 069: 2004 [65]. The calculations assisted the researcher in identifying the ADMD that was currently used on the selected electrical networks.

According to the table specified in the NRS 069: 2003 standard and NRS 034, for rural settlement, the ADMD ranges from 0.42kVA to 0.5kVA because of the high possibility that there might not be enough growth in the future. The designs of network configurations are different from one another. Therefore, the ADMD is also different depending on the area of supply. The following calculations assisted the researcher in determining how many transformer zones should be installed in the township [65].

$$ADMD = c\frac{a}{a+b}\ x\ \frac{230}{1000} \tag{3.1}$$

Or

$$ADMD = \frac{MD*90\%}{n} \tag{3.2}$$

Or

$$n = \frac{MD*90\%}{ADMD} \tag{3.3}$$

Where;

ADMD = Adverse Diversity Maximum Demand in kVA

MD = Maximum Demand in KVA

n = number of customers on the loaded phase on the network

α, b and c = Beta probability curve parameters

3.9 Component failure rate

In terms of performance, Eskom is assessed based on how many hours the customers (CIH) were affected and the number of customers (CI) affected. The data used for the calculations was derived from SCADA (Supervisory Control and Data Acquisition) and verified by the field service workers. The information indicated how many times the components on the line failed and how many customers were affected because of the specific component that failed. Component failure rate also measured the number of hours the customers were interrupted. All the failures that happened on the network were monitored on component failure rate. This provided a summary of the interruptions that occurred on the network over a period of time to determine the trends of failures. The data were collected over five years, from 2013 to 2018.

3.10 Summary

Several approaches and methods are employed in the research environment to collect data, which can be used to support research. The research approaches guide researchers to follow certain frameworks or plans to collect data. The research approach may comprise three main components including a philosophical worldview, strategies inquiry and research methods [55]. The research design consists of three main sources, which can be used to collect data: qualitative sources, quantitative sources and mixed methods [55]. The relevant approach to collect data was discussed in this chapter and the criteria used to select the MV lines to be studied were outlined. A flow chart showing the process that was followed to obtain the relevant results was discussed.

The literature revealed that the environment is one of the main factors that affects the age of the electrical network. The climate of the selected areas in the Northern Cape was explained. The three primary methods selected to collect data for this study were observations, simulations and performance trends, which all revealed electrical component failures on the network thus determining the performance of the network. The multiple methods employed in this study helped clarify the rate at which the electrical components deteriorated.

CHAPTER 4: RESULTS AND DATA ANALYSIS

4.1 Introduction

The aim of this study was to investigate the influence of ageing electrical components, the environment and loading on medium voltage components on the electrical network, which can affect safety, quality of supply and performance of the networks in semi-urban areas. Data were obtained from different sources, namely, visual inspections, simulations and calculations. The ageing of the components installed on the network age vary from one another depending on their utilization. Furthermore, the components exposed to high humidity age much quicker than those in environments where humidity is low [66]. Components that are made of steel react differently in relation to the climate to which they are exposed [66]. This study focused on components installed on medium voltage networks in semi-urban areas.

To analyze the condition of the network on site, photographs were taken to highlight some of the defects that occurred on some of the selected networks. Specifically, the photographs were taken to analyze how each network deteriorated and whether the effect was because of the area/location or the utilization. Accelerated ageing was mainly the result of heat generated within the component as well as the climate where the network was located [40]. Wood pole structures reacted differently to the environment [4]. The most important factor taken into consideration was the treatment they received before they were commissioned.

The condition of the network usually results in interruptions. Because of the number of customers connected to these networks, a few interruptions can decrease the performance of the network in general. Electrical utilities throughout the world are measured in accordance with the KPIs set by their national regulatory bodies [67]. The most commonly used performance indicators include SAIDI and SAIFI, which measure the duration customers were interrupted and how frequently they were interrupted. Planned and unplanned interruptions can be tracked over a certain period and can be calculated to determine the performance improvement. The preliminary results were also presented at SAUPEC Conference, which was held at Central University of Technology in January 2019. A journal article in which the preliminary results for this study were discussed was also accepted. The paper can be found in Annexure A.

4.2 Network analysis

4.2.1 Reticulation network 1

Sizamile Township is one of the townships in Port Nolloth, which is approximately 150km from Springbok. Sizamile is supplied from the Muisvlakte-Port Nollorth 11kV overhead line, which comes from the Muisvlakte Substation, approximately 9km away. At the time of the study, there were approximately 520 customers in Sizamile with five pole-mounted transformer zones. The township had 4x200kVA pole-mounted transformers and one 50kVA pole-mounted transformer. Most of the customers connected in the Muisvlakte-Port Nolloth 11kV overhead line were prepaid customers. Sizamile is one the few semi-urban areas that is near the coast in the Northern Cape. Port Nolloth and Sizamile are part of Richtersveld Local Municipality. Port Nolloth was first established in 1854 as a small-vessel harbour [68]. Sizamile was previously an informal settlement where black people resided [68].

Black people started moving to Port Nolloth in 1921 and later moved to Sizamile, then an informal settlement. Sizamile was officially established in 1993 when the electrification project was initiated [68]. The original network is still operating. Due to the salty moisture from the ocean, most of the components are exposed to rust. The Muisvlakte-Port Nolloth 11kV overhead line was constructed by employing different types of conductors with different current ratings. The lines include three different types of conductors including the main line, which is known as the backbone and the T-offs. The main backbone is made of Oak conductor and the T-off going to Sizamile is made of FIR conductor. The Muisvlakte-Port Nolloth 11kV conductor type is illustrated in Figure 4.1.

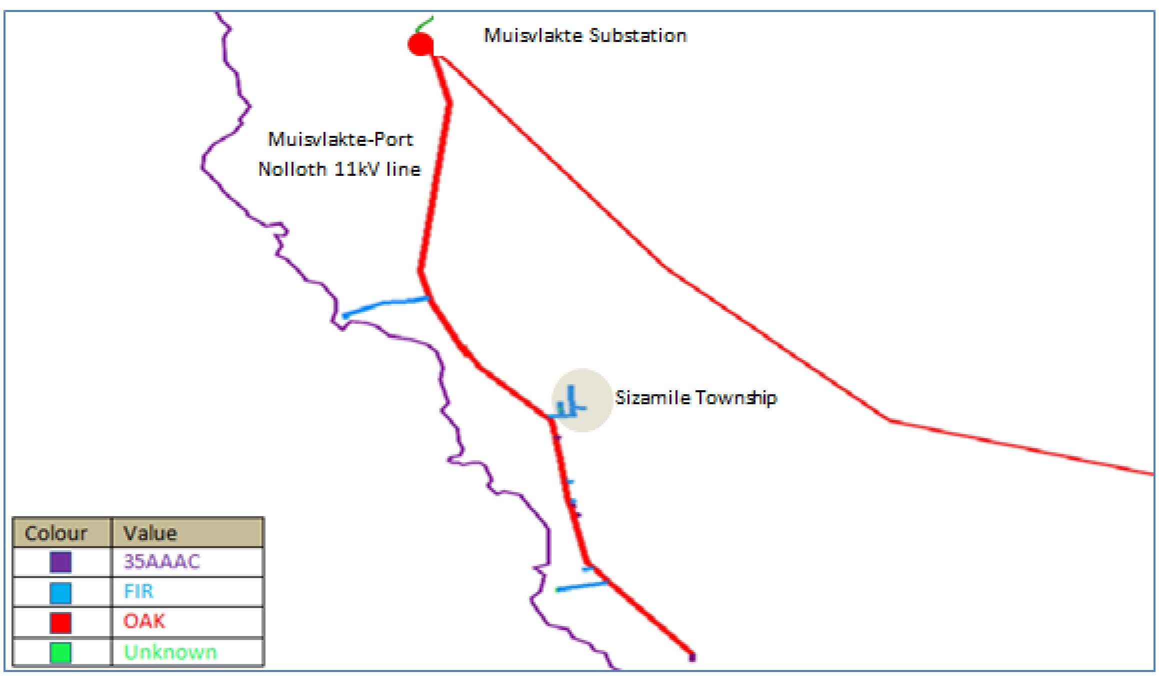


Figure 4.1: Muisvlakte-Port Nollorth 11 kV conductor type

4.2.2 Reticulation network 2

Kuyasa Township, also known as Colesberg Township, is situated in Colesberg and had 2 603 customers in 2018 [69]. The township is supplied by the Colesberg–Coleskop 11kV overhead line, which comes from Colesberg substation. The network comprises both MV and LV. The latter is supplied by an aerial bundle conductor while MV uses both open and covered bare conductors. The Colesberg-Coleskop 11kV overhead line was built in 1974 and it was built as a radial network. Kuyasa is located next to Colesberg, which is approximately 235km from Bloemfontein. Most of the customers supplied from the Colesberg-Coleskop overhead line were PPU (Prepaid Power Users) customers who mainly resided in Kuyasa. The Colesberg-Coleskop overhead line was initially built to supply the farmers in the area and Colesberg before the development of Kuyasa.

The length of the line including all the T-offs and the main backbone is approximately 300km. The line also supplies the farmers around the Colesberg area. Colesberg is currently being serviced by Umsobomvu Local Municipality [69] while Kuyasa is serviced by Eskom. The Colesberg-Coleskop overhead line consists of different types of conductors, ranging from small conductors to large conductors, that is, Rabbit, Magpie, Fox, Squirrel and Mink conductors. There are two types of networks on this line: a single-phase conductor known as SWER and a normal three-phase network. The section of the network known as SWER mainly supplies the farmers located in remote areas. Customers are supplied from SWER networks usually do not use large loads. Most of the wood pole structures for three phase systems are T-frame structures and some are wishbone structures. The electrical network layout of the Postmasburg-Boichoko 11kV overhead line is depicted in Figure 4.2.

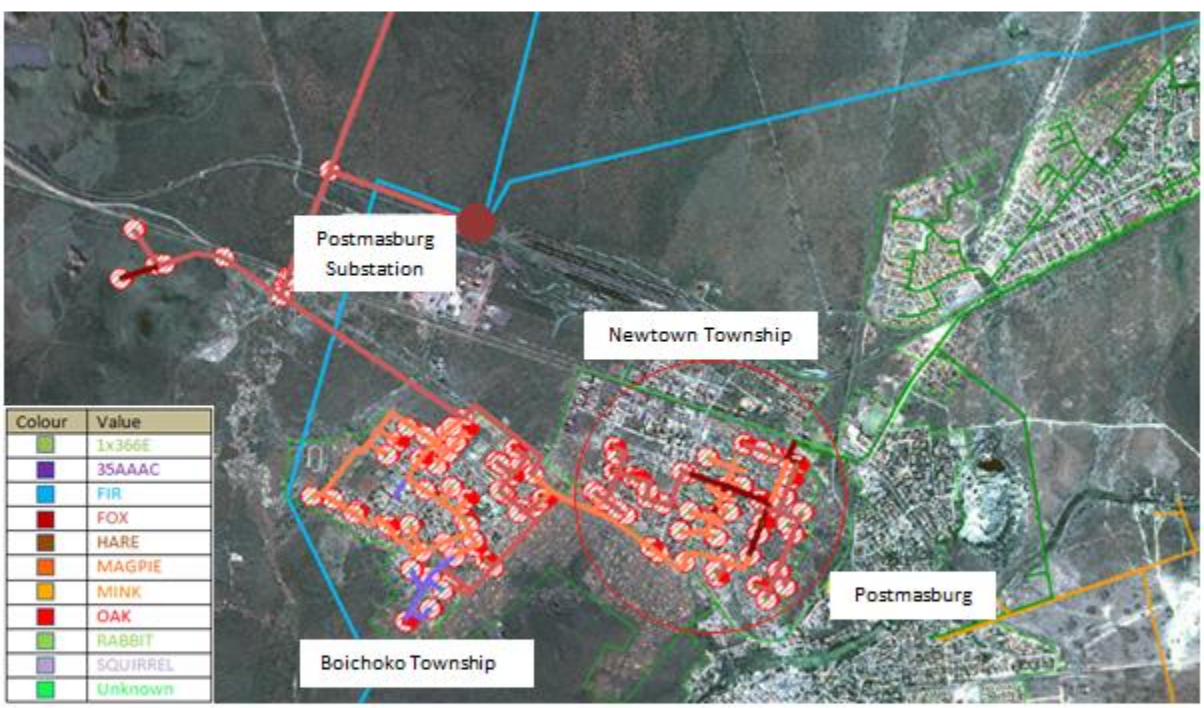


Figure 4.2: Electrical network layout of Postmasburg-Boichoko 11kV overhead line

4.2.3 Reticulation network 3

Newtown Township is located near Postmasburg Town alongside other semi-urban areas. Newtown is supplied by Eskom from Postmasburg Traction Substation, which is approximately 6km outside the town. The medium voltage network, which is supplied from Postmasburg Traction substation, supplies different towns in Postmasburg. The electrical network consists of two different sources: Postmasburg Traction Substation and Hillside Substation. Although the network is supplied from different sources, it relies mainly on Postmasburg Traction Substation. Previously, the network was only supplied from Hillside Substation. As the population increased, the establishments of semi-urban areas grew as did the load in Hillside Substation. Newtown was one of the first townships to be electrified when the network was built around 1989.

The medium voltage network was built to supply only a certain number of customers. Currently, the line supplies as many as 3 000customers from different areas around Postmasburg. The Postmasburg-Boichoko 11kV overhead line supplies Newtown, Boichoko feeder and White City. The electrical network, specifically, wood pole structures, pole-mounted transformers and jumpers showed signs of deterioration. This network is mostly affected by lightning, which causes most of the interruptions around the area. Postmasburg is surrounded by mining activities thus making it highly possible that the population will increase in the future. The area already had a high number of informal settlements that needed to be electrified. Unlike other selected networks, the Postmasburg-Boichoko 11kV overhead line comprises new and old electrical network configurations. The entire line of the Postmasburg-Boichoko 1 11kV overhead line from the substation is shown in Figure 4.3.

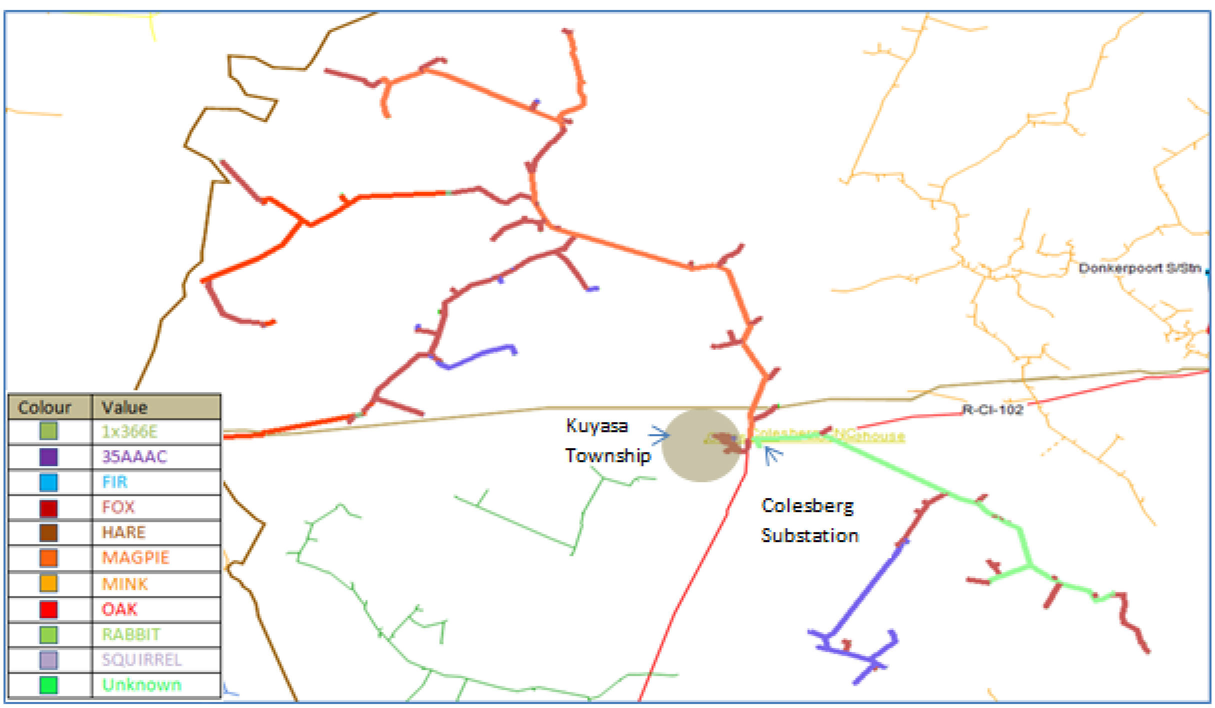


Figure 4.3: Electrical network layout of Colesberg-Coleskop 11kV feeder

4.3 Method 1 Results: Visual inspections analysis (Three Townships)

4.3.1 Reticulation network 1

4.3.1.1 Sizamile Township

Muisvlakte Substation is the only substation that currently supplies Port Nolloth, Sizamile and other areas around Port Nolloth. There is no other 11kV network around the area to back-feed and supply Port Nolloth and Sizamile. Because of the number of customers connected on this line, the radial network is the only option unless another substation is built in order to back-feed. Tweepad Substation, which is approximately 80km from Sizamile, is the nearest substation.

Figure 4.4: Geographical layout of Sizamile Township in Port Nolloth

The geographical layout depicted in Figure 4.4 shows the network layout of Sizamile with the 11kV network and pole-mounted transformers. Sizamile is the only area with an overhead network in this area thus making the metallic material on the overhead line vulnerable to accelerated degradation because of high humidity [5]. The number of customers and transformers in Sizamile is presented in Table 4.1.

Table 4.1: Sizamile Township: Number of customers

Sections	No. Transformers	Number of Customers
Section 1	4	520

4.3.1.2 Condition of the network in Sizamile Township

Sizamile is located approximately 1.39km from the Atlantic Ocean just outside Port Nolloth. Due to its close proximity to the ocean, the area experiences high moisture generated from the sea as the water evaporates. Moisture can have an effect on the rate at which the metallic material deteriorates [66]. Any metal components such as conductors, pole-mounted transformer tanks, jumpers and stays that are exposed to high salty moisture from the ocean have a high chance of corroding as shown in Figure 4.5 and 4.6.

Figure 4.5: a) Corrosion on the conductors, b) Ageing and corroded breaker

Although the electrical network in Sizamile is only 27 years old, the rate at which it has corroded is shown in Figures 4.6a and 4.6b.

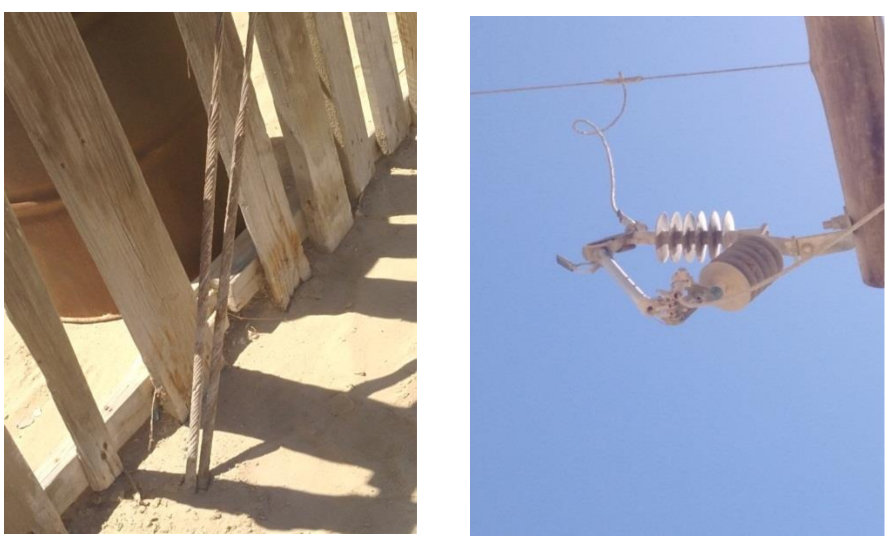


Figure 4.6: a) Corrosion on the stay on one of the poles, b) Corrosion on one of the newly installed jumpers

4.3.2 Reticulation network 2

4.3.2.1 Kuyasa Township

Kuyasa Township is a large township with many customers. The sections of the township with the number of customers connected are shown in Figure 4.7. The number of transformers and customers in each section is presented in Table 4.2.

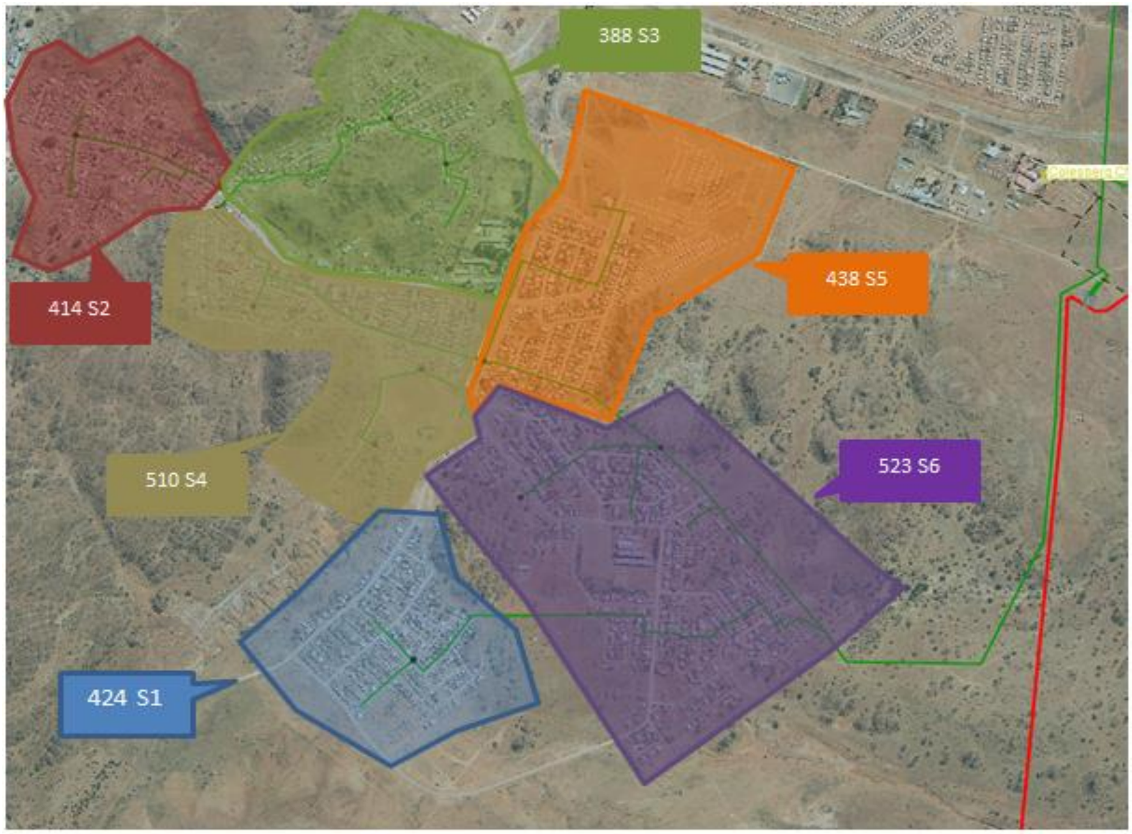


Figure 4.7: Kuyasa Township network configuration

Table 4.2: Kuyasa Township pole-mounted transformer zones

Sections	No. Transformers	Number of Customers
Section 1	4	424
Section 2	4	414
Section 3	5	388
Section 4	8	510
Section 5	5	438
Section 6	8	523
		2697

4.3.2.2 Visual inspections of Kuyasa Colesberg-Coleskop 1 11kV overhead line

The safety of customers is an important factor in the supply of electricity. A live line underneath customers' properties may have an adverse effect on the safety of customers.

Figure 4.8: a) Low hanging concentric cables in Kuyusa, b) Pole-mounted transformer installed without MV Fuses on the primary side

Lines that are very close and above customers' properties are shown in Figure 4.8a. A pole-mounted transformer without fuses is depicted in Figure 4.8b.Having MV fuse-links ensures that whenever there is a fault on a pole-mounted transformer, the affected transformer can be isolated from the rest of the network.

Figure 4.9: a) MV and LV lines connected to the same poles, b) An overloaded transformer

Some of the pole-mounted transformers are installed in customers' properties. Consequently, when they leak, the oil spill may contaminate the soil beneath it rendering the soil unusable. Oil spillage is an immense environmental concern, which is taken seriously. Pole-mounted transformers may leak because of heat generated due to overloading. Most pole-mounted transformers start leaking from the mounting bushing on the tank of the transformer. MV and LV lines connected to the same poles are illustrated in Figure 4.9a and the oil leaks underneath a pole-mounted transformer are shown in Figure 4.9.

4.3.3 Reticulation network 3

4.3.3.1 Newtown Township

The number of customers connected in Boichoko Township, Newtown Township and White City as well as two new areas in the Postmasburg area is portrayed in Figure 4.10. While one of the new areas is electrified, the other is not. Because of the new settlements in the area, the load is increasing rapidly. Furthermore, the number of customers and pole-mounted transformers in Newton can be found in Table 4.3.

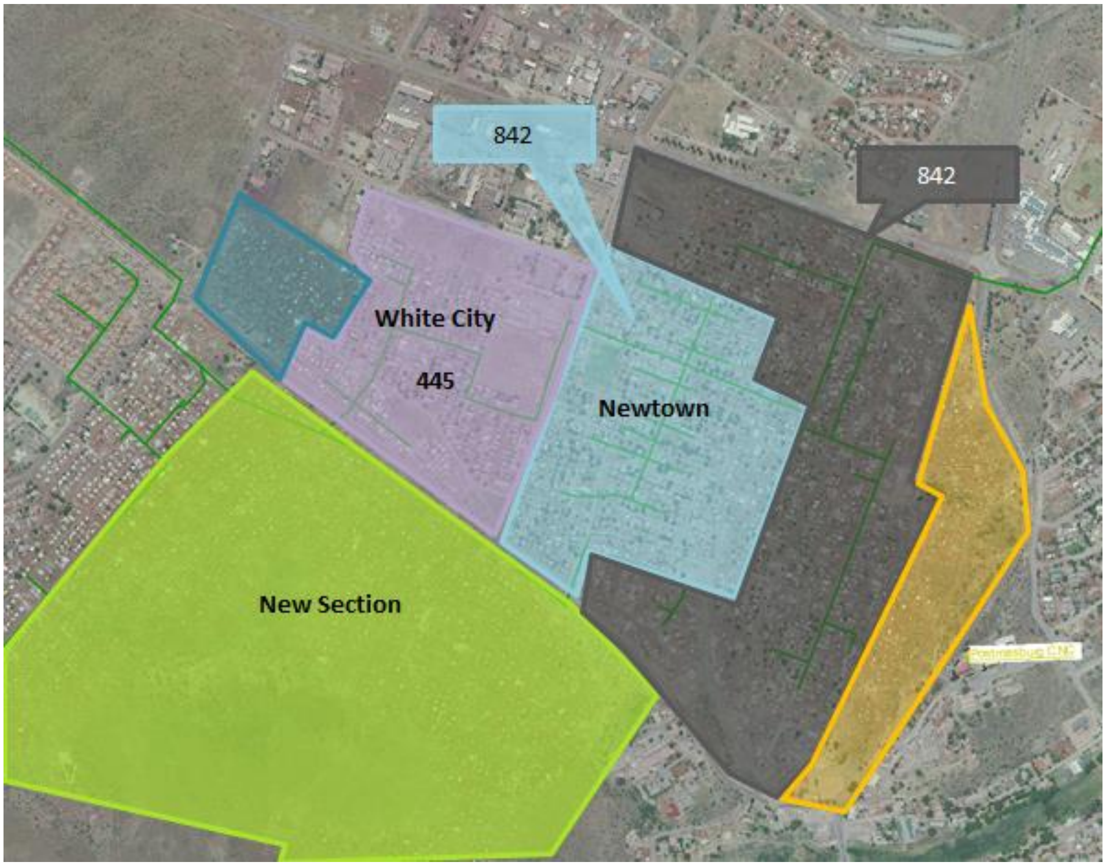


Figure 4.10: Newtown Township network configuration

Table 4.3: Newtown Township pole-mounted transformer zones

Sections	No. Transformers	Number of Customers
Newtown	10	842
White City	15	445
New Location	0	-

4.3.3.2 Visual inspections of Kuyasa Colesberg-Coleskop 1 11kV overhead line

In Figure 4.11a and 4.11b, the condition of the electrical network in Newtown showing wood pole structures, the LV network and pole-mounted transformers is highlighted.

Figure 4.11: a) A pole in the middle of a street, b) Tree underneath the line

The Newtown electrical network configuration is one of the old networks around Postmasburg; some of the electrical networks were built before the layout of the township. Figure 4.11a shows a pole located in the middle of a street thus indicating that some of the network configurations are old and were not integrated in the layout of the township. A mid-block configuration, which previously caused field service workers problems because of its lack of accessibility is shown in Figure 4.11.

Figure 4.12: a) A pole-mounted transformer with oil leaks, b) One of the leaning LV poles in Newtown

Transformer overloading is caused when heat in the winding exceeds the designed winding heat temperature. Because of the number of customers in the township, most of the transformers are over-connected. Connecting more customers on a single pole-mounted transformer can increase the loading on the transformers and thus, increase the operating heat. An ageing LV pole on the Newtown network is portrayed in Figure 4.12 and 4.12b.

4.4 Method 2 Results: Load studies

4.4.1 Voltage profiles

Electrical utilities are also regulated according to the quality of power, in particular, the voltage limits and thermal limits supplied to customers [46]. The electrical utility in South Africa is also regulated by NERSA to ensure a safe, reliable and good quality supply that complies with the regulated limits is provided. The most important factor that needs to be monitored especially in MV lines is the voltage drop. In this study, DigSILENT Power Factory was used to simulate the voltage study of the selected areas. The study revealed the existing voltage profile on the network. If there were problems related to volt drops on the network, the solutions thereof would be simulated. Volt drops on the network can result in many problems for customers and the electrical utility.

4.4.1.1 Muisvlakte-Port Nolloth 1 11kV overhead line voltage profile using Power Factory 2018

The Muisvlakte-Port Nolloth 11kV overhead line is a radial network along the coast that supplies electricity to various customers around Port Nolloth. The line is modelled according to the specifications on site, which include NMD and the types of conductor used on the line. With the NMD of 2.5MVA, the voltage profile of this line was simulated.

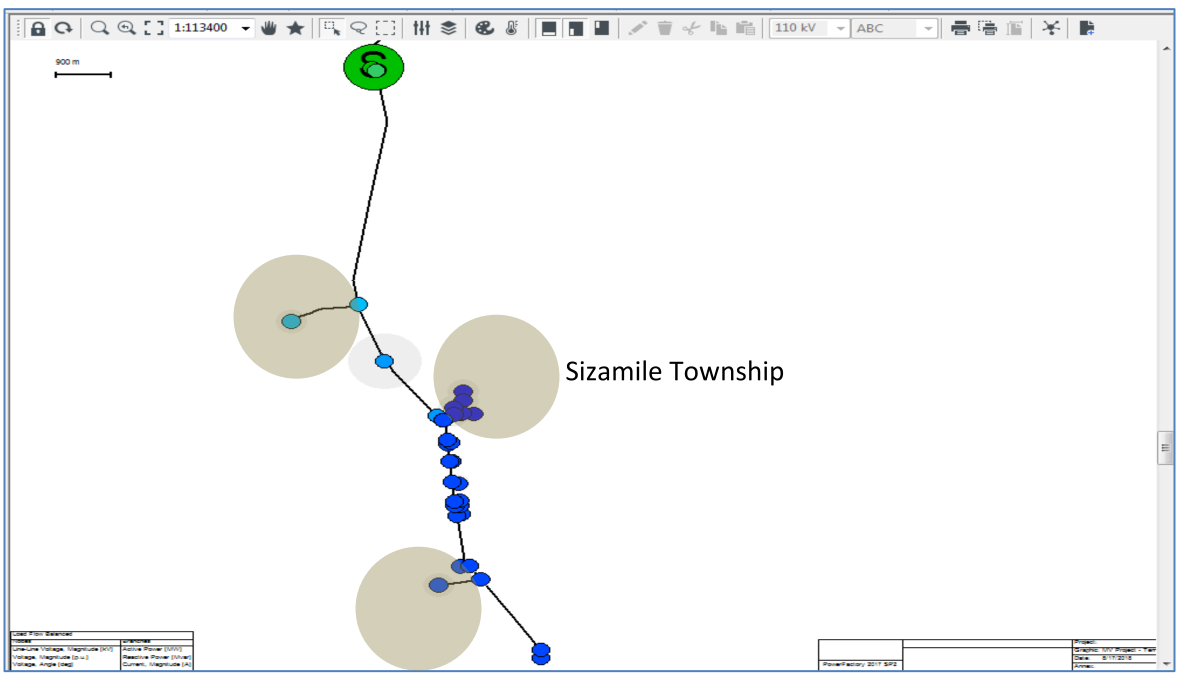


Figure 4.13: Muisvlakte-Port Nolloth 11kV overhead line simulation layout

The entire line as modelled on Power Factory 2018 with all the key points including the substation and the main T-Offs, which are circled with grey, is depicted in Figure 4.13.

4.4.1.2 Muisvlakte-Port Nolloth current voltage profile

The results of the modelling of the Muisvlakte-Port Nolloth overhead line on Power Factory with the correct scaling and line characteristics are shown in Figure 4.14. The voltage profile for the Muisvlakte-Port Nolloth 11kv overhead line was found to be within the voltage limits, with the lowest being just below 0.98p.u.

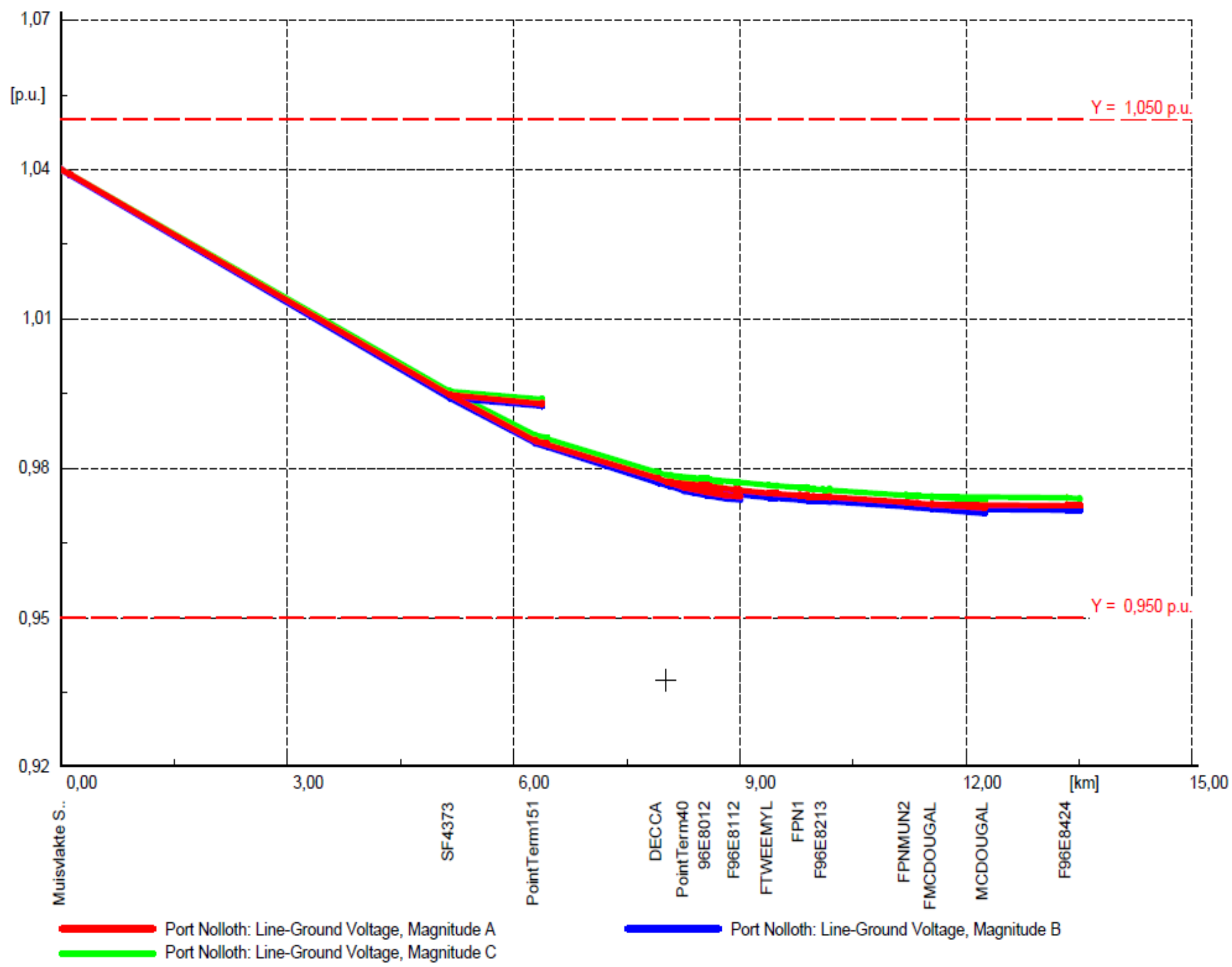


Figure 4.14: Muisvlakte-Port Nolloth 11kV overhead line voltage profile

The y-axis in the figure indicates the voltage calculated in p.u. and the x-axis indicates the length of the line as well as the pole numbers. There are three main T-offs shown on the graph in Figure 4.14. The length, which is indicated on the graph, is the actual length of the main backbone and not of the whole line. The graph indicates the value of the voltage in p.u for all three phases from the source of supply until the end of the main line. The voltage limits are shown with the dotted line on the y-axis. The higher and lower voltage limits are 1.050 p.u and 0.950 p.u., respectively.

4.4.1.3 Colesberg-Coleskop 11kV overhead line voltage profile

The Colesberg-Coleskop 11kV line is one of the longest lines in the Northern Cape. Most of the customers reside in Kuyasa. There are different types of conductors used on this line for three-phase networks as well as SWER networks. The electrical network, which is highlighted with grey circles, indicates the SWER network in the Colesberg-Coleskop 11kV network. Although there is no SWER network in Kuyasa itself, a SWER network supplies farmers in remote areas. The Colesberg-Coleskop 11kV line is portrayed in Figure 4.15.

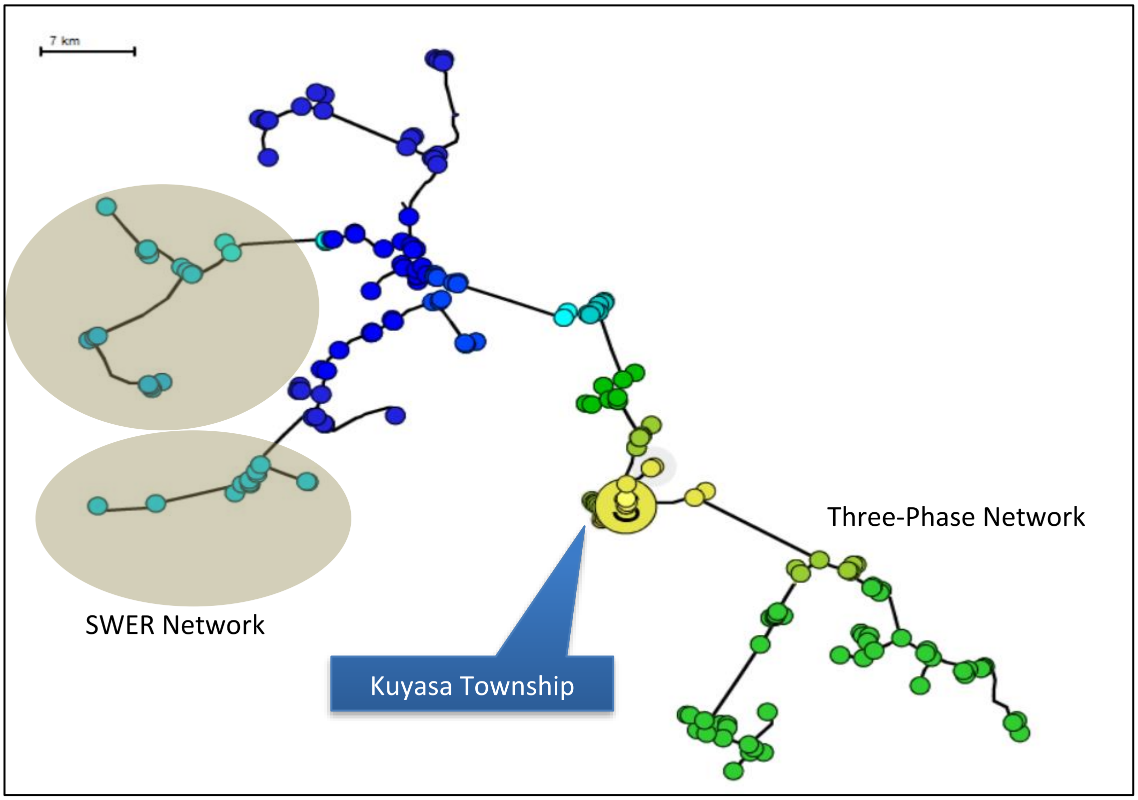


Figure 4.15: Colesberg-Coleskop 1 11kV overhead line voltage profile

The total length of the line includes T-offs, which supply farmers around the Colesberg area. The main backbone of this line comprises Mink conductor with many T-offs made from Fox conductor, which is smaller than Mink conductor. Kuyasa has many customers and is not far from the substation. Because of its load, the voltage drop at the far end of the line is affected.

This line was modelled according to its specifications on-site with the types of conductors used. The colours in the graph indicate the voltage levels at each node in accordance with the NMD of the line. The simulation should be able to show the true voltage profile as it is on site. The dark green nodes portrayed in Figure 4.15 indicates the health of the network in relation to voltage.

4.4.1.4 Colesberg-Coleskop 11kV overhead line existing voltage profile

As noted previously, the total length of the line including all the T-offs are approximately 300km. Due to its length, after approximately 20km from the source of supply, the feeder experiences a volt-drop below the limit of 95%. The voltage profile of the line after the simulation is portrayed in Figure 4.16.

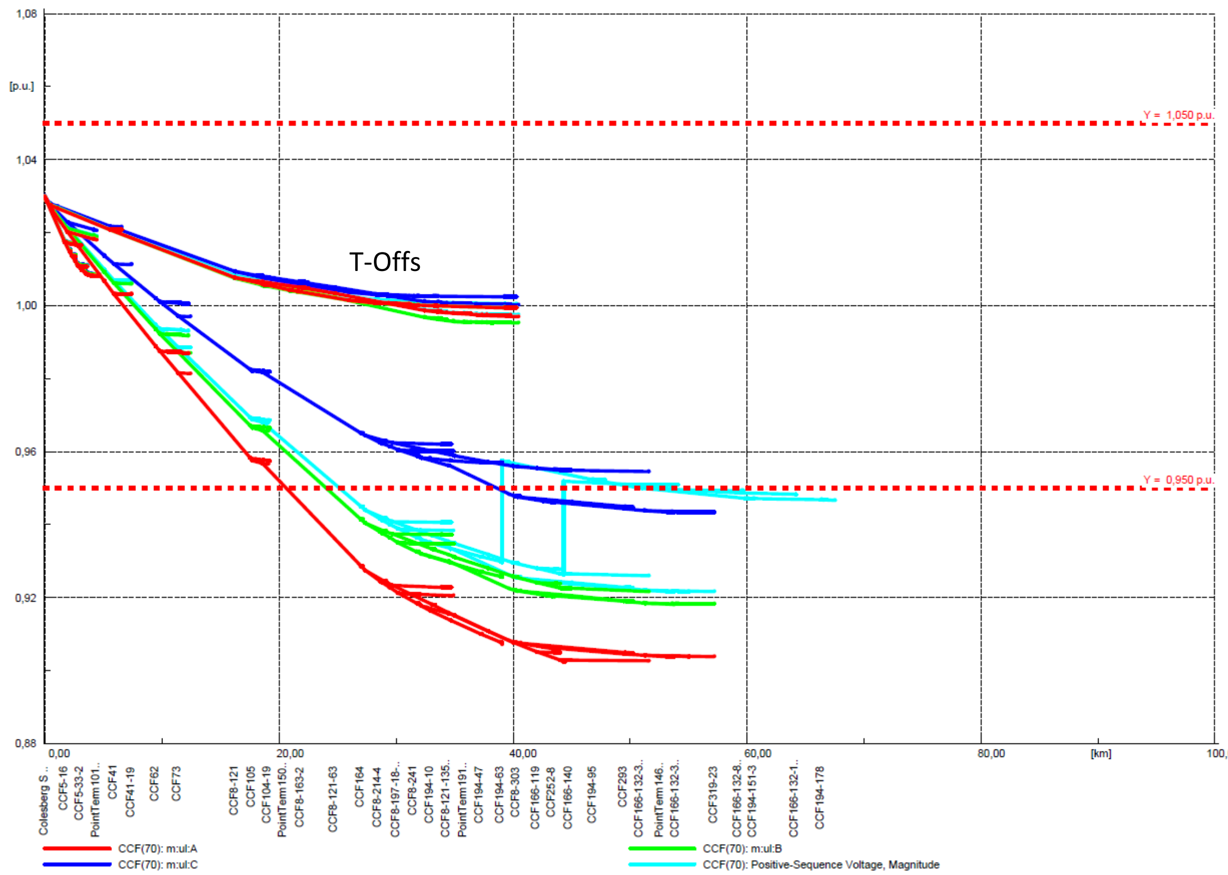


Figure 4.16: Colesberg-Coleskop 11kV overhead line current voltage profile after the simulation

When the voltage reaches customers 40km away, the voltage has dropped significantly below the limit, which is not in accordance with NRS48-2 [46]. The red, blue and green lines on the graph indicate the phases on the three-phase system. The light blue line indicates the voltage level in the SWER network system. The SWER line goes up because of the tapings of the SWER transformer. Depending on transformer tapping, the voltage in the SWER network used in most lines in the Northern Cape can either be 19kV or 23kV. In comparison to the green line, the blue and red lines have the lowest voltage drop. The voltage limit is indicated by the broken line at 0.95p.u. and 1.05p.u.

4.4.1.5 Colesberg-Coleskop 1 11kV overhead line voltage profile simulations after conductor upgrade

The voltage profile of the line after the conductor on the main backbone was upgraded from Mink conductor to Hare conductor is depicted in Figure 4.17. The voltage is just above the voltage limit of 0.95p.u as defined by the grid code. The dotted line indicates the voltage limits in per unit values. The two spikes, which are circled, indicate the SWER network voltage. The red, blue and green lines represent the phases in a three-phase network.

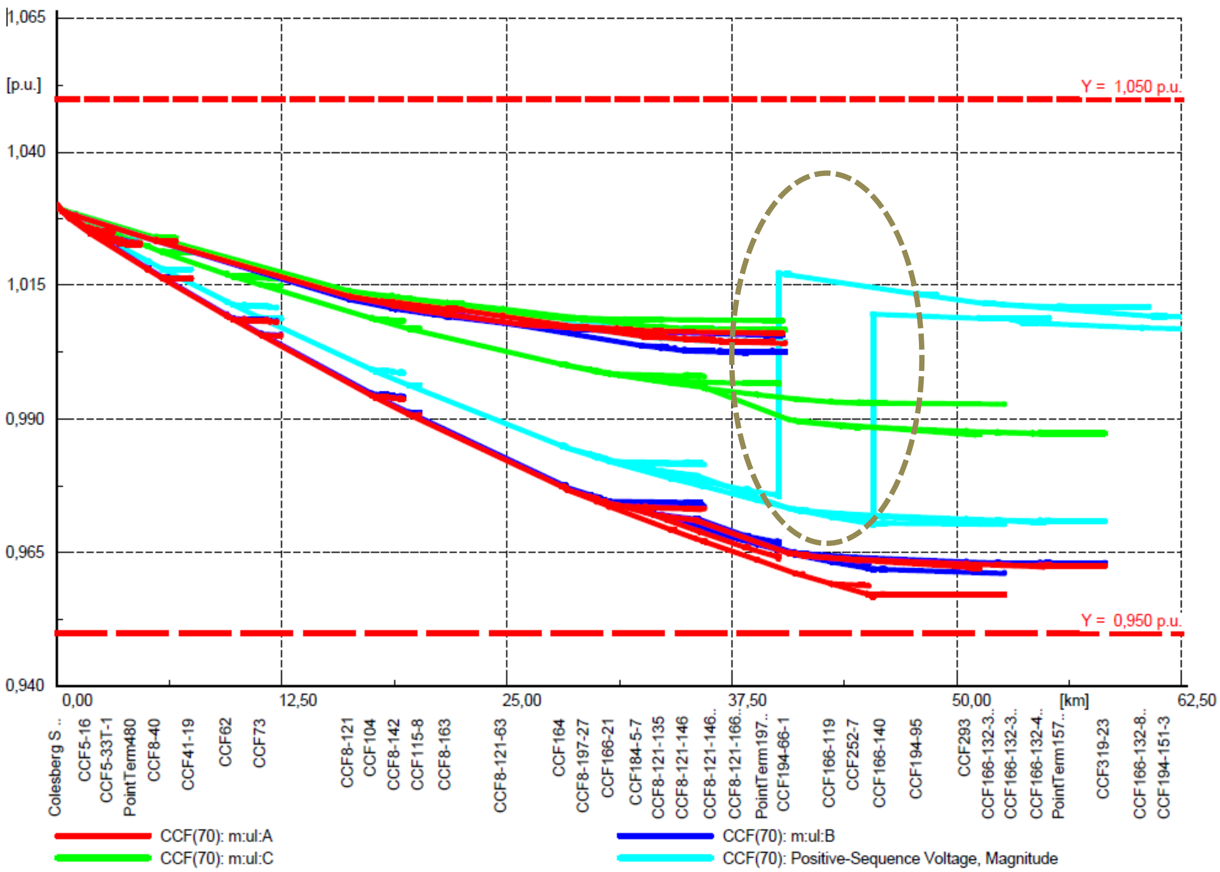


Figure 4.17: Colesberg-Coleskop 11kV overhead line voltage profile after backbone conductor upgrade simulation

The results demonstrated an improvement in the voltage profile of the line after the simulation. The voltages were within the required limits even though at 50km the voltage was closer to the limit. The graph also reveals that as much as the system is three-phase, the voltage profile for each phase is different possibly because some of the phases have more loads connected to them. Figure 4.17 reveals that the blue and red phases were affected mainly by low voltage.

4.4.1.6 Colesberg- Coleskop 1 11kV overhead line voltage profile simulations after the voltage regulator installation

One of the most effective solutions to the voltage constraints on this network was to add the voltage regulator to boost the voltage to the required limits. In order to install the voltage regulator in the correct place so that the voltage was within the required limits, the correct point on the network had to be selected so that there were no low or high voltages on the network. The correct point to connect the voltage regulator in this study is portrayed in Figure 4.18.

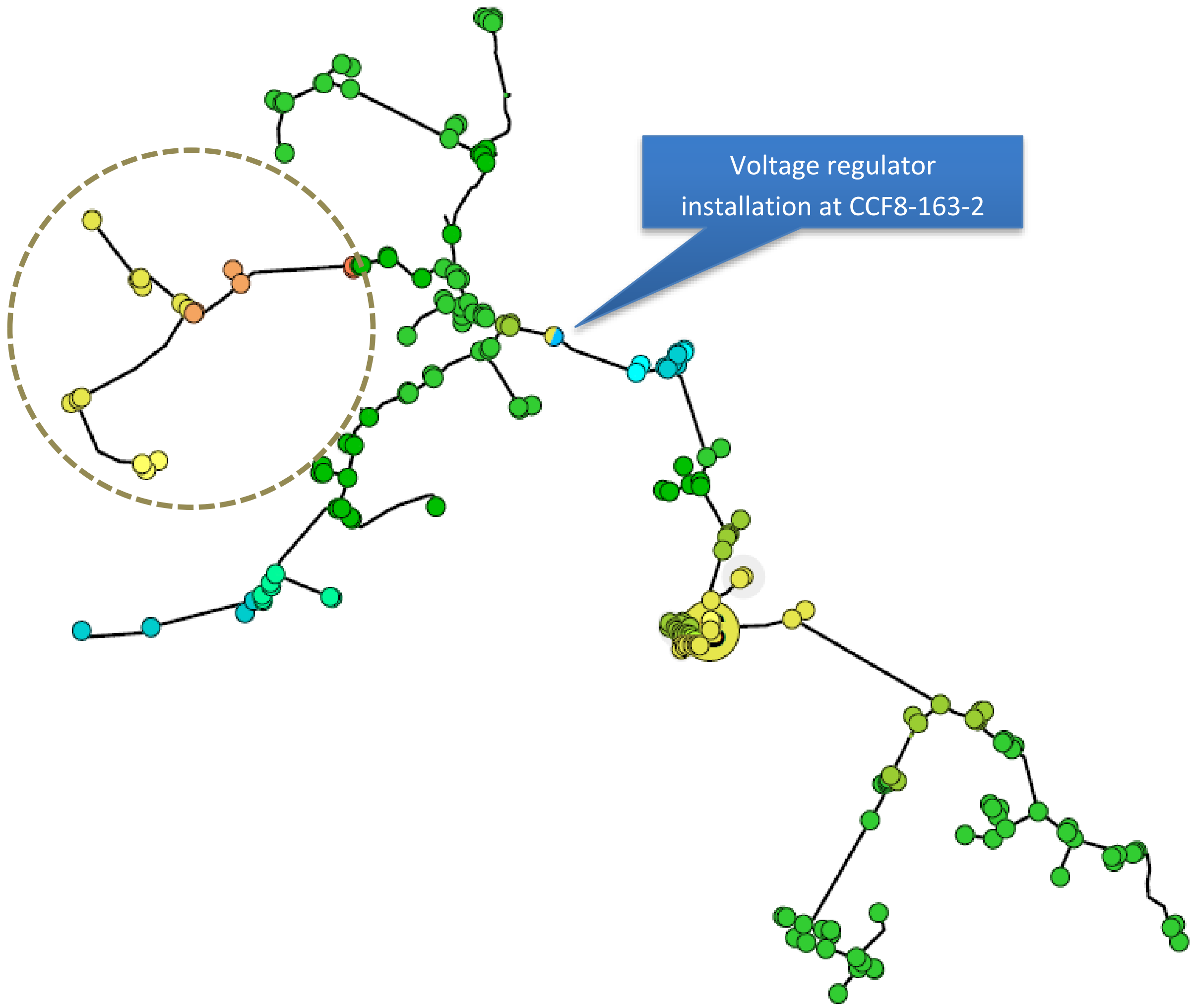


Figure 4.18: Voltage regulator installation at CCF8-163-2

The various shades of green on the nodes depicted in Figure 4.18 indicate the health of the voltage on the line. The orange and yellow nodes represent the constrained nodes on the network. The colour of the nodes indicates the voltage was healthy after the installation of the voltage regulator. However, the SWER network that supplied the customers on the remote site had voltage problems.

4.4.1.7 Installation of the voltage regulator

The results after the voltage regulator was installed at CCF8-163-2 are shown in Figure 4.19. The voltage profile reveals that there was voltage improvement after the installation of the voltage regulator. The voltages were below the limit. The lowest voltage was at CCF8-163-2, the location where the voltage regulator was installed. The red line represents the lowest voltage at ±0.96p.u and the blue line represents the highest voltage at ±1.045p.u.

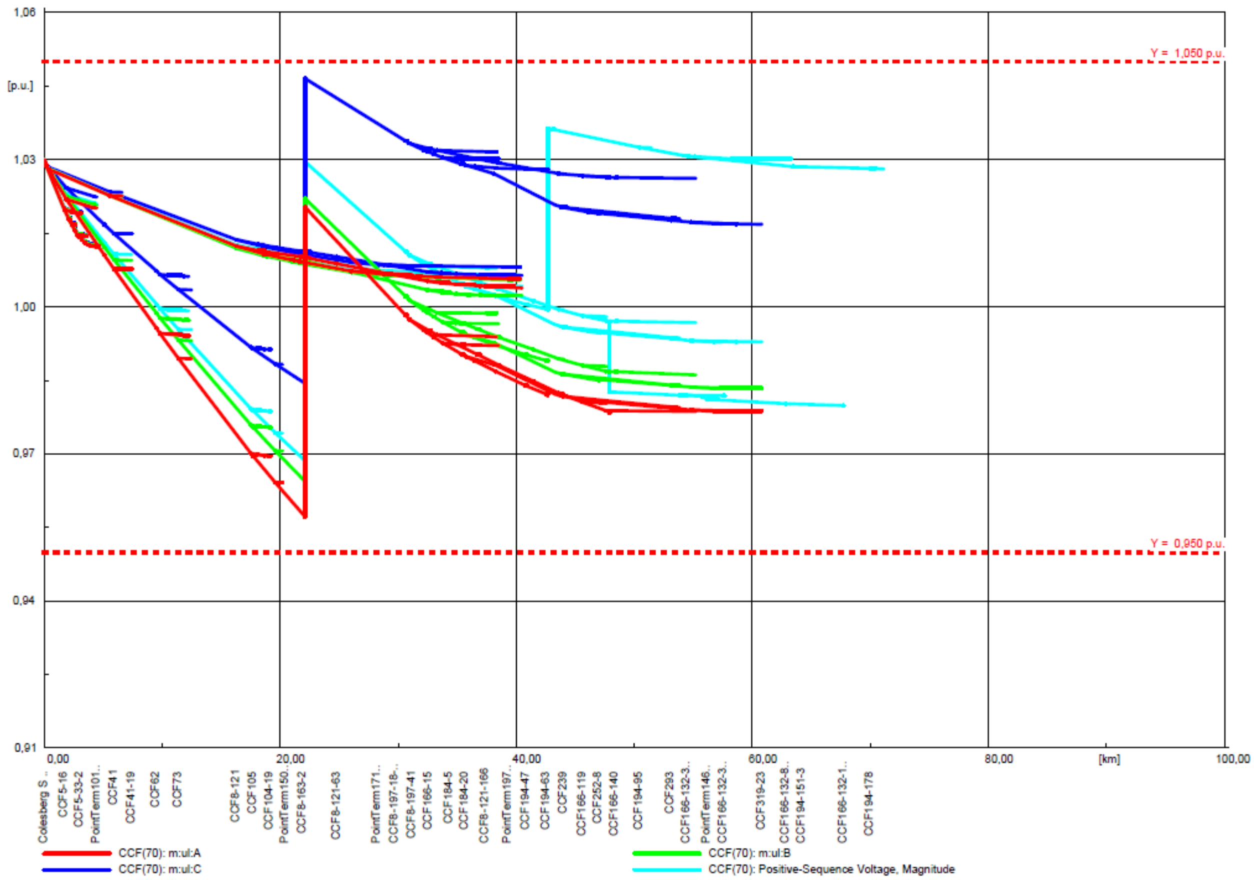


Figure 4.19: Colesberg-Coleskop 11kV overhead line voltage regulator installation

After the simulation, the voltage was now within the limits set by the NRS48-2; a minimum of 0.95pu and a maximum of 1.05pu. Even if the voltage is within the required limits, if the load in the area becomes too high, this will serve as a temporary solution to the problem and the strengthening of the entire network should be considered. The voltage profile reveals that voltage in all the phases increased after the installation of the voltage regulator for both the three-phase and SWER systems. The voltage of the main T-off, which supplies Kuyasa, is well below the regulation limit because the township is located close to the source, namely, the substation. The voltage improvement is evident on the main backbone of the line.

4.4.1.8 Postmasburg Traction- Boichoko 11kV overhead line voltage profile

Three townships are are supplied from the Postmasburg-Boichoko 11kV overhead line. The whole line was modeled by employing DigSILENT Power Factory 2018. The colours indicated in Figure 4.20 reveal the voltage level at each township as well as other points on the network. The line has new and old electrical networks, which are designed differently from one another. Boichoko is much closer to the source than Newtown; hence, the different colour nodes. The voltage in Boichoko is much healthier that that in Newtown.

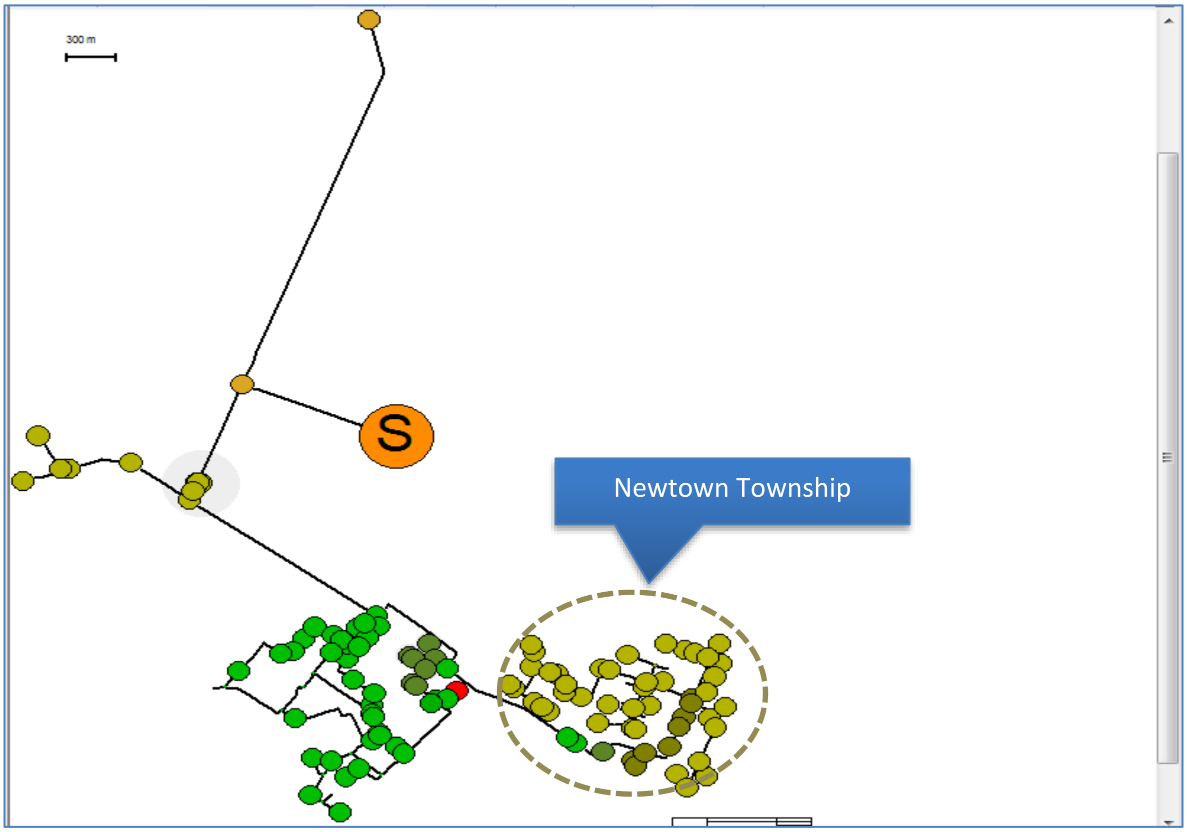


Figure 4.20: Postmasburg- Boichoko 11kV overhead line network layout as modelled on DIgSILENT Power Factory

The types of conductors used on this line are different from one another because the older electrical designs used a certain type of conductor, which was standard at the time while the new electrical standards recommend other conductors. The network was modelled by employing the same network specifications that are used on site so that improved voltage readings on the results could be obtained. The NMD at the substation that supplied the line and other customers was 7.5MVA. The voltage profile for this line was simulated to show the voltage level. The simulation included the entire line from Postmasburg Traction Substation to the areas of supply. Compared to the other townships, Newtown, which is highlighted in Figure 4.20, has the oldest network.

4.4.1.9 Colesberg- Coleskop 11kV overhead line voltage profile after simulation

The overhead line is supplied from Postmasburg Traction Substation with an installed transformer of 7.5MVA. The voltage profile that was simulated at Postmasburg-Boichoko 1 11kV network is portrayed in Figure 4.21. All the phases were within the voltage regulation limits of 0.95p.u and 1.05p.u. Even on the T-offs, the voltages were stable. The lowest voltage was at POBO50T-36-5. The voltage profile of the Postmasburg-Boichoko 1 11kV network is illustrated in the graph in Figure 4.21.

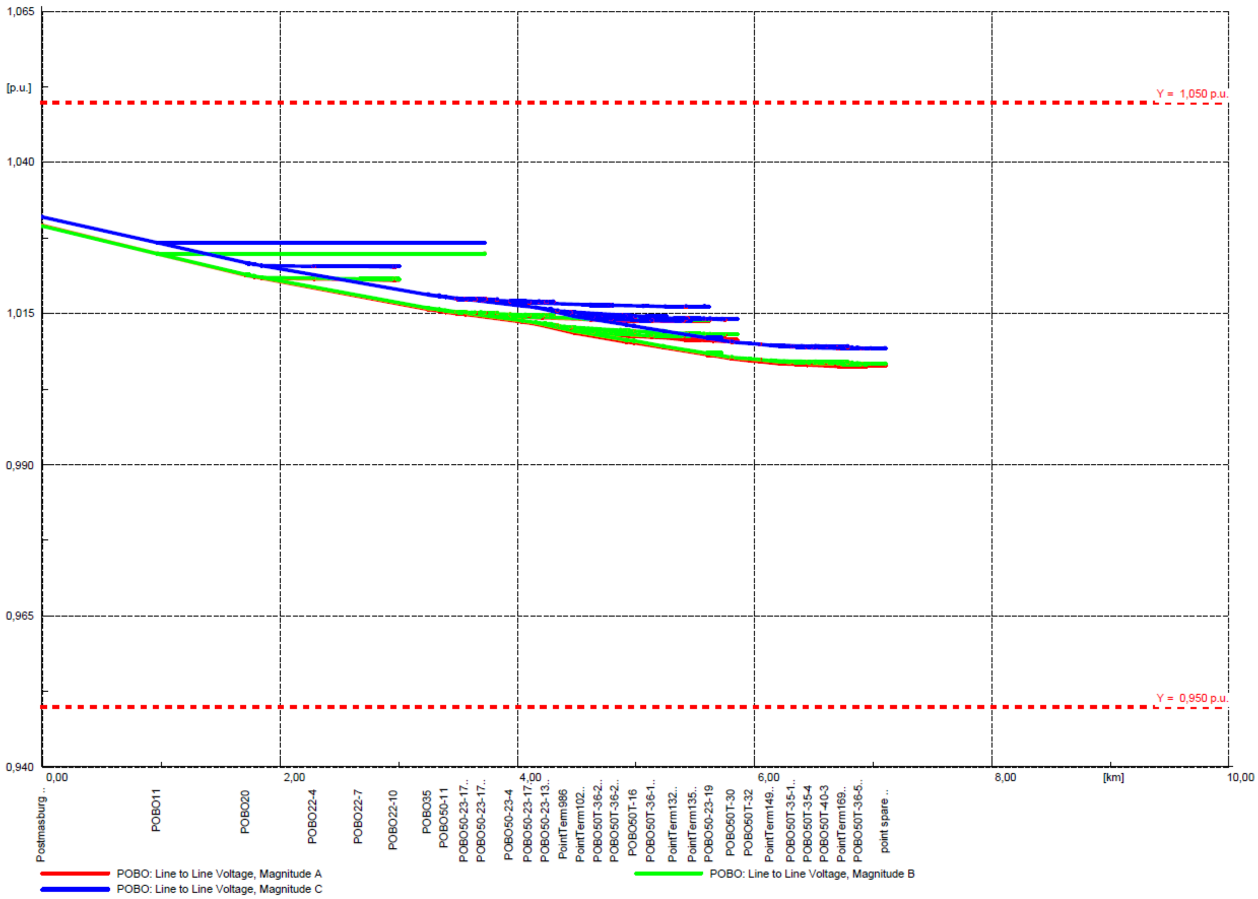


Figure 4.21: Voltage profile of Postmasburg- Boichoko 11kV overhead line

Although most of the customers on this line are prepaid power users, the line also supplies Kumba Mine. Furthermore, most of the customers live in Boichoko, which has almost 3 000 customers. The different colour lines indicate different phases on the electrical network from the Postmasburg-Boichoko 1 11kV overhead Line. Figure 4.21 reveals that the voltages are well with the required limit of 0.95p.u and 1.05p.u. The lines on the graph show the number of T-offs from the main T-off. The voltage in the three-phases is within the limit; the strongest is indicated by the blue line and the weakest by the red line.

4.4.2 ADMD calculations

Customers per 50kVA transformer

Using the ADMD of 1.2kVA

Therefore: $No.\ Customers = \frac{Transformer\ Rating * 0.9}{ADMD}$

$$= \frac{50*0.9}{1.2}$$

$$= 38\ customers\ per\ TRFR$$

This calculation indicates that for every 50kVA transformer only 41 customers can be connected. In Kuyasa, most of the 50kV transformers have up to 83 customers. There are 105 transformers installed on the Colesberg-Coleskop 11kV overhead line. As indicated in Table 4.4, most of the transformers are 50kVA and 100kVA transformers.

Table 4.4: Kuyasa Township ADMD per pole-mounted transformer

TRFR No.	Link Object Type	Link KVA	PPU	SPU	LPU	TOTAL Customers	ADMD per TRFR in kVA	Required Customers with ADMD of 2.4kVA	Extra number of connections per TRFR zone	No. Additional TRFR Required
1	Two Winding Transformer	50	51	0	0	51	0.88	19	32	1
2	Two Winding Transformer	50	54	2	0	56	0.8	19	35	1
3	Two Winding Transformer	100	99	0	0	99	0.91	38	61	2
4	Two Winding Transformer	100	104	0	0	104	0.82	38	66	2
5	Two Winding Transformer	100	56	0	0	56	1.6	38	18	1
6	Two Winding Transformer	50	73	0	0	73	0.61	19	54	1
7	Two Winding Transformer	50	82	0	0	82	0.55	19	63	1
8	Two Winding Transformer	50	94	0	0	94	0.48	19	75	1
9	Two Winding Transformer	100	97	0	0	97	0.92	38	59	1
10	Two Winding Transformer	50	112	0	0	112	0.4	19	93	2
11	Two Winding Transformer	100	126	0	0	126	0.71	38	88	2
12	Two Winding Transformer	50	101	0	0	101	0.45	19	82	2
13	Two Winding Transformer	100	135	0	0	135	0.67	38	97	2
14	Two Winding Transformer	50	85	0	0	85	0.53	19	66	1
15	Two Winding Transformer	50	73	0	0	73	0.62	19	54	1
16	Two Winding Transformer	100	91	1	0	92	0.98	38	54	1

All of the transformers that are installed in Kuyasa are three-phase transformers. Single-phase transformers are installed mainly at SWER networks. The number of customers connected per transformer is displayed in Table 4.4. The data revealed that there are only three small power users and no larger power users in Kuyasa. Most of the customers in Kuyasa are prepaid customers.

In Table 4.5, statistics for Newton are displayed. The table reveals the number of pole-mounted transformers installed in Newtown. Most of the customers located in Newtown are prepaid customers. The table also indicates the number of customers connected per transformer zone and the expected number of customers that should actually be connected per transformer zone after the ADMD calculations. The number of extra transformers to be installed in Newtown in order to de-load the existing transformers is also presented in Table 4.5. Mid-blocks is the LV network configuration in Newtown thus making it easier to connect four customers on a single top pole box.

Table 4.5: ADMD and the number of customers connected per transformer in Newtown Township

Link Standard Label	Link KVA	PPU	Top Pole Box	Top Pole Boxes 4 way	LV Poles	ABC Conductor Length	Total Customers	kVA per customer	Required Customers per ADMD of 2.4kVA	Extra Customers	Extra Transformer Required
POBO65-8-11-1	50	84					88	0.51	19	69	1
POBO65-8-2-3	100	93	9	23	31	1046.81m	93	0.968	38	55	2
POBO65-8T-1-2	100	77	15	17	43	658.63m	77	1.169	38	39	1
POBO65-8-4-2	100	108	8	21	36	1024.18m	108	0.833	38	70	2
POBO65-8-16	100	80	14	16	38	939.09m	80	1.125	38	42	1
POBO65-8-8-4	100	77	9	15	36	985.0m	77	1.169	38	39	1
POBO65-8T-8	100	84	7	16	39	937.62m	84	1.071	38	46	1
POBO65-8-11-2	100	12	14	14	39	1019.46m	12	7.5	38	0	0

In Sizamile, most of the pole-mounted transformers are 200kVA. Most of the customers in the township are prepaid customers and there are only two small power users in the township as indicated in Table 4.6.

Table 4.6: The calculated ADMD for Sizamile Township

Link Object Type	Link Description	Link KVA	PPU	SPU	LPU	TOTAL Customers	ADMD per TRFR
Two Winding Transformer	SIZAMT4 11kV/400V Trfr	200	126	1	0	127	1.43
Two Winding Transformer	SIZAMT2 11kV/400V Trfr	200	127	0	0	127	1.42
Two Winding Transformer	SIZAMT3 11kV/400V Trfr	200	133	0	0	133	1.35
Two Winding Transformer	SIZAMT1 11kV/400V Trfr	200	112	0	0	112	1.61
Two Winding Transformer	96E8007 11kV/400V Trfr	50	0	1	0	1	45

The ADMD that is applied in all the installed pole-mounted transformers in Sizamile currently range from 1.4MVA to 1.6MVA. While all transformers installed in Sizamile are step-down transformers and range from 11kV to 400V, most are 200kVA transformers. There is one 50kVA transformer that is dedicated to the pump station.

4.4.3 Load forecasts

4.4.3.1 Muisvlakte-Port Nolloth 1 11kV overhead line

Currently, Muisvlakte Substation has one 5MVA power transformer installed. The 5MVA transformer currently supplies the mines, Sizamile and the municipality bulk supply around Port Nolloth. Presently, there are other developments in Port Nolloth, which will necessitate more capacity in the future. The rate at which the load is increasing on the Muisvlakte-Port Nolloth 11kV line is portrayed in Figure 4.22.

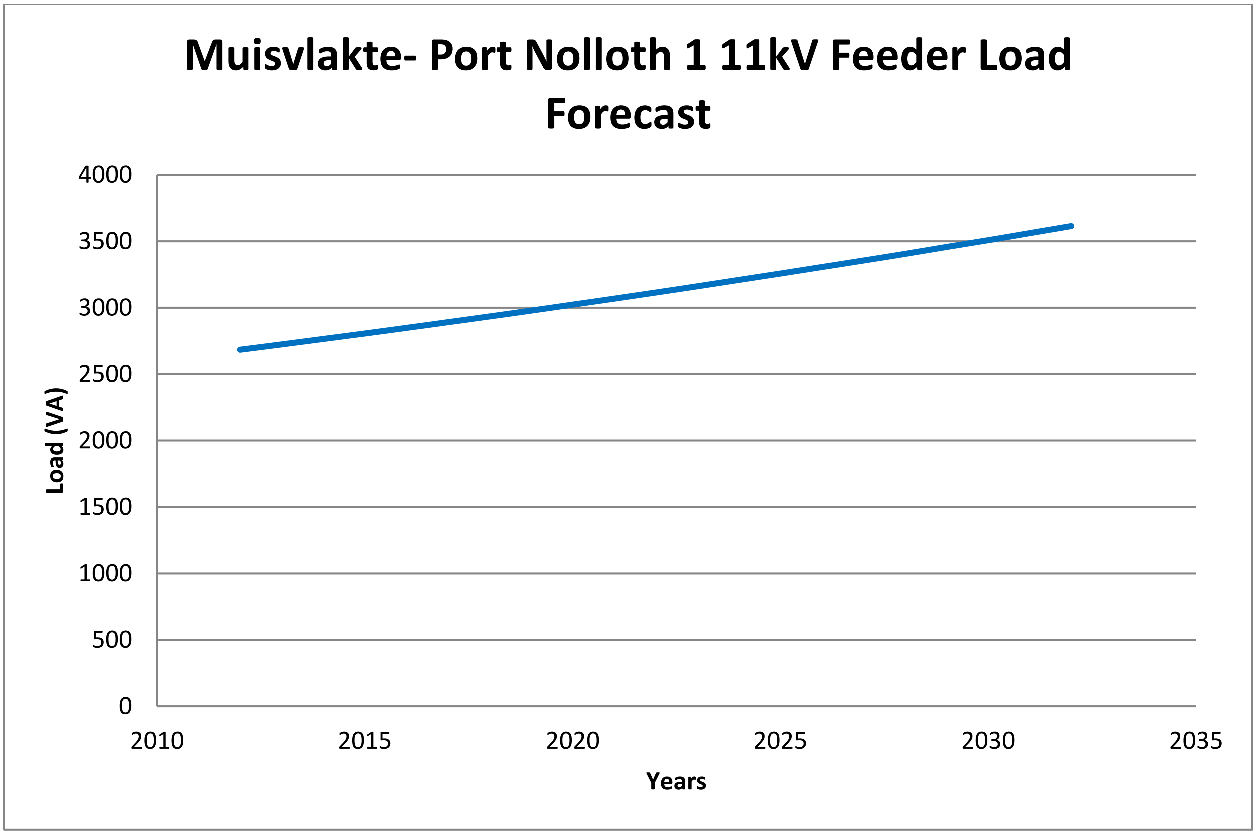


Figure 4.22: Muisvlakte-Port Nolloth 1 11kV overhead line load forecast

A 25-year load forecast for the Muisvlakte-Port Nolloth 11kV feeder is portrayed in Figure 4.22. The load for 2019 was just below 3MVA and by 2020, was expected to be above 3MVA. Because of the constant developments in the Port Nolloth area as a result of the mines, the load by 2032 is predicted to be approximately 3.6MVA. The loading is the load estimated to occur in the future. Other developments in the area include new schools, churches and retail stores. Because of the developments, the transformer at Muisvlakte might not be enough to allow such development due to its age. Furthermore, the electrical network around Sizamile is ageing rapidly because of the climate around the coastal area.

4.4.3.2 Colesberg-Coleskop 1 11kV overhead line load forecast

The load on the Colesberg-Coleskop 11kV feeder is increasing because of developments around Colesberg and electrification projects in Kuyasa. The load increase in the Colesberg-Coleskop 11kV line supplied from the Colesberg Substation has installed a 5MVA power transformer. The line supplies Kuyasa and the farmers located in the Colesberg area. This line also has a 25-year forecast.

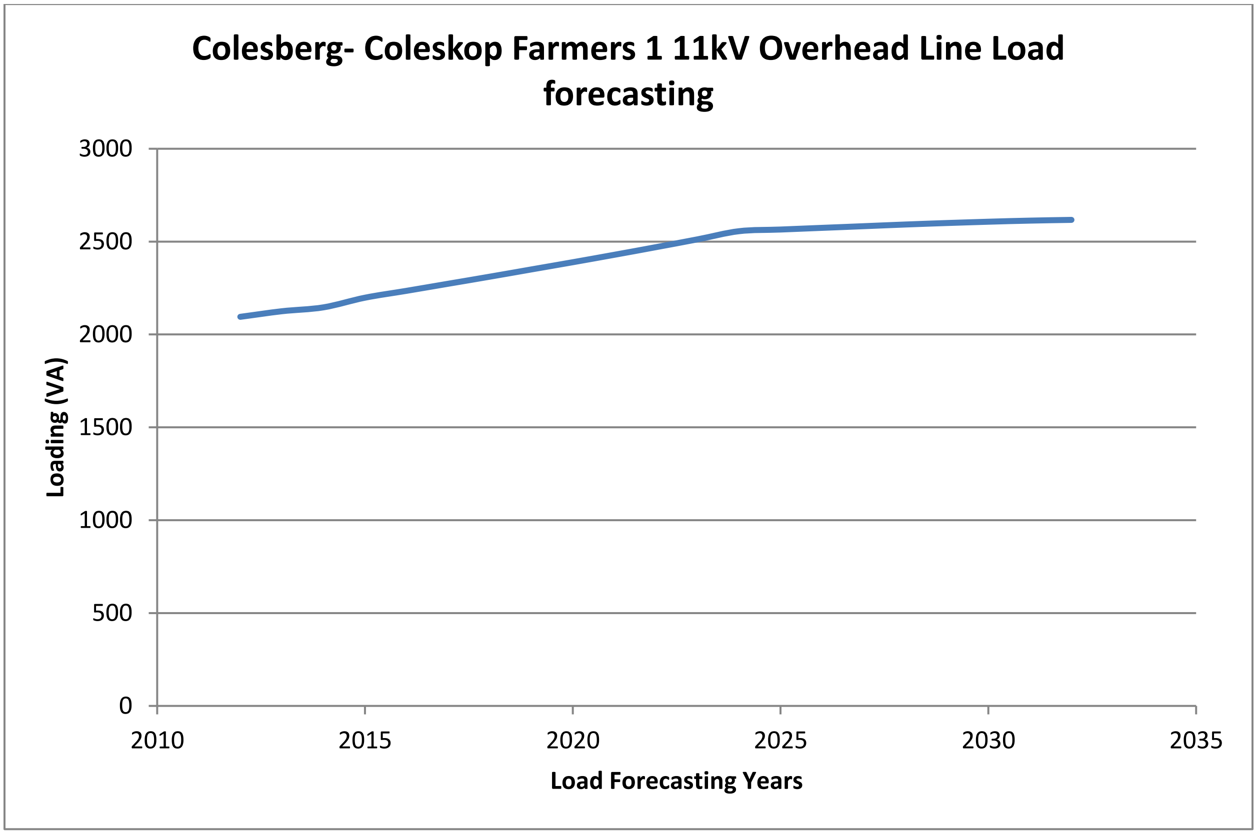


Figure 4.23: Colesberg- Coleskop 1 11kV overhead line load forecast

The x-axis of the graph in Figure 4.23 indicates the years of the forecast and the y-axis indicates the forecasted load measured in VA. The forecast was from 2010 to 2035. In 2017, the load was 2.243MVA and in 2018, it was 2.311MVA. Currently, it is 2.35MVA. Figure 4.26 reveals that the load will continually increase until 2025 thus revealing a very slow increase in terms of load. However, the estimation is dependent on the transformer in Colesberg Substation. According to the load forecast, the load will be 2.61MVA in 2033. The load on this network is mostly located in remote farming areas. The total load shown in Figure 4.23 includes the entire load on the network including Kuyasa. The rate of the increase remains well within the limit.

4.4.3.3 Postmasburg-Traction Boichoko 1 11kV overhead line load forecast

The Postmasburg-Boichoko11kV feeder is supplied from Postmasburg Traction Substation with an installed capacity of 17.5MVA. Two power transformers of 10MVA and 7.5MVA are installed in the substation. While the Postmasburg Traction Substation is supplied from the 7.5MVA transformer, the 10MVA is a dedicated supply. The 25-year load forecast for the Postmasburg-Boichoko line is portrayed in Figure 4.24.

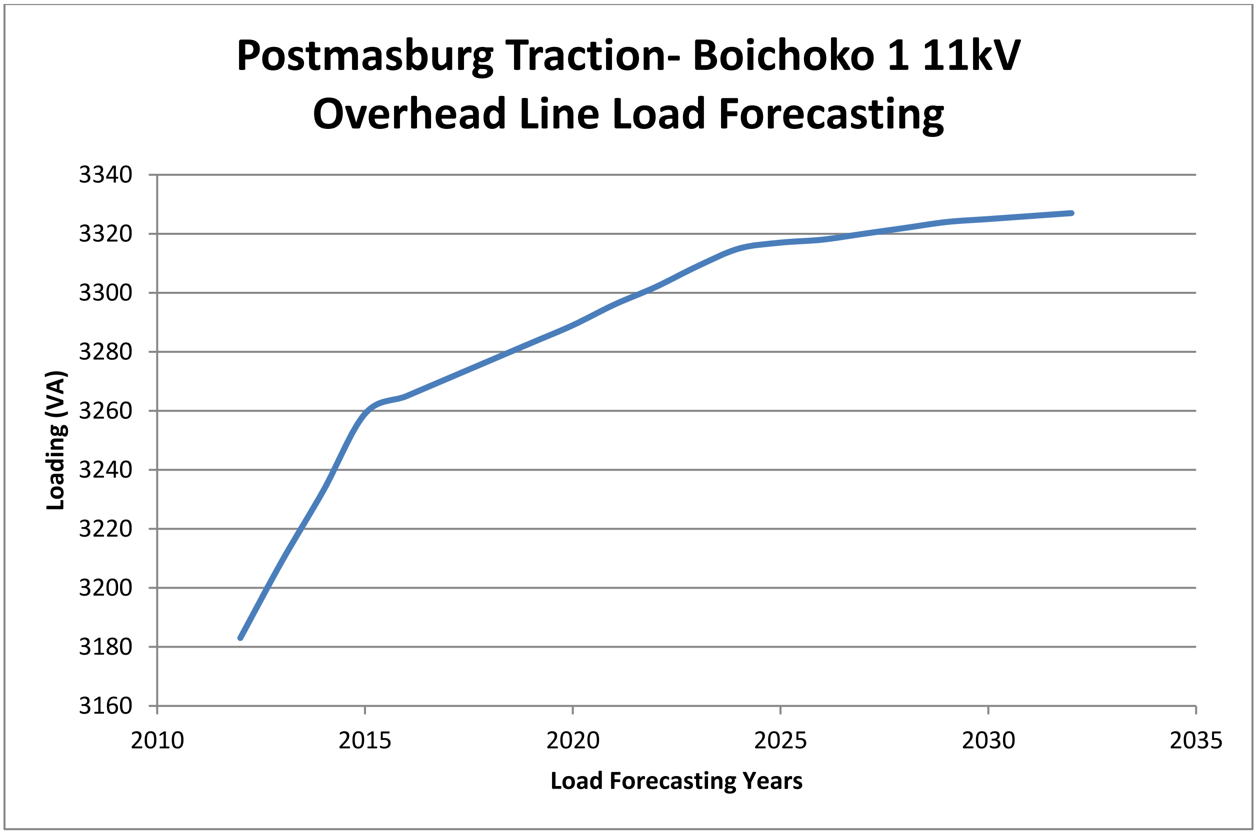


Figure 4.24: Postmasburg- Boichoko 11kV overhead line load forecast

The x-axis of the graph indicates the years of the forecast and the y-axis shows the forecasted load measured in VA. Although the load increased from 2015, it was slower than it had been previously. Currently, the load is 3.27MVA (43%) of a total installed capacity of 7.5MVA. From 2024, it is expected that the load will increase to 3.38MVA until 2032, which is still less than the total installed capacity. This line supplies a few semi-urban areas including Boichoko, Newtown and White City, which is also known as the new Newtown. The graph does not show the total installed capacity for the entire substation, but only for the 7.5MVA power transformer, which supplies the Postmasburg-Boichoko 11kV overhead line. The loading on the line is currently well within the limit and according to the load forecast, no cause for concern. The load forecast reveals that by 2030, the load will still be below 7500VA; it is expected the highest will be 3327VA in 2032.

4.5 Method 3 Results: MV lines performance trends

4.5.1 Reticulation network 1: Muisvlakte-Port Nolloth 11kV line (Sizamile)

4.5.1.1 Muisvlakte-Port Nolloth 11kV overhead line SAIDI trends

In Figure 4.25, planned and unplanned SAIDI as well as the actual SAIDI calculated over a period of 5 years are depicted. The Muisvlakte experienced planned and unplanned interruptions frequently during the last five years. However, the restoration time was faster than anticipated even though the line is a long way from the service centre.

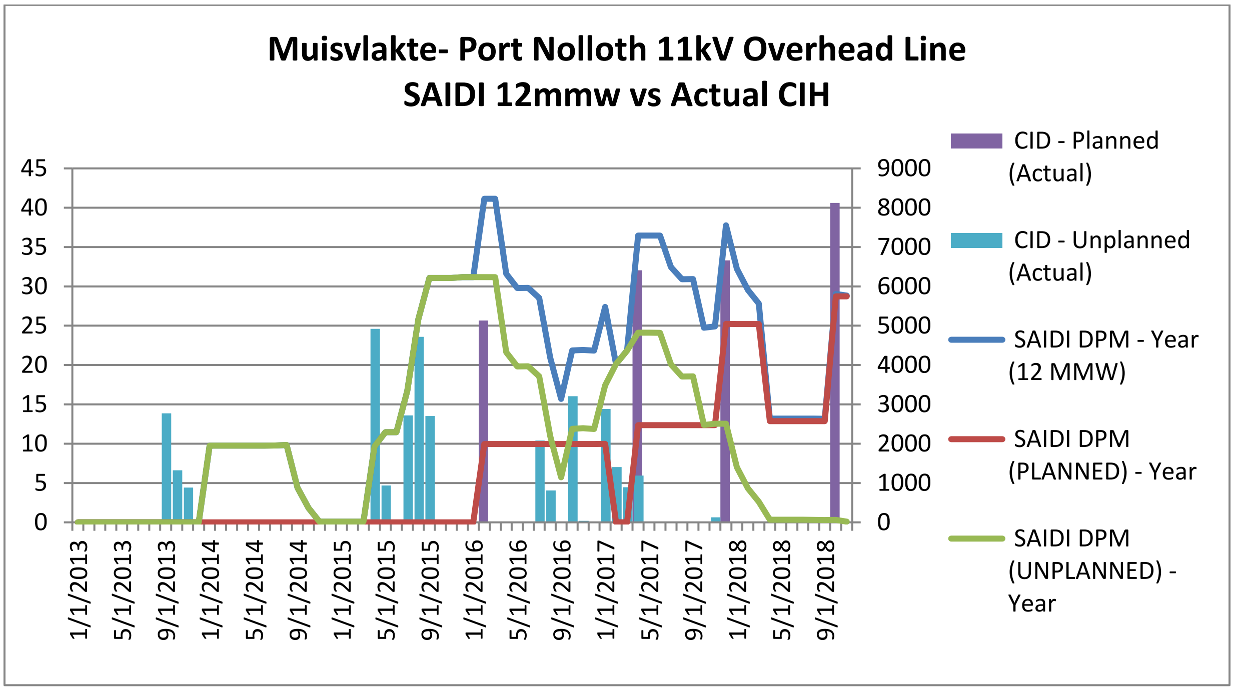


Figure 4.25: Muisvlakte-Port Nolloth 11kV overhead line SAIDI trends

The data in Figure 4.25 reveals the number of graphs plotted together to show the trends over a period of five years on the Muisvlakte-Port Nolloth 1 11kV overhead line in relation to the SAIDI. The columns indicate the number of planned and unplanned hours of customer interruption that occurred on this line over a certain period. From January 2013 to September 2013, no data were calculated for this feeder. Even though it did not affect many customers, the unplanned CIH occurred from September. The planned SAIDI was its highest in February 2016 and April 2017.

4.5.1.2 Muisvlakte-Port Nolloth 11kV overhead line SAIFI trends

Unplanned SAIDI decreased steadily from May 2017 until it was at its lowest in September 2018 while planned SAIDI increased from August 2018. Planned CIH were their highest in October 2018. The calculation of SAIFI is based on the number of customers interrupted on the line. Furthermore, how frequently customers were interrupted is measured. The trends depicted in Figure 4.26 were recorded over a period of five years from 2013 to 2018. The graph shows the rate at which planned and unplanned interruptions occurred from 2013 to 2018. There were very few events in 2014 and thus, these are not indicated on the graph.

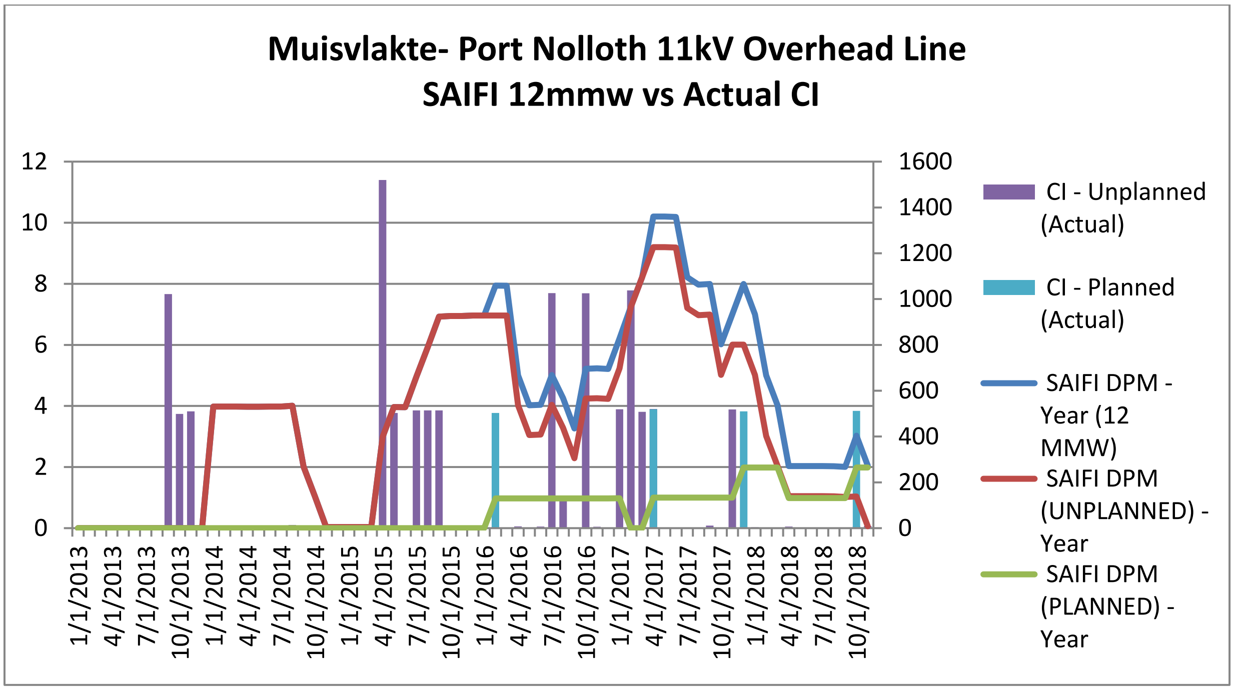


Figure 4.26: Muisvlakte-Port Nolloth 11kV overhead line SAIFI

Between September 2013 and January 2014, many unplanned events were recorded because of the rains in the area. In April 2015, rain interrupted customers on the line for a long period of time. Furthermore, there were a few planned interruptions on this line. Most of the customers who the planned interruptions affected lived in Sizamile. As indicated on the graph, between 0 and 600 customers were affected. On this line, only Sizamile is serviced by Eskom. The rest of the line supplies other customers such as the municipality and mines. The interruptions that affected those serviced by the municipality are not included on the graph.

4.5.2 Reticulation network 2: Colesberg-Coleskop 11kV line (Kuyasa)

4.5.2.1 Colesberg-Coleskop 1 11kV overhead line SAIDI trends

A comparison between planned and unplanned SAIDI in the Colesberg-Coleskop 11kV overhead line is portrayed in Figure 4.27. The planned and unplanned customer interruption hours on the line are shown.

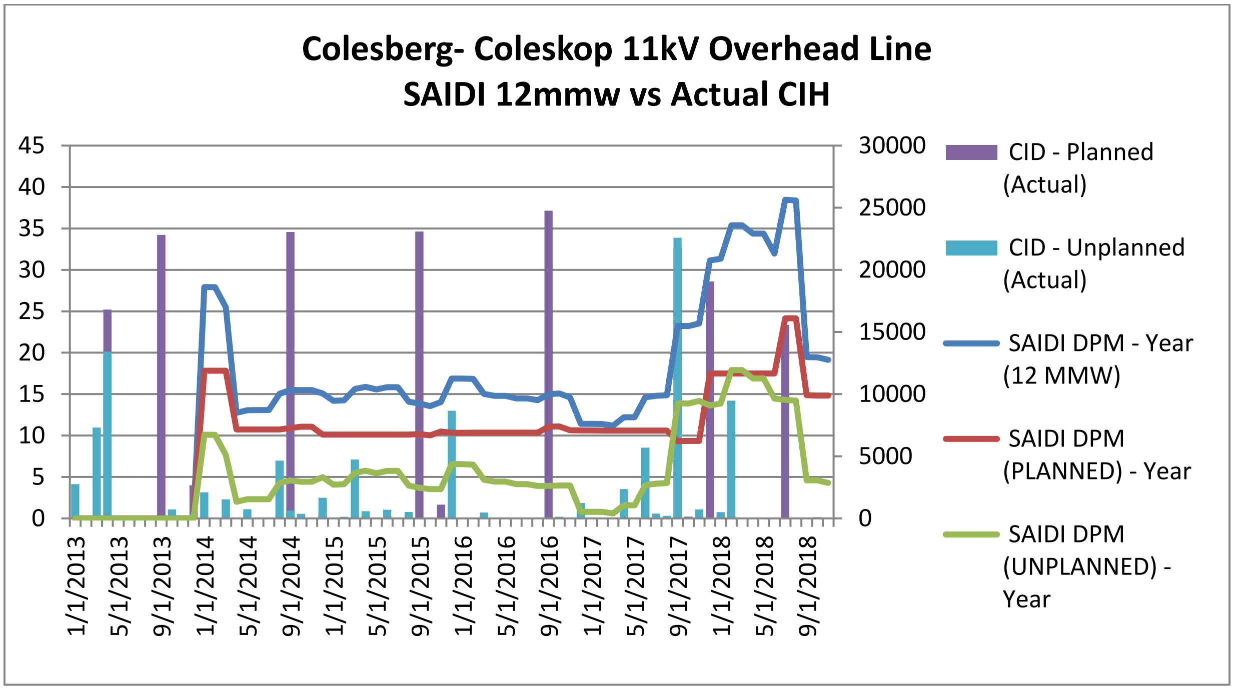


Figure 4.27: Colesberg-Coleskop 1 11kV overhead line SAIDI trends

This line has different types of customers including domestic customers and commercial farmers. As shown in Figure 4.27, planned interruptions are usually scheduled annually. If there is a special request to interrupt customers, it must first be approved by the relevant people in the electrical utility. Although interruptions are usually planned once a year, unplanned interruptions occurred over the five-year period. The longest planned interruption occurred in 2016 because it took a long time to restore the supply after the outage.

The duration of the outage has an effect on the performance of the network. The graph in Figure 4.27 indicates the number of hours of interruptions. Unplanned customer interruptions on this line have occurred frequently over the last five years. The details of what caused the interruptions are discussed subsequently in equipment component failures. The longest recorded event happened between July and October 2017. Planned SAIDI has been fairly constant from 2014 to January 2018, with unplanned SAIDI just below 10 customer duration hours while the actual SAIDI for this line was higher than planned and unplanned SAIDI for a period of five years. SAIDI trends for 2013 are not included on this graph.

4.5.2.2 Colesberg-Coleskop 1 11kV overhead line SAIFI trends

Data for SAIFI trends were also captured for a period of three years as depicted on the graphs inFigure 4.28, which indicate planned and unplanned SAIFI. Planned SAIFI is usually planned for very low interruption hours for cost-saving purposes. However, because of the component on the line of townships, unplanned SAIFI usually occur more than actual planned SAIFI during a 12-month period. The columns shown in Figure 4.28 indicate the actual customer interruptions (CI) while the graphs indicate the SAIDI for a 12-months moving window (MMW). The trends shows the planned and unplanned trends for a period of 12 months in relation to the target, which is decided by the relevant regulations.

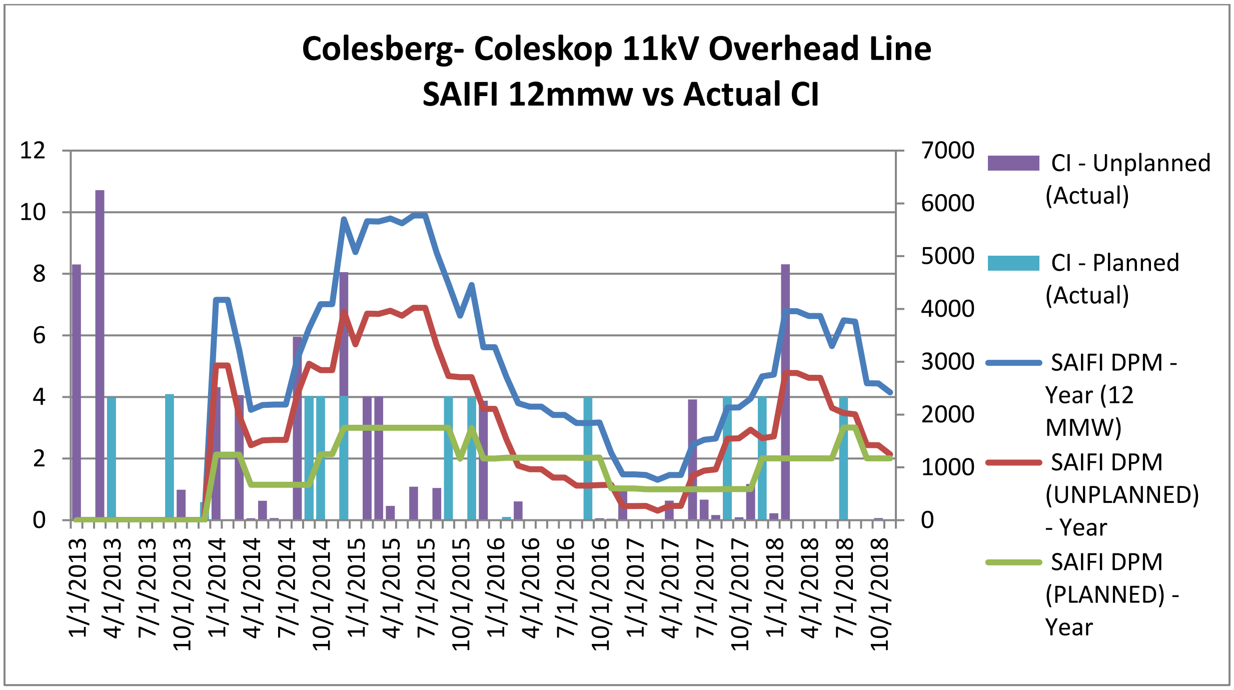


Figure 4.28: Colesberg-Coleskop 11kV overhead line SAIFI trends

The graph clearly shows the actual SAIFI was slightly more than planned and unplanned SAIFI. This line has many customers of which most are located in Kuyasa. The number of planned interruptions for this line ranged between 2 000 and 3 000 customers from 2013 to 2018. The graphs show the frequency the customers were interrupted. For a period of five years, from 2013 to 2018, the actual SAIFI was highest between 2014 and 2016. From January to April 2017, SAIFI trends were at their lowest and the numbers of unplanned interruptions were very low. The highest number of unplanned interruptions on this line occurred in March 2013. The other major interruption events occurred in January 2013 and March 2018. The details of the events that cause such high interruptions are discussed in component failures.

4.5.3 Reticulation network 3: Postmasburg-Boichoko 11kV line (Newtown)

4.5.3.1 Postmasburg-Boichoko 1 11kV overhead line SAIDI 12mmw trends

Different trends including planned and unplanned customer interruption duration are portrayed in Figure 4.29. The graphs also indicate planned and unplanned SAIDI as well as the actual SAIDI for a period of five years. As indicated on the graph, in 2014 and 2015, planned interruptions happened on numerous occasions.

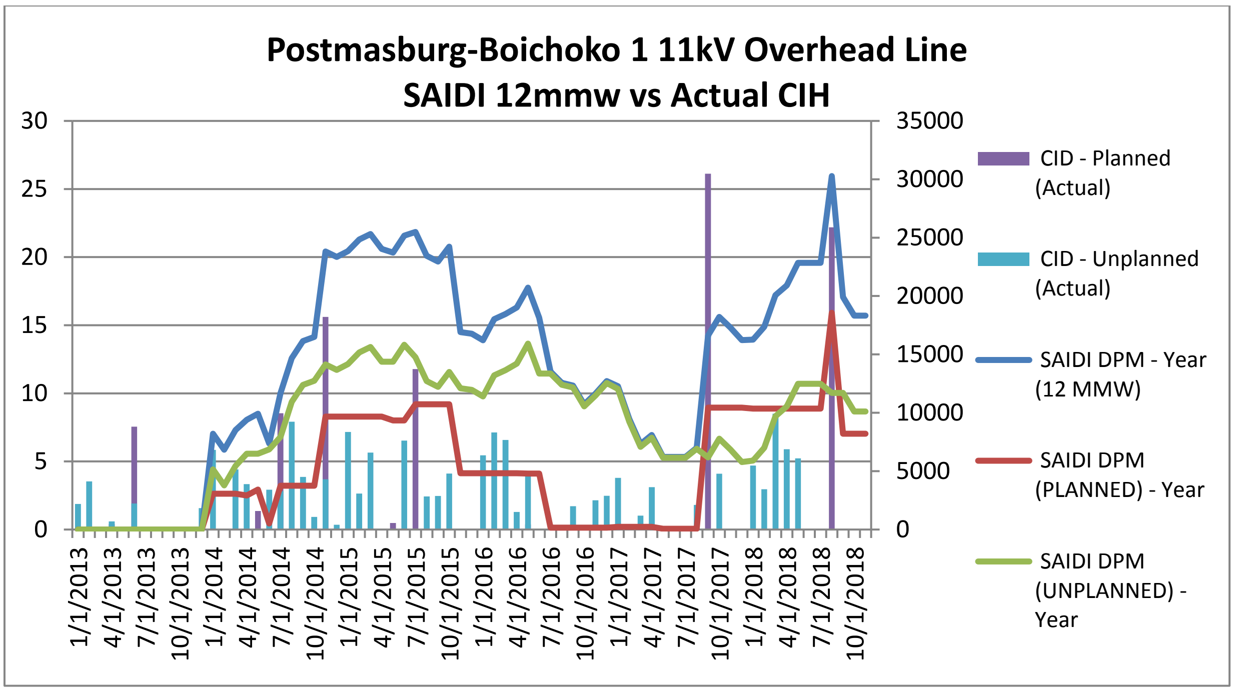


Figure 4.29: Postmasburg-Boichoko 1 11kV overhead line SAIDI 12mmw

The longest and second longest planned interruptions occurred in September 2017 and in August 2018, respectively. The graph indicates that the SAIDI trends for 2013 were at 0 and only increased in December 2013. The unplanned customer duration index (CID) was more than the planned CID over a period of five years with the exception of between October 2017 and March 2018. No planned interruptions were recorded from September 2016 to September 2017. The values on the left-hand side of the graph indicate actual CIH while the values on the right-hand side indicate the SAIDI 12-months moving window (12mmw). SAIDI 12mmw was the highest in October 2018. Furthermore, planned CI duration and planned SAIDI DPM were also high thus indicating there was an outage during that particular period.

4.5.3.2 Postmasburg-Boichoko 1 11kV overhead line SAIFI 12mmw trends

The trends portrayed in Figure 4.30 show the events that happened on the entire line and not only in Kuyasa. Many unplanned interruptions, which affected many customers, are indicated on the graph. The most unplanned interruptions occurred in December 2014 followed by one in January 2015.

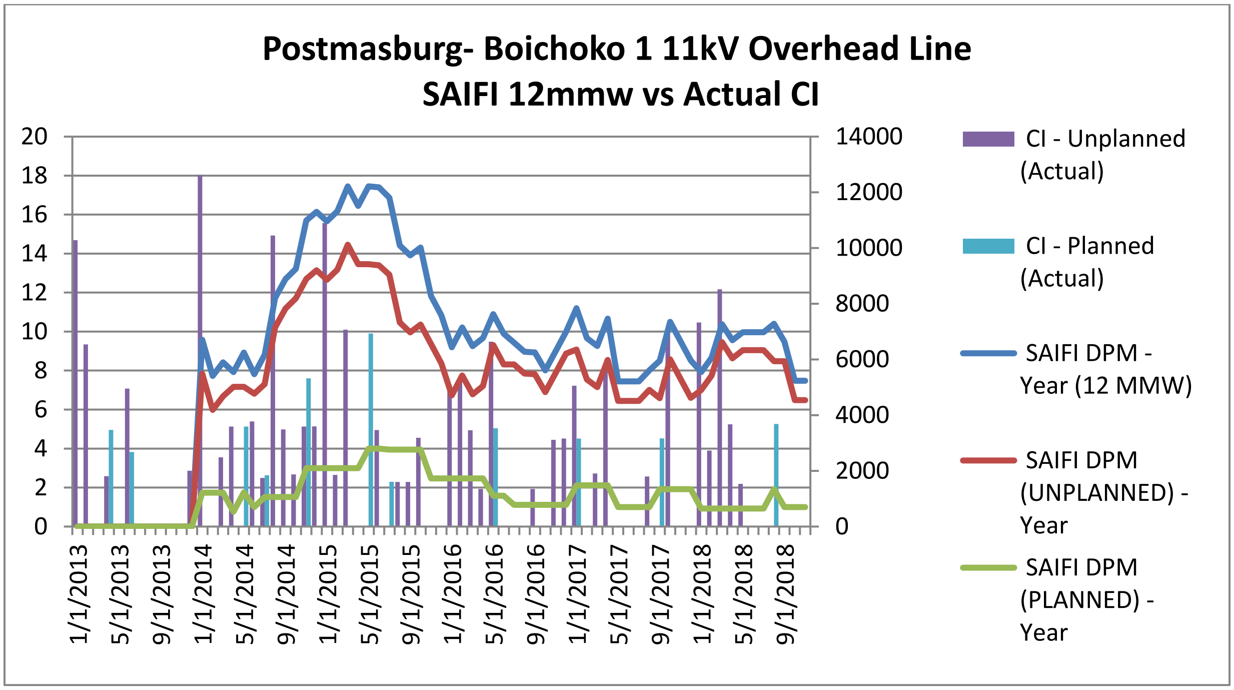


Figure 4.30: Postmasburg-Boichoko 1 11kV overhead line SAIFI 12mmw

Unplanned SAIFI trends were recorded from 2013 with the highest trends reaching almost 12 000 while there were fewer than 3 000 planned SAIFI 12mmw. From January 2016 to September 2017, the SAIFI DPM 12mmw and unplanned SAIFI trends occurred almost parallel to one another. From January 2013 to January 2014, no SAIFI trends were calculated with the values at 0. The data for the trends were recorded from January 2014 when the most unplanned CI were recorded. Figure 4.30 reveals more unplanned CI than planned CI. There were a great deal more unplanned SAIFI trends for the five-year period than planned SAIFI trends. The values on the left-hand side of Figure 4.30 indicate the actual values of CI while the values on the right-hand side denote SAIFI 12mmw trends for a five-year period.

4.6 Component failure rate analysis

From the component failures rates shown on the graphs, the data were downloaded by employing NEPS, which is the software used to record all the incidents that occur on the line. The data were gathered over a period of three years for the selected medium voltage lines that also supply the selected townships. Corrosion on the line remains the major challenge because the Muisvlakte-Port Nolloth 11kV feeder is a coastal line. The graphs may be classified into two types: the first indicates the time at which the customers were affected and the second the number of customers affected when the component failed. The data used for the calculations originated from SCADA and was verified by the field service workers. The information reveals how many times the components on the line failed and how many customers were affected by specific components that failed.

4.6.1 Muisvlakte-Port Nolloth 11kV component failure rate

4.6.1.1 Muisvlakte-Port Nolloth 11kV number of customer interruption hours (CIH)

The performance of the electrical network is determined by the rate at which the components fail. Components on an electrical network can fail because of various reasons including lightning, ageing, corrosion and damage caused by humans. In this section, the causes of customer interruptions discussed in section 4.4 are explained. The performance trends of the feeder are linked to the component failures on an MV line. In the Muisvlakte-Port Nolloth 11kV network, jumpers are the most affected component in that they were responsible for more than 15 000 CIH. This is portrayed in Figure 4.31.

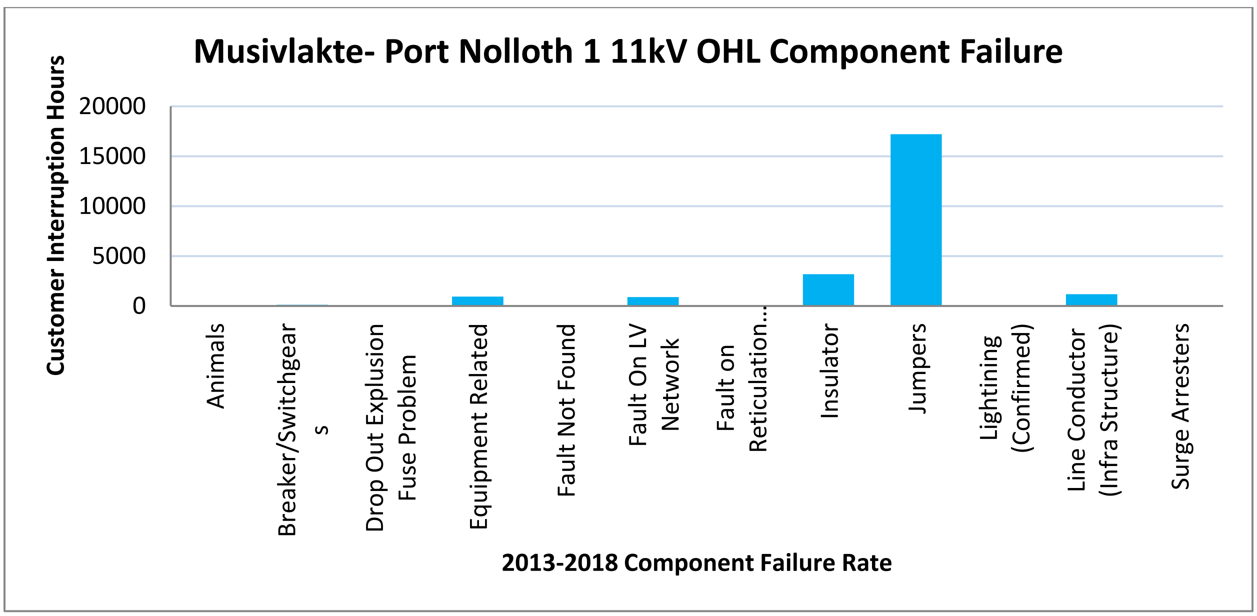


Figure 4.31: Muisvlakte-Port Nolloth 11kV overhead line customer interruptions

The causes of the component failures were recorded over a five-year period. The values on the y-axis indicate the total number of customer interruption hours while those on the x-axis denote the components that failed. Most of the jumpers are located in Sizamile because the township has the most pole-mounted transformers. The second highest contributor to component failure was insulators on the line. The network did not experience as many component failures as the other two townships selected for the study. Conductors also constituted component failures in the Muisvlakte-Port Nolloth 11kV feeder. Jumpers were the only component failure that resulted in more than 5 000 CIH.

4.6.1.2 Muisvlakte-Port Nolloth Port Nolloth 11kV number of customers affected

As indicated in Figure 4.32, jumpers were the cause of component failures. Over a five-year period, jumpers affected just over 4 000 customers. However, the interruptions could have affected the same customers more than once. The y-axis indicates the total number of customers that were affected due to component failures while the x-axis denotes the components that failed.

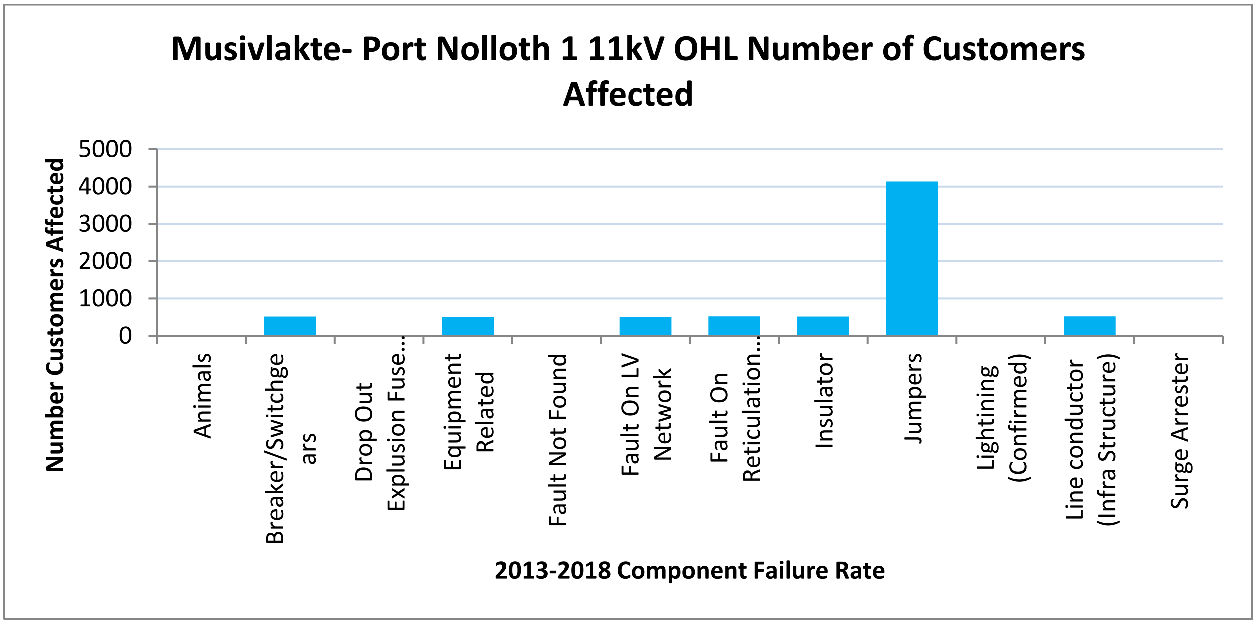


Figure 4.32: Muisvlakte-Port Nolloth 11kV overhead line number of customers affected

Although not to the same degree as jumpers, other components including insulators, conductors, lightning and breakers also contributed to the loss of supply. Most of other component failures affected less than 1 000 customers mainly in Sizamile.

4.6.2 Colesberg-Coleskop 11kV component failure rate

4.6.2.1 Colesberg-Coleskop 1 11kV number of customer interruption hours (CIH)

The Colesberg-Coleskop 11kV feeder comprises a three-phase system and SWER system. Consequently, the component failures were not the same as in the selected areas. In Figure 4.33, the CIH caused by the component failures are indicated on the x-axis. The y-axis denotes the total number of customer interruption hours. The data were recorded over a five-year period from 2013 to 2018. Every component failure during the five-year period was recorded even if it occurred on the same component or the same customers were affected.

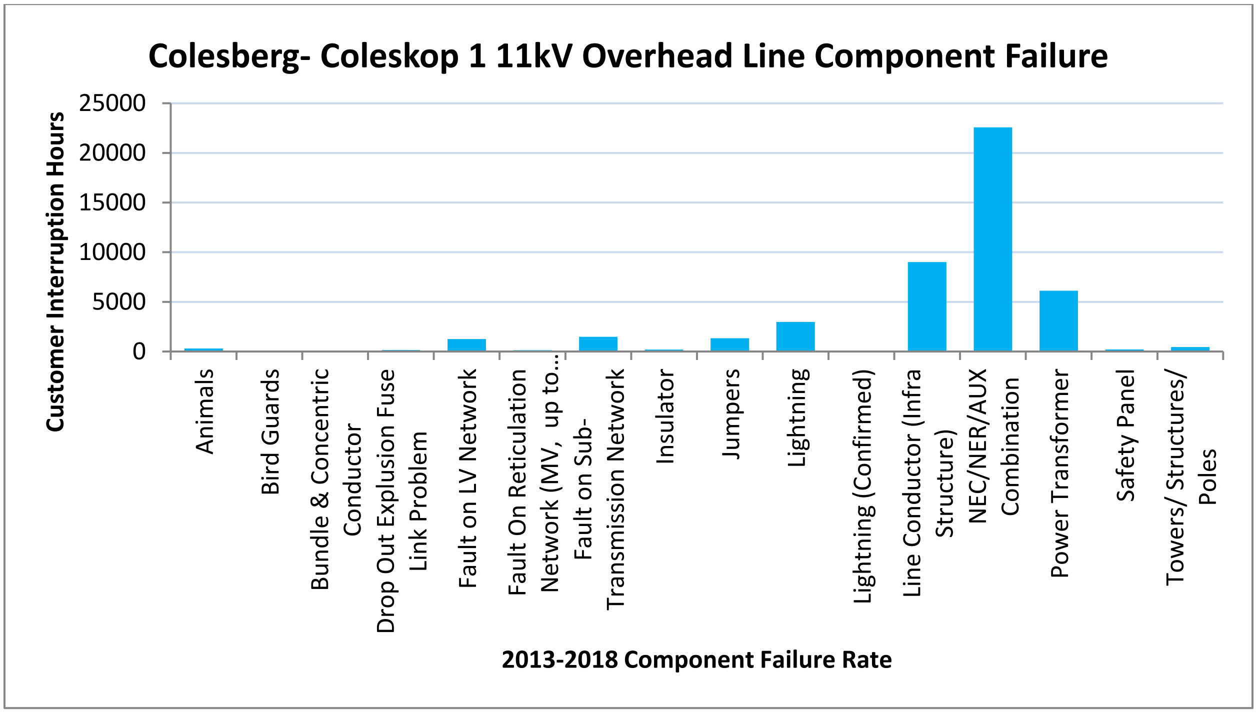


Figure 4.33: Colesberg-Coleskop 1 11kV overhead line component failure

The main backbone of the line is made of Rabbit conductor, which caused most of the failures on this network. A NEC/NER/AUX fault usually occurs on SWER networks and is mainly caused by earthing. The NEC/NER/Aux (SWER network section) caused the most CI on the Colesberg-Coleskop 11kV line. This line consists of a Squirrel conductor, which is a small conductor of 20mm^2. It usually burns if the load is too large thus contributing to the number of CIH. Power transformers are the third highest contributor to CIH; in this case, pole-mounted transformers located in Kuyasa. Three factors, depicted in Figure 4.33, contributed significantly to CIH.

4.6.2.2 Colesberg-Coleskop 11kV number of customers affected

The Colesberg-Coleskop 1 11kV overhead line has many customers; most of them reside in Kuyasa. When there is a component failure on the network, many customers are affected and lose power. The values indicated on the y-axis in Figure 4.34 represent the total number of customers that were affected due to a loss of supply while the values on the y-axis denote the component that failed on the network. The data were collected over a five-year period. The data do not only include the total number of customers affected in Kuyasa, but the total number of customers on that entire line.

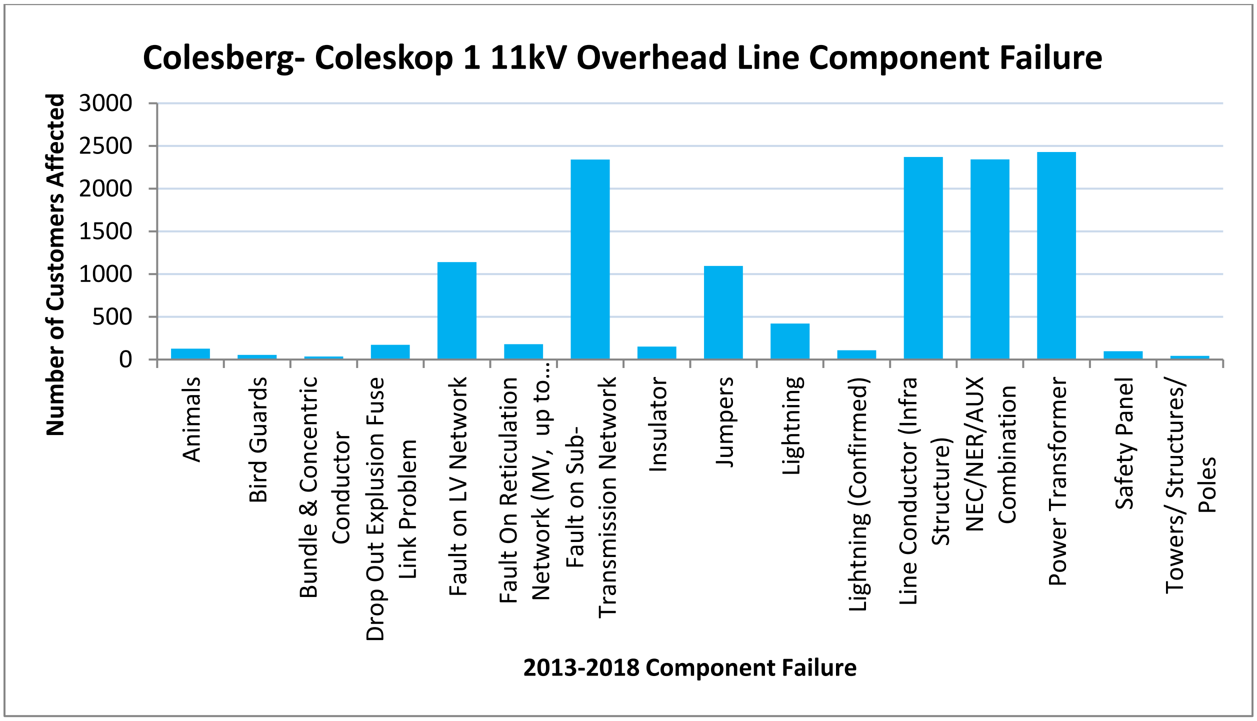


Figure 4.34: Colesberg-Coleskop 1 11kV overhead line number of customers affected

A study of Figure 4.34 reveals that power transformers are one of the leading factors that cause many interruptions on the network. NEC/NER/Aux, which is more evident on the SWER network, was also the cause of many interruptions. Because of the SWER network, most of the conductor failures on this section of the line are due to the size of the conductor. High thermal loading causes damage on the conductor. This also applies to the jumpers, which contributed the most to supply loss. Transmission networks where from where distribution networks are supplied also contributed to interruptions. The faults on the LV network mostly occur in Kuyasa with its many customers.

4.6.3 Postmasburg-Boichoko 11kV component failure rate

4.6.3.1 Postmasburg-Boichoko 1 11kV number of customer interruption hours (CIH)

The components that contribute the most to CI in the Postmasburg Traction-Boichoko 11kV network are portrayed in Figure 4.35. The data on the graph were recorded over a five-year period. Most of the faults originated from the MV network in Newtown. These failures contributed to most of the supply interruptions on this network. The component that contributed the most to the number of CIH were faults on the feeder including fallen trees, people throwing stones on the network, broken poles and vehicle collisions.

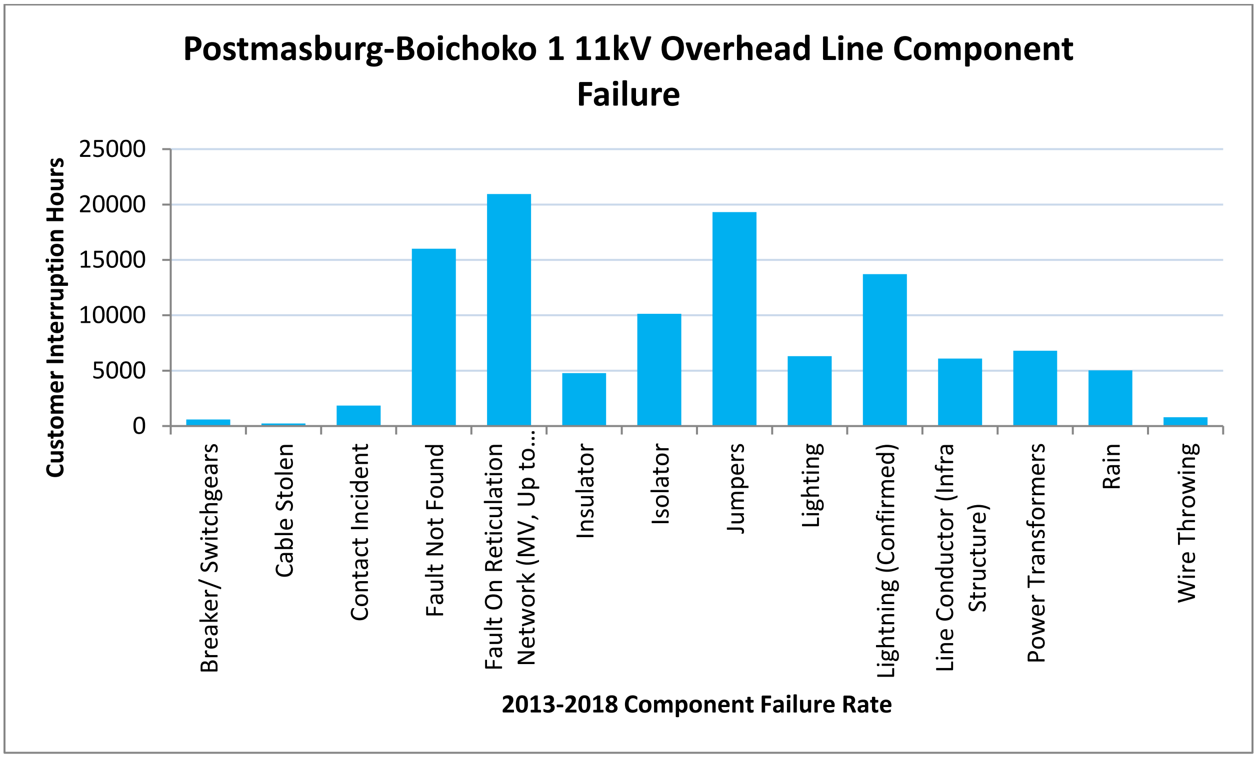


Figure 4.35: Postmasburg-Boichoko 1 11kV overhead line customer interruption hours

Jumpers contributed the second most to CIH. The reasons jumpers fail include using incorrect joints, burn due to excessive thermal loading and corroded joints. Faults that occur on the line and cannot be tracked contributed the third most to CIH. In most cases, the ARC (auto-recloser) usual clears the fault before the operator can be dispatched to find the fault, report and fix the fault. Minor faults include branches of trees that fall, faults on the line, flashovers between two phases and fall off, which involves someone throwing a wire over the line, which falls off. Most of the component failures contributed to less than 10 000 CIH on this feeder.

4.6.3.2 Postmasburg-Boichoko 11kV number of customers affected

The number of customers interrupted because of the faults that occurred on the line is portrayed in Figure 4.36. The data were recorded over a five-year period. Faults on the reticulation network affected the customers the most. Most of these faults occurred at anywhere along the line; when in the bush, poles were burned down. Faults on the reticulation network contributed to over 25 000 customer interruptions over the five-year period. This feeder had approximately 3 000 faults, which affected some customers on more than three occasions.

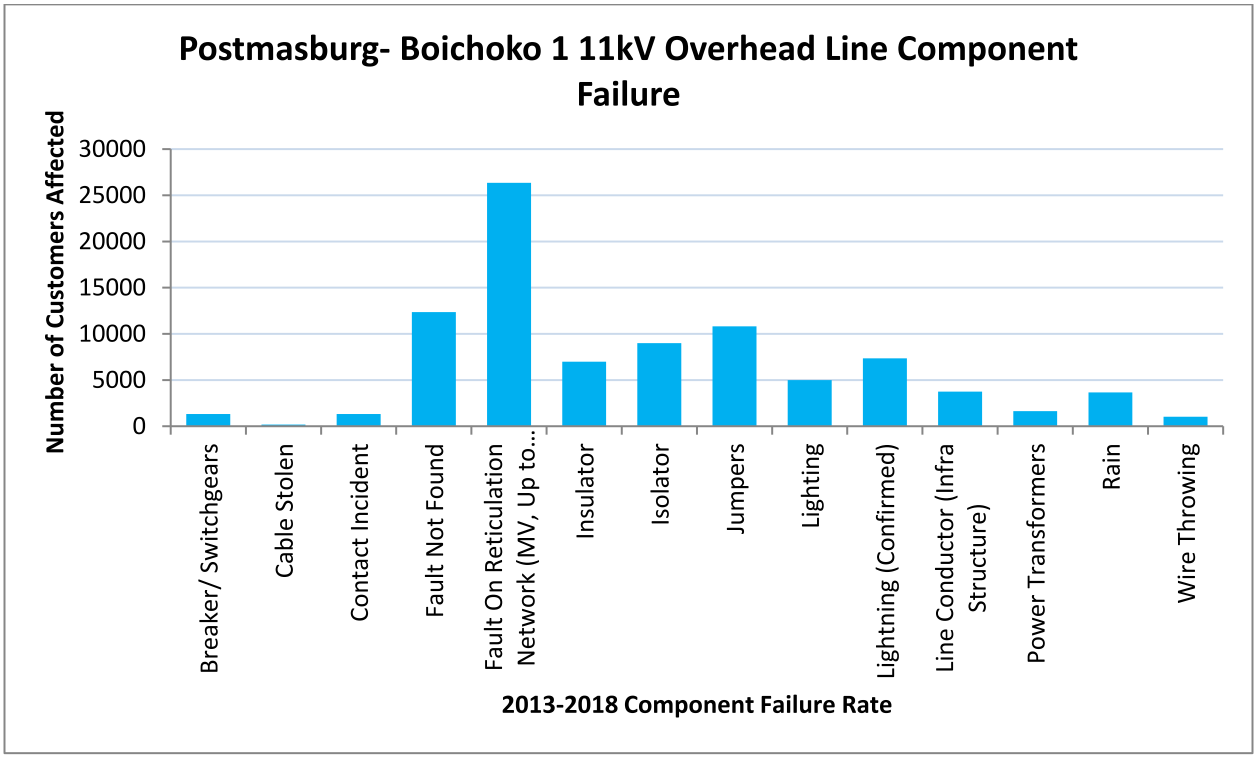


Figure 4.36: Postmasburg-Boichoko 11kV number of customers affected

The y-axis in Figure 4.36 indicates the actual number of customers that were affected by the interruptions over the five-year period. These faults were caused by general faults including the clashing of conductors, trees falling on the line, conductor snapping and high transient faults. Jumpers followed by lightning contributed the most to CI on this line. The components failures, but not general faults affected less than 15 000 customers.

4.7 Summary

Chapter 4 is based on the discussion of the results and data analysis which were obtained using the three methods which include Visual inspection analysis, Load studies and MV Performance trends. The three different methods employed and the results obtained were discussed in this chapter. In the first part of the chapter, the analysis of the network and locations were detailed. The conditions of the electrical network in the selected semi-urban areas were highlighted by conducting visual inspections to determine some of the defects that occur in different networks within different locations. The visual inspections were conducted on three electrical selected networks, namely, the Muisvlakte-Port Nolloth 1 11kV overhead line, which suppliesSizamile, the Colesberg-Coleskop 1 11kV overhead line, which supplies Kuyasa and the Postmasburg-Boichoko 1 11kV overhead line, which supplies Newtown. The visual inspections revealed that defects on the electrical networks selected for this study depended on the area of the location.

In the second part of this chapter, loading on the selected electrical networks by focusing on semi-urban areas were examined by employing DigSILENT Power Factory 2018. The electrical networks selected were modelled using DigSILENT Power Factory 2018 with all the electrical network characteristics and parameters. The main purpose of the simulations was to simulate the voltage profiles for all three networks and determine where the problems are. The calculations were conducted to determine the ADMD used per transformer zone in all the selected areas. The calculations indicated the pole-mounted transformers that are overloaded.

In the third part of the chapter, performance trends showing how SAIDI and SAIFI were affected in a five-year period were examined. The performance trends for each of the three electrical networks include the trends for SAIDI and SAIFI. The planned and unplanned CHI were revealed for the SAIDI trends. Subsequently, the planned and unplanned SAIDI with a 12-month moving average was depicted on the graphs for all selected networks. The planned and unplanned CI for SAIFI trends were also portrayed on the graphs. The planned and unplanned SAIFI trends for a 12-month moving average were also shown and discussed.

In the final part of the chapter, component failure rate showing what contributed to the number of failures that on the selected networks during the five-year period were outlined. Planned interruptions indicated on the graphs included the maintenance performed on the line by removing old insulators, the replacement of pole-mounted transformers, new projects that needed to be connected on the line. Unplanned events such as faults, equipment failures and bad weather also caused unplanned interruptions on the network. Most of the interruptions occurred because of unplanned events on the electrical networks.

Most of the component failures were more common in certain areas. The most common component failure that contributed to the number of customers that were affected included the jumpers and faults on reticulations. Premature failures and ageing of components on the MV network was one of the main causes of deteriorating performance on the MV network in semi-urban areas. Some of the results discussed in this chapter were presented at the SAUPEC Conference in 2019.

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1 Introduction

The aim of this research was to investigate the influence of ageing electrical components, the environment and loading on medium voltage components on the electrical network, which can have an impact on the safety, quality of supply and performance of the networks in semi-urban areas. The study of deteriorating medium voltage electrical networks was discussed in Chapter 4. The results shed light on why there are premature component failures such as jumpers on selected MV lines and how they affect the performance of the network. In this chapter, the results presented in Chapter 4 are discussed. Three semi-urban areas were investigated to shed light on how the deterioration of electrical components on the networks can affect the quality of supply and performance in semi-urban areas. Various methods were implemented to obtain results so as to arrive at a conclusion on the effects of ageing components on medium voltage networks in semi-urban areas. The software that was employed to obtain the results is discussed in this chapter. A journal article on the results of the chapter that was published can be found in annexure A.

5.2 Discussion

The electrical network in Newtown is the cause of most failures on its electrical network even though the line was enhanced in terms of performance. Most of the pole-mounted transformers installed in Newtown are overloaded because of the number of customers connected per transformer zone. Some of the customers are connected illegally and increase the expected number of customers installed on a pole-mounted transformer. Most of the medium voltage transformers are still operational even though they are older than 30 years. Due to age and the loading on these transformers, repetitive interruptions result in loss of supply, which affect the performance of the entire line.

Most of the pole-mounted transformers in Northern Cape medium voltage networks are loaded up to 100% thus exceeding the safe loading of Ant transformer. In Newtown, most of the transformers' load exceeded the required 90%. In order to verify if a transformer is overloading, various devices are used to determine if there is overloading on the pole-mounted transformers. One such device is the current voltage monitor, (CVM), which can signify which phases of the transformer are highly loaded and which are lightly loaded. These devices are quite expensive and only a few are installed in the Northern Cape. When a pole-mounted transformer is overloaded, it generates heat on the windings, which then heat up the oil in the transformer [70].

When oil heats, it expands and causes a rupture where the bushings are connected to the tank of the transformer [70]. Because of the number of transformers in the township, some of the transformers have many customers connected to them, which results in voltage on the MV transformer. This failure of pole-mounted transformers was prominent in most of the component failures in Chapter 4. This means that pole-mounted transformers will not last for their designed life span. Some of the common failures that occur on the MV/LV transformers are due to the bushings attached to the tank of the transformer. The bushings have a life span of 20 years for the transformers in the substation. They are tested regularly to ensure that they are still in good condition. However, no testing has been conducted on the bushings of MV transformers.

The bushings of the MV transformers cannot be replaced; rather, the entire transformer has to be replaced. Bushings are one of the most important components of transformers because they connect the inside of the transformer to the main line. Lightning has been the cause of a number of pole-mounted transformer failures [71]. Transient surges can also damage the MV/LV transformers if the surge arrestors are damaged [71]. Most of the MV lines are equipped with earth wires to redirect the lightning strikes to the ground and avoid damaging the components from excessive faulty currents [72]. However, in most cases, when lightning strikes the line, the voltage generated has more magnitude than the rated voltage and current of the conductor used on the line. In some cases, the lightning will strike the pole and break it, which will cause other poles on the line to break too.

Jumpers are conductors used to connect a component on the network to the main MV line. The component can either be a MV/LV transformer or an auto-recloser or even from pole to pole. When there is a loose connection on the jumpers, they may easily break down. Jumpers generally break during windy conditions and rainy weather mainly because they are not tight enough. Jumper failures usually occur on medium voltage networks; this was indicated in Chapter 4. Insulators usually take much longer to deteriorate than other components on the network depending on the location or the climate to which they are exposed. Conductors take much longer to age or deteriorate. The environment also contributes to the rate at which the conductor deteriorates [7]. When the conductor loses its conductivity, its resistance becomes high causing the heat on the conductor to increase. When the conductor reaches a certain age, it loses its conductivity and poses a high risk of failure because of the extreme heat generated.

Most of the medium voltage overhead electrical networks in the Northern Cape are radial networks and have no back feed or alternative source of supply. The Muisvlakte-Port Nolloth network is the only 11kV network in Richtersveld local municipality. Most of the electrical networks that were designed before 1990 were designed for a certain number of customers and their performance was not considered to be a high priority. The main focus was to electrify and increase the revenue for the utility. However, the configuration of these networks is not efficient and reliable because of the way they were designed. The effect of the ageing infrastructure is always identified through the network performance including the restoration time. Port Nolloth does not have a satellite station.

Considering Springbok is approximately 150km from Port Nolloth means that if there is a fault in Port Nolloth, it will take roughly three hours for field service workers to get to Port Nolloth and restore supply. The medium voltage network is only approximately 5km in total in Port Nolloth. It is one of the areas supplied by Eskom in the Northern Cape. Metallic material used in coastal areas should be galvanized. However, this also has limitations because over a certain period of time, zinc, which is used as the protection layer, also corrodes [73]. Corroded material on the network results in customers being interrupted which is often the case in the Sizamile electrical network.

The Postmasburg-Boichoko 11kV overhead line has two points of supply, namely, the Postmasburg Traction Substation and Hillside Substation. Although the primary source of supply comes from the Postmasburg Traction Substation, both Boichoko and Newtown can be supplied from the Hillside Substation for a period of not more than one hour because the installed transformers in the Hillside Substation are not capable of supplying three semi-urban areas. Both Boichoko and Newtown can also be supplied from Bulkop Substation, which is approximately 45km away. Different types of conductors are used in the Postmasburg-Boichoko 11 kV feeder. Although the main backbone from the substation comprises Fox conductor, some sections are made of Mink and Hare conductor. The standard feeder will usually have a larger conductor on the backbone for load purposes especially if there is high chance of a load increase in the area.

The Colesberg-Coleskop 1 11kV overhead line has a SWER network on the far end of the network. However, earthing rods when the soil resistivity is low are problematic on most SWER networks. Another leading cause of customer interruption involves burning conductors due to excessive loading on the network. This problem occurs on the three phase networks and SWER networks. The Squirrel conductor, which is very thin and easily damaged when exposed to excessive loads, is one of the conductors on the Colesberg-Coleskop SWER network. Faults in the substation and HV network can also have a negative impact on the performance of the MV network. During the rainy season, the number of unplanned events increases not only on this line, but on the majority of the lines in the Northern Cape. If there is a fault on the line affecting Kuyasa, the impact on SAIFI becomes very high.

As depicted on the graphs in Chapter 4, most of the CI were unplanned with only a few planned. These interruptions were recorded over a five-year period. The load forecast reveals the expected load in the next 10-20 years. This helps planning and ensures that when customers can no longer be supplied, plans such as installing a conductor with a higher rating or installing another transformer at the substation can be implemented. Due to the age of the substation, refurbishment of the transformer may improve the load on the line. The upgrade of the main backbone will definitely improve the capacity of the line in relation to the load if the conductor is upgraded. Planned interruptions usually occur once a year; if there is a request and it does not impact the trends in a negative way, it can be granted.

5.3 Visual inspection

Visual inspection was one of the methods used as a data collection method for the existing electrical network condition on site. Three electrical networks were selected for this study so as to understand how the effects of the ageing network affect the interruptions in townships. The objective of the study was to understand the effects of ageing components on medium voltage networks in semi-urban areas. Three networks located in different areas in the Northern Cape were selected. Northern Cape is the largest province in South Africa. Because of the large landscape, the medium voltage networks are usually longer than normal. Northern Cape comprises different climates, ranging from coastal to inland as well as semi-desert conditions.

When all three networks were observed or inspected visually, the results were compared to determine whether the electrical networks in different areas had the same defects and if the ageing behaviour was the same. The first semi-urban area that was observed was Sizamile, which is located in a coastal area near Port Nolloth. The electrical network in coastal areas behaves differently from those that are located inland. Sizamile is supplied through the 11kV electrical network from Muisvlakte Substation, which is not located far from the township. The Muisvlakte-Portnolloth network, which supplies Sizamile, also supplies the municipality in the area. Through the visual observations that were conducted, the analysis revealed that corrosion is the greatest problem affecting the network in this area.

The observations revealed there was corrosion on the conductors, stays, pole-mounted transformer tanks and joints used to connect the jumpers to the line. Although the network does not supply as many customers as the other studied networks, this corrosion causes many components on the network to fail. Furthermore, these interruptions affect the performance of the network. Although the material used for coastal networks is usually galvanized, the zinc material applied also corrodes after several years [74]. Coastal areas experience high winds occasionally When there are corroded components on the network and high winds, there is a high probability that some of these components may fail [74]. As noted in the literature review, harsh conditions can cause accelerated ageing of components on the electrical network. Accelerated ageing means the installed components age much quicker than their designed life span.

The second selected network was Kuyasa, which is supplied from the Colesberg-Coleskop line. Kuyasa has many prepaid customers. In Kuyasa, there are approximately 3 000 customers. This area varies from Sizamile because it is inland and although it is not affected by a coastal climate directly, it has its own problems. Because many customers reside in this area, pole-mounted transformers are the most important component. The Colesberg- Coleskop 11kV overhead line is one of the longest lines in the Colesberg area because of the different customers. The observations revealed that most of the pole-mounted transformers in Kuyasa are leaking oil. Due to the conditions of the location where many customers live in close proximity, some of the overhead lines run through customers properties.

Some of the pole-mounted transformers on the network are not equipped with MV links or fuses, which isolate the transformer from the network if there is a fault on the network. The signs of deterioration on the poles can clearly be observed onsite without using special tools. The faults that occur on the SWER network are mainly due to earthing on the isolation transformers or auto-reclosers. Newtown is located just outside Postmasburg in the Northern Cape. The township is supplied from the Postmasburg-Boichoko 11kV line with the main substation not far away from the township. Of the townships supplied from this line, Newtown is the oldest. Newtown has recently been reconfigured to make the network more reliable. Furthermore, it is one of the few townships in the Northern Cape that can be supplied from different sources. As a result of the age of the network in Newton and the number of customers connected, the defects related to ageing and overloading equipment are evident in the photographs that were taken.

Both the new and old sections of the township were included. However, many of the defects occurred on the old section of the network. Due to the limited space in the streets, mid-block is the LV network configuration and the network is also shared with Telkom telephone lines. Most of these poles exhibit extensive signs of deterioration, which makes it impossible for field service workers to climb on when conducting fault-finding. The medium voltage going to Kuyasa is a radial network with only one recloser in the entire township. There is no other source of supply on this network. There is eight of T-offs from the main backbone distributing supply throughout the township including schools. Some sections of the MV networks run through the customer's property, which affects customers in various ways.

Low hanging bundle conductors and cables may result in fatal consequences for community members. Unfortunately, as the network ages, it loses some of its strength because of stress, which leaves the network vulnerable and weak at some sections. The pole-mounted transformers installed in Kuyasa do not have MV fuses. The MV fuses on the primary side means the transformer cannot be isolated if there is a fault on the secondary side of the transformer. This forces the overhead line to be switched off from the source in order to attend to the fault on the transformer, which affects other customers supplied from other transformer zones. Old conventional meters have the breaker on the top pole boxes. If the main breaker in the house reaches or exceeds the rated current, it will trip the breaker in the top pole box, which requires the field service worker from Eskom to come out and switch it back on. If there is no access, the field service worker will not be able to fix the fault.

5.4 Load studies

Heat is one of the main causes of accelerated ageing of electrical components on the MV electrical network. [70]. Heat is generated when the load connected is greater than the designed specifications. The study focused more on the loading of MV electrical networks in townships where most customers are connected. Due to the growing population in semi-urban areas, it is also necessary to consider the load forecast on the MV lines that supply the selected townships. Load forecasting involves studying current loading and predicts the future load on the network for the following 10 years. The forecast was indicated on graphs for the selected networks to determine whether the load will increase at a faster or slower rate.

Voltage is one of the most important factors to consider on the MV network, especially in the Northern Cape because of the size of the province and the length of the lines. One of the main challenges that occur when dealing with the voltage is the voltage drop, especially on longer lines. The type of conductor used for transmitting electricity can also play a role in limiting the capability of the line to supply the required voltage. The voltage profiles of the three selected networks for this study were simulated by employing DigSILENT Power Factory 2018. The voltage drop on the network depends mostly on the type of customers being supplied. For areas with many crop farms, many motors need to be supplied, which causes a great deal of voltage fluctuation on the network.

The voltage supplied to the motors must be consistent because it could affect the operation of the motor if not managed [75]. Of the three selected networks, only one network has voltage problems currently. The voltage limits are clearly stated in the NRS48-2 standard and mitigations must be made if those limits are not met. The Colesberg-Coleskop line is the only line with a voltage drop below the limit of 0.95pu. Different solutions can be implemented to boost the voltage to the required limit. However, the financial implications thereof should be considered. Usually, a short- and long-term plan is considered by the utility. In this instance, the long-term solution for networks with voltage problems is to upgrade the conductor on the main backbone of the network.

The simulations revealed that upgrading the conductor of the main backbone allows more capacity on the network and also improves the voltage drop on the network. This also improves the voltage on the SWER network, which is at the far end of the network. Most of the customers that are connected on the SWER network do not consume much power. Furthermore, it is unlikely that they experience the effects of voltage drop on their electrical appliances. The simulation to upgrade the conductor from Mink conductor to Hare conductor on the main backbone was done by employing DigSILENT Power Factory 2018. The Muisvlakte-Port Nolloth 11kV network and Postmasburg-Boichoko line were not experiencing any problems and thus, the simulation to upgrade the network was not considered.

The voltage drop is affected by the load, which impedes the network [76]. The more customers connected to the network, the higher the voltage drop. To calculate the load consumed by the customers connected, ADMD was used to calculate the number of customers connected per transformer zone. This is problematic for older semi-urban areas because pole-mounted transformers were not designed to carry many customers. ADMD is used to predict the consumption of power by customers. ADMD depends on the type of location; in this study, three selected semi-urban areas.

The three selected semi-urban areas were built prior to 1990 and still use original the network configuration. In these townships, the streets are narrow and the space is very limited because of the high number of residents in the same area. Even the networks become complicated because of limited space. Because of the layout of the townships, there is a limited number of pole-mounted transformers installed in the townships. Hence, these pole-mounted transformers are used to carry or connect many customers per phase. Sizamile does not have as many customers as the other areas selected for this study and thus, does not encounter as many connection problems. The network in Sizamile is mostly affected by ageing and corrosion because of the moisture from the ocean.

Because of the many customers in Kuyasa, most of the pole-mounted transformers are forced to connect more customers with low ADMD. The ADMD used in Kuyasa is mostly 0.2kVA, which allows more customers to be connected on a single pole-mounted transformer. Using a low

ADMD on a pole mount can strain the transformer in the long term especially if the transformer is utilized up to 90% of its capacity. Most of the pole-mounted transformers in Kuyasa are connected beyond 110% thus not allowing any more customers to be connected. The problem of illegal connections can also adversely affect pole-mounted transformers already operating at a 100% load. When the pole-mounted transformers are operated beyond their capability, leaking of oil on its bushings and tank are the first sign of overloading.

The same problem of overloading pole-mounted transformers is also experienced in Newtown. Although there has been an extensive reconfiguration of the Postmasburg-Boichoko 11kV overhead line, the electrical network in Newtown was not included. Most of the pole-mounted transformers installed in Newtown are 100kVA transformers with an average of 77 customers connected per transformer. There are eight pole-mounted transformers installed in Newtown of which many leak oil. Over the years, transformers have been replaced because of the extensive leaking and failures. According to the standard, the established township should use an ADMD of 2.4kVA per customer, which will allow a 100kVA transformer to connect at least 37 customers. Although it has long been argued whether the customers can use that power at the same time, to have a reliable and long-lasting network the standard should be applied to save costs.

5.5 Performance trends

The interruption of supply to customers determines the performance at which the network operates. All the utilities are measured in accordance with the quality of supply to customers, reliability and performance of the network [67]. SAIDI and SAIFI are the most important KPIs used to measure the electrical utilities. These KPIs indicate the duration the customers were interrupted and the frequency they were interrupted. Data for the three selected areas were obtained and discussed in Chapter 4 in which the trends for both SAIDI and SAIFI are shown. The MV lines only and not HV lines and the substations were the focus of this study even though the latter both have an impact on the performance of the MV lines if there are faults or equipment failures.

The performance trends include the actual planned and unplanned CIH and CI. These interruptions were plotted on the same graphs as the planned and unplanned SAIDI and SAIFI. The observations conducted on all the performance trends revealed the SAIDI and SAIFI DPM per year is almost the same or above the planned and unplanned SAIDI and SAIFI. These is because some of the events that occur on the line are not planned and the SAIDI and SAIFI calculations depend on the events that occurred on the line so that the average SAIDI or SAIFI trends can be plotted. The trends plotted are based the events that occurred on the feeders. The data presented were collected over a five-year period for both SAIDI and SAIFI. Different countries have a way of measuring the performance of their electricity based on their regulations [77].

The overview of SAIDI and SAIFI can be measured extensively nationally. However, in this study, the focus was on the three selected networks. The effect of ageing components on the network increases the interruptions on the network, which increases the values of SAIDI and SAIFI. As far as possible, the plan is to have low SAIFI and SAIDI values. This is achieved through reliable and well maintained equipment on the lines. For new assets such as lines, the SAIDI and SAIFI values are usually very low depending on the network configuration of the line. In this study, the trends clearly show that the older the network becomes, the more interruptions are experienced on the network and the higher the values of planned and unplanned SAIDI and SAIFI. An examination of the graphs reveals the values of planned SAIDI and SAIFI are always lower than unplanned and actual SAIDI and SAIFI values because the utilities usually plan their outages based on the maintenance that needs to be performed on the network.

Planned interruptions usually occur when there is a project that needs to be connected to the network such as electrification projects, new developments and if poles and/or jumpers need to be replaced. These outages usually depend on the duration thereof; the utilities usually have a standard duration during which the outage should occur. The data presented do not include the SAIDI and SAIFI trends for 2013, but only planned and unplanned CI and CIH.

5.6 Component failure

The performance of the network is measured by CIH and CI. However, these interruptions do not just happen, but are caused by other factors. In this section, component failures that cause interruptions on the network and affect the performance of the network, namely, SAIDI and SAIFI were examined. Failure of components is affected by many factors including ageing, environmental factors and maintenance. Depending on the area and their design, electrical components have different failure rates. In this study, the effects of ageing components on the electrical MV networks in semi-urban areas were examined. Many methods are used to predict the failure rate of components such as power transformers and cables.

Power transformers are fairly expensive and thus, have been widely studied throughout the world. Extensive studies on ageing transformers and switch gears have been conducted and documented. However, in this study, the focus was on MV networks in semi-urban areas where low or middle incoming earners reside. Most of the networks that supply these customers were previously considered to be a low priority by utilities. The supply to every customer is crucial because they also contribute to the revenue the utility collects annually. Although the interruption of a few customers does not show a significant impact on SAIFI and SAIDI performance, most customers without a supply can make a significant difference to the performance of the utility. In the Northern Cape, there are various climate conditions that affect the ageing of components on the electrical network.

Components such as jumpers and pole-mounted transformers fail because of their loads. More loads on the components cause the heat on the components to increase thus accelerating the rate at which they age. When a high load is constantly applied to conductors, jumpers and pole-mounted transformers with the same temperature, too much stress will be placed on the components and their lifespan may be shortened. The most common failure in two of the three selected semi-urban areas were pole-mounted transformers. No maintenance has been performed on pole-mounted transformers because of financial reasons. However, the impact is immense if too many pole-mounted transformer failures occur. Some of the components on the network fail because of natural causes, which cannot be prevented but can be mitigated to minimize the risk.

Failures on inland networks such as the Colesberg-Coleskop 11kV and Postmasburg-Boichoko 11kV overhead lines are based on the load because of the number of customers and network configuration. Some of the components on these networks age because of the way they are utilized. The more customers, the higher the load becomes and the more electrical components are stressed thus leading to accelerated ageing and eventually failures. Although some of faults occur because of natural phenomena, most of the faults are the result of ageing and thermal loads. The environment is the primary factor involved in component failure and rapid ageing of components in the Muisvlakte-Port Nolloth network, which supplies Sizamile.

5.7 Research objective

The objective of the study was to examine the effects of ageing components on medium voltage networks in semi-urban areas and how they affect the following:

- ✓ Quality of Supply;
- ✓ Performance of the network; and
- ✓ Safety

The study revealed that the three selected networks, which were built prior to 1990, show extensive signs of deterioration. The signs of deterioration are due to natural ageing of the network and exposure. Ageing components on the MV network increase the probability of failure and affect the performance of the network in general [78]. Ageing components also pose a safety risk to members of the community and the field service workers. Ageing electrical components lead to the high cost of maintenance and refurbishment. Due to the large size of the Northern Cape, the MV lines are very long in comparison to other provinces.

Voltage drop becomes a problem for most long medium voltage lines thus affecting the quality of supply. The voltage profiles for the selected areas were simulated and where the voltage was the problem, one of the methods was used to improve the voltages. Of three selected networks, only one network has voltage problems while the other two networks had a voltage within the limits between 1.05 pu and 0.95 pu. Townships around South Africa usually have many customers with yards close to one another because of very limited space. Consequently, the network configurations in the townships are designed in such a way that they should accommodate everyone in the area. The high number of customers lead to the risk of losing many customers in case there is a fault on the line. This was outlined in the performance trends in Chapter 4. The objective of this study was realized and revealed that ageing of components can affect the performance, quality of supply and safety.

5.8 Study limitations

The cost implications were not included in the study. Information thereof could not be obtained from the electrical utility because of the sensitivity of the information, which could not be shared. The general power system did not form part of the study as only medium voltage networks formed part of the investigation.

5.9 Recommendations

Electrical utilities should consider having refurbishment plans for all the assets on the network; not only in critical areas, but in semi-urban areas because that is where the majority of the people in South Africa reside [79]. Refurbishment plans will ensure that each asset is not operated beyond its lifespan. The maintenance of medium voltage networks should also be taken into consideration to avoid the risk of interruptions, which can end up affecting the performance of the network. To avoid long lines, which may affect the quality of supply, the lines must split and utilize nearby sources of supply. If there are no other sources of supply close by, employing larger conductors and voltage regulators could be taken into consideration.

Reconfiguring of the network will ensure that all the overloaded transformers are de-loaded and comply with the updated standards so that they last longer according to their design. The network reconfiguration should include the following:

- ✓ The correct type of conductor to ensure a long-lasting conductor on the network and to avoid conductors and jumpers breaking;
- ✓ Checking the voltage profiles before and after reconfiguration;
- ✓ Checking the fault levels on the feeders;
- ✓ The inclusion of voltage regulators and checking that they improve the voltage drop; and
- ✓ Additional transformers on the line to distribute the load to decrease the stress level on the existing transformers.

The correct size of the conductor will also assist in relation to choosing the best network that is safe to work on. The selection of the network using the system will also assist in terms of finding out if there will be enough capacity to supply more customers in the future. The correct size of the conductor will also reduce the number of failing conductors during stormy conditions or heavy rains.The correct selection of the transformer rating can be done by using the right calculations to obtain the number of transformers that should be connected on the network. The way the network is configured can have an impact on the rate at which the components age and the rate at which the components fail. Old networks pose safety risks because they break easily if they are not monitored correctly.

5.10 Summary

Ageing of electrical components on power system networks have various implications that can affect how networks perform. The main aim of this study was to investigate the influence of ageing components on medium voltage network configurations in semi-urban areas. The results were obtained using various methods, namely, network observations, simulations and data collection. The results obtained during the study indicate that, electrical components such as jumpers, pole-mounted transformers and conductors age and fail according to the environmental exposure. The investigation results revealed that each of the selected electrical networks within semi-urban areas has its own challenges related to component failures.

Deterioration and ageing of electrical components contributes the most to the poor performance of the electrical networks and high capital cost of the replacement or refurbishment of the infrastructure. More maintenance is required on the electrical networks within semi-urban areas to improve the reliability and safety for members of the public as well as field service workers working on these networks.

REFERENCES

[1] D. Malzbender, "Domestic Electricity Provision in the Democratic South Africa," Pretoria, 2005.

[2] T. Harris, "Insights into the links between electricity access and household dynamics in South Africa between 2008 and 2012," University of Cape Town, 2016.

[3] S. (South A. W. P. Association), "Wooden Piling or foundation poles used for permanent buildings," *SAWPA*, Gauteng, p. 2, Nov-2015.

[4] J. J. Morrell, "Estimated Service Life of Wood Poles," in *North Ameriacan wood Pole council Technical bulletin*, 2016, pp. 1–8.

[5] B. H. Chudnovsky, *Electrical Power Transmission and Distribution- Aging and Life Extension Techniques*. Boca Raton: CRC Press, 2013.

[6] X. Zhang and E. Gockenbach, "Assessment of the actual condition of the electrical components in medium-voltage networks," *IEEE Trans. Reliab.*, vol. 55, no. 2, pp. 361–368, 2006.

[7] S. U. M. Rao, "Influence of environmental factors on component/equipment reliability," *Indian J. Eng. Mater. Sci.*, vol. 5, no. 3, pp. 121–123, 1998.

[8] W. E. Vesely, "Approaches for age-dependent probabilistic safety assessments with emphasis on prioritization and sensitivity studies," Washington, 1992.

[9] A. A. Beutel *et al.*, "Electrical Model of Phase-to-Woodpole Bird Electrocution," *SAIEE Africa Res. J.*, vol. 110, no. 3, pp. 125–135, 2019.

[10] M. Nitoi and M. Pavelescu, "Modelling ageing at the level of electrical systems from Cernavoda NPP," *Rom. Reports Phys.*, vol. 55, no. 1–2, pp. 53–67, 2010.

[11] D. Zhu, "Electric Distribution Reliability Analysis Considering Time-varying Load, Weather Conditions and Reconfiguration with Distributed Generation," Virginia Polytechnic Institute and State University, 2007.

[12] B. Magoro, "South African Distribution Code- Version 6," Johannesburg, 2014.

[13] G. S. Hendri Geldenhuys, "Earthing of MV and LV Distribution Lines : A multi-faceted problem .," vol. 292, no. 15 October, pp. 1–9, 2007.

[14] R. Dupin and A. Michiorri, "Current Carrying Capacity-Dynamic line rating forecasting," in *Renewable Energy Forecasting: From Models to Applications*, 2017, pp. 325–339.

[15] L. Wang, "The fault causes of overhead lines in distribution network," in *MATEC Web of Conferences*, 2016, pp. 1–5.

[16] D. Panth, "Reasons for Failure of Transmission Lines and Their Prevention Strategies," *Int. J. Electr. Electron. Data Commun.*, vol. 2, no. 1, pp. 1–4, 2014.

[17] M. A. M. Saran, M. L. B. Martinez, R. R. Bonon, H. R. P. M. de Oliveira, C. Nucci, and M. Paolone, "Performance of Medium Voltage Overhead Distribution Lines Against Lightning Discharges," in

CIRED - 19th International Conference on Electricity Distribution, 2007, pp. 1–6.

[18] S. Messalti, F. Zitouni, and I. Griche, “Design Of MV/LV Substation Transformer,” *Engineering*, vol. 5, no. 1, pp. 20–25, 2013.

[19] V. Mlambo, “An overview of rural-urban migration in South Africa: its causes and implications,” *Arch. Bus. Res.*, vol. 6, no. 4, pp. 1–9, 2018.

[20] T. Gaunt, M. Salida, R. Macfarlane, S. Maboda, Y. Reddy, and M. Borchers, “Informal electrification in South Africa,” Cape Town, 2015.

[21] CSIR, “Grid Electricity- Guidelinea for Human Settlement Planning and Design,” Pretoria, 2000.

[22] R. Nath, “Guidelines for Specifications of Energy Efficient Outdoor Type Three Phase abd single Phase Distribution Transformers,” New Delhi, 2008.

[23] M. Straka and D. Malindzak, “Classification of distribution networks,” *Total Logist. Manag.*, vol. 3, no. 3, pp. 79–86, 2010.

[24] S. F. Tan and S.K. Salman, “Investigation into the implementation of auto reclosing scheme in distribution networks with high penetration of DGs,” in *Proceedings of the Universities Power Engineering Conference*, 2008, pp. 1–6.

[25] T. U. A. Maheshwari, B. Rusek, B.Sweeney, C.Fischer, D.Makareinis, L.Gauthier, L.O’Sullivan, N.Amyot, P.Crego Delamo, T.Minagawa, “Ageing High Voltage Substation Equipment and Possible Mitigation Techniques Ageing High Voltage Substation Equipment and Possible Mitigation Techniques,” Sydney, 2018.

[26] T. . Short, *Electric Power Distribution Handbook*, vol. 3, no. 4. CRS Press, 2005.

[27] H. A. K. M. Mamdouh Abd El Aziz, Doaa Khalil Ibrahim, “Estimation of the lifetime of the electrical components in distribution networks,” *Electron. Electr. Eng.*, vol. 2, no. 3, pp. 269–273, 2007.

[28] S. Refsnses, L. Rolfseng, E. Solvang, and J. Heggset, “Timing of wood pole replacement based on lifetime estimation,” in *2006 9th International Conference on Probabilistic Methods Applied to Power Systems, PMAPS*, 2006, vol. 1, no. 1, pp. 1–9.

[29] F. L. R. Vidor, M. Pires, B. A. Dedavid, P. D. B. Montani, and A. Gabiatti, “Inspection of wooden poles in electrical power distribution networks in Southern Brazil,” *IEEE Trans. Power Deliv.*, vol. 25, no. 1, pp. 479–484, 2010.

[30] B. Wareing, *Wood Pole Overhead Lines*. London: IET Power and energy series no.48, 2005.

[31] V. Singh and M. N. Bailey, “Document Classification : Controlled Disclosure Title : Distribution Guide – Part 19 : SEPARATIONS AND CLEARANCES FROM POWER Unique Identifier : Document Type : Revision : Total pages : Review date : BUILDING LINE RESTRICTIONS , SERVITUDE Unique Identifie,” Johannesburg, 2011.

[32] C. Baker, J. Baker, and H. Nouri, “Sag-tension calculation program for wood pole overhead lines,” *Power Eng. Conf. (UPEC), 2013 48th Int. Univ.*, vol. 2, no. 13, pp. 1–7, 2013.

[33] T. A. Short, “Overhead Lines,” in *Electric Power Distribution Equipment and Systems*, CRC Press,

2012, pp. 33–90.

[34] Ensto, “Solutions for Overhead Line Networks,” Finland, pp. 1–108, 2017.

[35] S. K. Lau and S. K. Ho, “Open-circuit fault detection in distribution overhead power supply network,” *J. Int. Counc. Electr. Eng.*, vol. 7, no. 1, pp. 269–275, 2017.

[36] Don A. Genutis, “Top Five Switchgear Failure Causes and how to avoid them,” Addison, 2010.

[37] S. T. Jan, R. Afzal, and A. Z. Khan, “Transformer Failures , Causes & Impact,” in *International Conference Data Mining, Civil and Mechanical Engineering (ICDMCME’2015)*, 2015, pp. 49–52.

[38] F. A. Netshiongolwe, “Distribution Transformers Using Smart Grid Techniques,” University of Witwatersrand, 2016.

[39] K. R. P.E.L Risi, “Creating Failsafe Maintenance Methodologies In an environment of Diminishing resources,” no. 33, pp. 1–8, 2006.

[40] Y. Khan, M. I. Qureshi, N. H. Malik, and A. A. Al-Arainy, “Performance of composite insulators in simulated environmental conditions related to central region of Saudi-Arabia,” in *Proceedings - 2nd International Conference on Emerging Technologies 2006, ICET 2006*, 2006, pp. 378–384.

[41] T. S. D. E. and N. E. David Eccles, “Asset Management Plan: Pole Mount Transformers-Distribution,” 2013.

[42] M. Preez and W. J. D. Van Schalkwyk, “Protecting pole mounted MV transformers,” in *Cigre’s 7th Southern Africa regional conference*, 2014, pp. 31–36.

[43] R. Godina, E. M. G. Rodrigues, J. C. O. Matias, and J. P. S. Catalão, “Effect of loads and other key factors on oil-transformer ageing: Sustainability benefits and challenges,” *Energies*, vol. 8, no. 10, pp. 12147–12186, 2015.

[44] A. Reyers, “An Introduction to Medium and Low Voltage Cables in Distribution Networks as support of Smart Grids,” Brussels, 2014.

[45] S. A. Nagy, I. S. Ibrahim, M. K. Ahmed, A. S. Adail, and S. Soliman, “Network Reconfiguration for Loss Reduction in Electrical Distribution System Using Genetic Algorithm,” *Arab J. Nucl. Sci. Appl.*, vol. 46, no. 1, pp. 78–87, 2013.

[46] S. A. E. S. I. (ESLC), “ELECTRICITY SUPPLY — QUALITY OF SUPPLY Part 2 : Voltage characteristics , compatibility levels , limits and assessment methods,” Pretoria, South Africa, 2003.

[47] E. N. Association, “Danger of death: Network essentials one,” *Energy Networks Association (ENA)*, London, p. 2, Oct-2007.

[48] R. Akçan *et al.*, “Electrical Fatalities in Ankara over 11 years,” *Turkish J. Med. Sci.*, vol. 42, no. 3, pp. 533–538, 2012.

[49] B. M. Isobel van der Stoep, “Farmer’s perspective - Eskom’s application for MYPD4,” 2019, no. January, p. 19.

[50] E. T. Jean Arlet, Volha Hrytdkevich, Haya Mortada, Tigran Parvanyan, Jayashree Srinivasan,

"Getting electricity- Measuring reliability, prices and transparency," 2013.

[51] T. Schoeman and M. Saunders, "The Impact of Power Outages on Small Businesses in the City of Johannesburg," in *1oth International Conference on Education, Business, Huminities and Social Sciences Studies*, 2018, pp. 328–333.

[52] M. Kolcun, M. Kornatka, A. Gawlak, and Z. Conka, "Benchmarking the reliability of medium-voltage lines," *J. Electr. Eng.*, vol. 68, no. 3, pp. 212–215, 2017.

[53] D. M. Washko, "Electric Service Reliability in Pennsylvania," Pennsylvania, 2017.

[54] R. Karhammer *et al.*, "Sub-Saharan Africa: Introducing Low Cost Methods in Electricity Distribution Networks," Washington, 2006.

[55] V. Grover, "Research Approach: An Overview," *ResearchGate*, vol. 4, no. 8, p. 12, 2015.

[56] K. Jilcha Sileyew, "Research Design and Methodology," in *Text Mining - Analysis, Programming and Application*, 2019, pp. 1–14.

[57] M. Tadross and P. Johnston, "Climate Systems Regional Report : Southern Africa August 2012 Authors : Mark Tadross and Peter Johnston," 2012.

[58] P. Lehohla, "Stats in brief," Pretoria, 2009.

[59] H. A. K. M. Mamdouh Abd El Aziz, Doaa Khalil Ibrahim, "Estimation of the lifetime of the electrical components in distribution networks," *OJEEE*, vol. 2, no. 3, pp. 269–273, 2007.

[60] C. F. Bai, W. S. Gao, and T. Liu, "Analyzing the impact of ambient temperature indicators on transformer life in different regions of Chinese mainland," in *The Scientific World Journal*, 2013, pp. 1–11.

[61] R. Kumar, "Signific Significance of wood seasoning," *Trop. For. Res. Inst.*, vol. 4, no. 11, pp. 1–7, 2017.

[62] Koppen Climate, "Koppen Climate Type of South Africa." p. 1, 2016.

[63] M. O. G. Portella *et al.*, "Atmospheric corrosion rates of copper, galvanized steel, carbon steel and aluminum in the metropolitan region of Salvador, BA, Northeast Brazil," in *Procedia Engineering 42*, 2012, pp. 171–185.

[64] M. Basyir and N. Safitri, "Inverter Model and Control Strategies for Single-Phase Rooftop Photovoltaic in Unbalance Three – Phase Residential Network Inverter Model and Control Strategies for Single-Phase Rooftop Photovoltaic in Unbalance Three – Phase Residential Network," *Sci. J. PPI-UKM*, vol. 3, no. 4, pp. 192–196, 2016.

[65] K. B. S Salvoldi, H.B. Barnard, "NRS 069- Rationalized User Specification CODE OF PRACTICE FOR THE RECOVERY OF CAPITAL COSTS FOR DISTRIBUTION NETWORK," Pretoria, South Africa, 2004.

[66] J. Ruoranen, "Effects of Static Loading and Environmental Conditions on the Aging Behavior of Aluminum Adhesive Joints Johanna Ruoranen Effects of Static Loading and Environmental Conditions on the Aging Behavior of Aluminum Adhesive Joints Julkaisu 1576 • Publication," Tampere University of Technology, 2020.

[67] I. N. Kessides, Z. Bogetic, and L. Maurer, “Current and Forthcoming Issues in the South African Electricity Sector,” St. Louis, 2007.

[68] R. Municipality, “Port Nolloth History,” 2018. [Online]. Available: http://www.south-north.co.za/rich_rt_pnolloth.html%0A16n June 2018.

[69] D. Atkinson, N. Buso, D. Pienaar, R. C. V. S. Carin, P. Simes, and T. Lekhanya, “EVALUATION OF SERVICE DELIVERY : COLESBERG,” Colesberg, 2003.

[70] Denver Office, “Permissible Loading of Oil-Immersed Transformers and Regulators,” Colorado, 2000.

[71] P. J. R. Lucas and D. A. J. Nanayakkara, “Lightning protection of pole-mounted transformers and its applications in Sri Lanka,” in *Transactions of the IEE Sri Lanka*, 2001, pp. 1–10.

[72] D. Jacob and K. Nithiyananthan, “Effective Methods for Power Systems Grounding,” *WSEAS Trans. Bus. Econ.*, vol. 5, no. 1, pp. 151–160, 2008.

[73] X. Wang, X. Li, and X. Tian, “Influence of temperature and relative humidity on the atmospheric corrosion of zinc in field exposures and laboratory environments by atmospheric corrosion monitor,” *Int. J. Electrochem. Sci.*, vol. 10, no. 10, pp. 8361–8373, 2015.

[74] B. Valdez, J. Ramirez, A. Eliezer, M. Schorr, R. Ramos, and R. Salinas, “Corrosion assessment of infrastructure assets in coastal seas,” *J. Mar. Eng. Technol.*, vol. 15, no. 3, pp. 124–134, 2016.

[75] A. H. Bonnett and R. Boteler, “The impact that voltage variations have on AC Induction motor performance,” in *Proceedings ACEEE Summer Study on Energy Efficiency in Industry*, 2001, pp. 301–316.

[76] M. J. Russell, “The Impact of Mains Impedance on Power Quality,” *Orig. Present. Power Qual.*, vol. 4, no. 203, pp. 1–13, 2000.

[77] CEER, “CEER Benchmarking Report 6.1 on the Continuity of Electricity and Gas Supply,” Brussels, Belgiumm, 2018.

[78] D. P. G. Jazimah Abdul Majeed, Halin Osman, “Managing Ageing Assets,” *CIRED Work.*, no. 79, pp. 1–4, 2010.

[79] L. Pernegger and S. Godehart, “Townships in the South African geographic landscape: Physical and social legacies and challenges,” Pretoria, 2007.

[80] B. Chatterton, “Network Reliability Measurement, Reporting, Benchmarking & Alignment With International Practices,” in *2005 IEEE Power Engineering Society Inaugural Conference and Exposition in Africa*, 2004, pp. 1–11.

[81] Peda.net, “Heating Effect of an Electric Current,” 2020. [Online]. Available: https://peda.net/kenya/ass/subjects2/physics/form-32/heoaec September 2020.

*An Investigation into the Effect of aging components on the Medium Voltage network configurations in the Semi-Urban Areas**

1st Nosi Mpelo
Department of Electrical, Electronics and Computer Engineering
Central University of Technology
Bloemfontein, South Africa
mpelonp23@gmail.com

2nd P. Hertzog
Department of Electrical, Electronics and Computer Engineering
Central University of Technology
Bloemfontein, South Africa
phertzog@cut.ac.za

Abstract*— Access to electricity for all South Africans is a goal that is still achievable; it is not a luxury to have access to electricity but a need for every individual. Electricity improves our way of life, even for people who are living in the Townships. Most of the medium voltage electrical networks supplying the Semi-Urban areas/Townships are more than 30 years, and some of them have reached the end of life. The existing electrical network configurations can cause accelerated ageing of the electrical components which can have a negative impact on performance, quality of supply and safety of members of the public. The aim of this paper is to discuss the effects of the environment on the medium voltage components on the electrical network which might affect safety, Quality of supply and performance of the networks in Semi-Urban areas. Ageing of components on the electrical network can result in a capital loss, loss of life and high supply interruptions which will also result in loss of revenue for the power utility. Three Semi-Urban areas located in different parts of Northern Cape will be selected for the investigation. Visual inspection and components failure rate will be used during the investigation to understand the details of the selected networks and their ageing characteristics. Components on the electrical networks selected for the research have different deterioration characteristics based on their environment and design of electrical network configuration. Safe, reliable and correctly design electrical networks in Semi-Urban Townships can improve the performance, quality of supply and reduce maintenance cost of the network. Northern Cape has one of the largest landscape in South Africa, which makes the distribution networks to be much longer than normal and takes more time to inspect that any other province in South Africa.***Keywords*— ageing of components on the network, component failure, network reconfiguration s**

I. INTRODUCTION

Prior to 1993, only 36% of the South African population had access to electricity which was mainly in the urban areas [2]. Before 1994, electricity infrastructure was mainly built for industrial, agricultural, mining as well as domestic applications (Certain Domestic Suburbs). The expected lifespan of an MV Line pole is approximately 30 years of age depending on the type of maintenance performed [3]. In the Northern Cape, most of the reticulation lines were and are still being built using wood pole structures. The rate at which the poles deteriorate depends on the environment where the network is built [4]. As with other assets in the a distribution network, each component is designed to operate over a specified period [4].

MV/LV electrical network consists of components like transformers, Auto- Reclosers, isolators, fuses, conductors, cables and jumpers [4]. All these components have a specific life expectancy, but there are a lot of factors that can shorten the lifespan of each component [5]. Most of the electrical network configurations in the Townships were built around 1960's to 1970's and some of them are still operational today. The component affected mostly by age in the network is the wooden structures, insulators and MV Transformers. Ageing of the network can have a safety risk for members of public and field service workers. The design of the old electrical network configuration in the townships is the main problem affecting the performance and the quality of supply.

However, though significant research has been conducted previously, most researchers focused their studies more on the urban areas, cities and industries where the electrical networks are underground, and the length of the medium voltage lines are much shorter with multiple sources of supply. This research is necessary because it will provide better understanding of the ageing behaviour of electrical networks components in different areas of the Northern Cape where the infrastructure is not as complex or well-maintained as in the developed urban areas. This will ensure that the quality of supply which is safe and reliable will not only be achieved in well-established urban areas but can also be achieved in Semi-Urban areas. To obtain satisfactory results during the study, three Semi-Urban areas which are located in different areas in the Northern Cape will be investigated. Visual inspection will be conducted, the component failure rate will be obtained, and simulations for thermal loading of the conductor will be investigated. The purpose of this paper is to study the ageing phenomenon of an electrical component in different areas in the Northern Cape based on the environment and the network configuration used in the Semi-Urban areas. This paper will benefit the electrical power utility in South Africa to provide a safe, reliable and electrical supply of high-quality electrical network that can last longer and improve cost saving. The literature review which focuses on previous studies that were conducted before will be discussed in this paper. For collection of data, visual inspection of the electrical network will be obtained using captured images from the site and through the component failure rate data. This data will then be used to compare the ageing characteristic of components in different locations in the Northern Cape. Based on the comparison of ageing components on the selected networks in different areas, the conclusion will be drawn based on the results gathered for all three selected networks.

II. DISTRIBUTION NETWORK COMPONENTS.

Ageing of electrical components on the networks has been widely discussed in different countries. In previous years, different studies have been conducted to come with models and formulas that can estimate the life expectancy of components on the network [6]. The ageing process of electrical components is mainly due to electrical stress, thermal stress and mechanical stress. The study shows that there is a relationship between the ageing process of the components on the network and the performance of the network.

The probability failure rate of the components can be classified through the rate at which the components age [7]. The deterioration of Mechanical stress of the poles can be weakened by many factors which include the decay of the wood due to moist, insects and woodpeckers [8]. Failure of poles can have a negative impact on the performance and mainly the safety of personnel/human in distribution networks [9]. The research was focusing on the inspection of wood poles of about 10000 over 23 Cities in Southern Brazil [9].

Table I. Classification of Poles after they have been inspected

Inspection		Class	Procedure	
Internal	*External*		*Evaluation*	*Action*
Healthy wood	*Rotten wood*			
>0.10m	Without	1	Good	None
0.07m to 0.10m	Max. 0.01m	2	Initial Decay	Retreat Int/Ext.
0.03m to 0.70m	Max. 0.02m	3	Advanced Decay	Retreat Int/Ext.
<0.03m	total	4	Failure	Replace

In this research, it is observed that the deterioration of poles differs from country to country. It is specified that in Europe and America, the poles lifetime can last in the range of 25-50 years depending on the treatment used. In Europe and America, they use different treatment than the treatment used in Brazil.

Different types of conductors are used around the world for distribution of electricity. This is the case with Eskom, overhead lines makes use of different types of conductors mainly based on the load and the length of the overhead line. The most common conductor used in distribution networks is an aluminium conductor (ACC, AAAC and ACSR))[10]. Aluminium conductors has advantages and disadvantages, unlike copper conductor which is corrosion resistant and easily repaired, the aluminium conductor is affected by corrosion especially near coastal areas [10].

Temperature can affect the overhead line conductor in several ways,

- High ambient temperature which reduces the cooling effect of conductor and can allow highly loaded conductors to exceed the design temperature.
- The electrical load can also lead to conductor temperature above the design load [10].
- High temperature can cause the material used on the conductor to become soft which can allow the conductor so stretch beyond their elastic limit and exceed the clearance limit and pose a safety risk to the public [11].

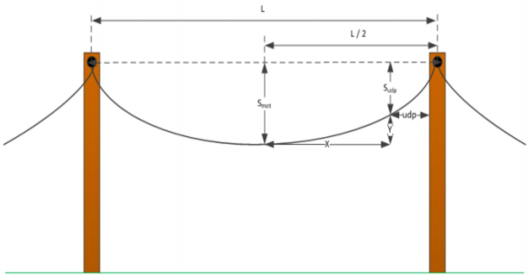


Fig.1. Conductor Sag at any point along span length

For a wide range of temperature, the resistance rises almost linearly with temperature for both the Aluminum and copper. The effects of temperature are simplified as a linear equation as can be seen in equation 1.

$$R_{t2} = R_{t1}\,[1 + \alpha\,(t_2 - t_1)] \quad (1)$$

Too small a conductor size, vibration and poor compression joints can all cause jumper failures. Poor installation and the use of inappropriate connections can also lead to fault conditions. Stays are frequently broken at the pole connection, especially if eyebolts are used. Stays rarely break due to overloading, fatigue failure and corrosion being the major problems [10].

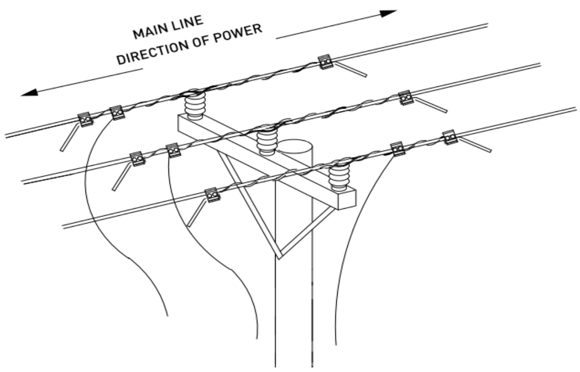


Fig.2. Connection of the Jumpers on the Medium voltage Overhead Line

In most of the studies that were conducted before, it was discovered that jumpers usually fail because of loose connection between the jumpers and the main line. When the termination connected to the overhead jumpers, they cause an overheating on the conductor and burn the jumper [13]. Loose connection increases the resistance at the point of connection which the generate heat which will escalate until the thermal failure occurs [14].

$$P = I^2 R \qquad (2)$$

Where

P is Power (Watt), I is Current (A), and R is Resistance (Ω)
Pole mount transformers form part of medium voltage network in the distribution system. Pole Mount transformer step down the medium voltage to low voltage that is usable by the consumer and in order to distribute the power to several customers.
The area that is supplied by a single transformer is known as the transformer zone. Transformers consist of different ratings which are selected based on the load they are supplying. The medium voltage network in the Township will be useless without medium voltage transformers [15].
Pole mount transformers can be divided into three types depending on the type of network they are installed in. These are the types of pole mount transformers;

- Single Phase Transformer,
- Three Phase Transformers,
- Single Wire Earth Return (SWER) Transformers,
- Isolating transformers (Rarely used in South Africa) [16].

The most studied component on the network is the transformer with many researchers coming with various models to estimate the remaining life of the transformer insulation. With the transformer that was constructed using IEC 60076 the relative ageing rate can be expressed in the following equation [6]:

$$V = 2^{\frac{\theta_{HS} - 98}{6}} \qquad (3)$$

Where θ_{HS} is the hot spot temperature and V is the relative loss of life.
The relation between insulation deterioration to time and temperature can be described using Arrhenius reaction rate theory using this equation 4 [17]:

$$Per\ unit\ life = Ae^{\left(\frac{B}{\theta_h + 273}\right)} \qquad (4)$$

Where A and B are constants

Electricity can be very dangerous because it cannot be touched, smelled and it is invisible. Unsafe distribution electrical networks can pose a high safety risk for members of the public. The voltage as low as 400V or even 230V can kill a Human being [19] if they get into contact with it without protective equipment. Ageing poles are the most high risk because they carry the conductors that distribute power on the network. During heavy storms, lines usually fall down if the poles are not strong enough. From the survey shown at [19] for fatalities that happened in UK which was done from 1997 to 2006. The survey mentioned in Fig. 3 includes the members of public and the third party contractors only.
South African electricity is regulated by NERSA when it comes to the supply of Electricity. The second edition of the NRS 048 covers the voltage parameters that might affect the normal operation of the electricity process to customers.

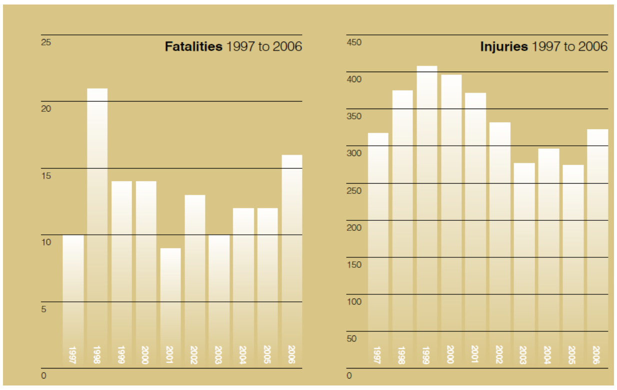


Fig. 3. Incidents which include members of public and third party contractors

According to the regulation, the LV network shall be the standard voltage of 230/400V. In the case of HV and MV, the reference voltage shall be nominal voltage or declared voltage (a fixed voltage agreed between the customer and the utility) [16]. It is then recommended that the declared voltage is within the limit of 5% of nominal voltage. The regulation also states that all the phases of the supply voltage should be monitored.
Different countries make use of different medium voltage network configurations. The reliability of distribution systems not only depends on the reliability of the distribution technology but is also dependent on the network configuration. Two significant models are to be distinguished [20].

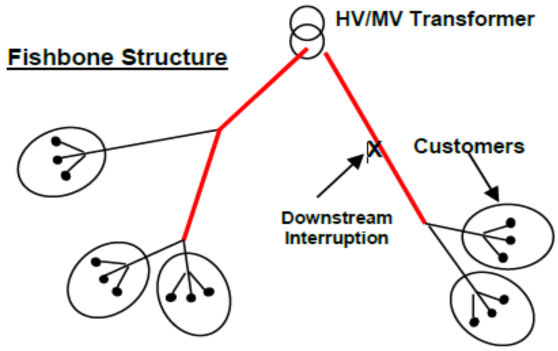


Fig.4. Radial/Fishbone network configuration

In Fishbone network configuration, customers may lose energy only in case of a breakdown on a circuit below the HV/MV transformer.

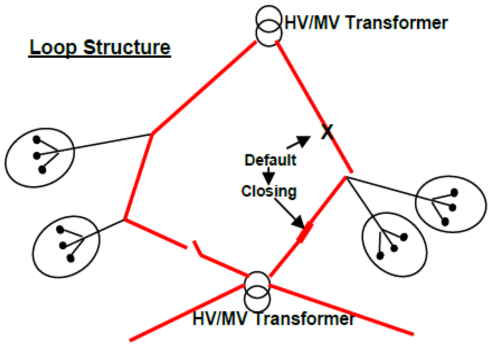


Fig .5. Loop network configuration

The network reconfiguration can be implemented to decrease the losses on the system and improve the reliability of the network. The network reconfiguration can be a difficult problem that many researchers have investigated before [20].

III. METHODOLOGY.

To obtain the results for the presented study, the area of study will be identified based on the environment, number of customers, type of networks, and the type of conductors used, that might accelerate the deterioration of the network in the selected areas. Three Townships will be selected based on their condition of the network. These Semi-Urban areas are located in different parts of the Northern Cape.
Before going to site, the desktop exercise which involves identifying the type of networks to select was done using the software called Geoviewer. This software shows the overview of the network, including the type of customers connected, the type of conductor used and the location of the network.

Table 1: SELECTED TOWNSHIPS

Overhead Line	Township	Area
Muisvlakte- Port Nolloth 11kV	Sizamile Township	Port Nolloth- Springbok
Colesberg- Coleskop 11kV	Kuyasa Township	Colesberg
Postmasburg Traction- Boichoko 11kV	Newtown Township	Postmasburg

For Visual inspection results, a physical site visit was done with the help of a camera to capture some of the sections of the network. When doing visual inspections, the following where the focus point;

- Corrosion on the conductor
- corrosion on the jumpers and joints
- leaking transformers and corrosion on the tank
- Sagging on the span of the medium voltage line
- Unsafe connections on both medium and low voltage
- Decay on the wood poles
- Cracks on the poles and the cross-arms

After obtaining visual analysis from site, the data was then compared to the information with the component failure rate which is obtained using Network and Equipment Performance System Replacement (NEPSR). The system is updated daily for monitoring the interruptions that are recorded on the network. From this information, we can then identify what is causing most failures on the selected networks.
Results obtained from visual analysis and component failure rate will help assist with modelling the network using the software such as Power factory and ReticMaster.
The networks will be modelled on the software using the same information or characteristics of the network on site just as it is to obtain the actual behaviour of the network on site.
The following Parameters will form part of the main focus when conducting the simulation.

- Voltage and current profile
- Loading of the Township
- Type of conductors
- Spare capacity
- Auto-recloser location and,
- Normally Open Points on the network

The study will also benefit Eskom and Municipality by ensuring that the electrical network in the Townships.

- Is Reliable
- Minimize the faults/interruptions
- Create back-feed or other points of supply
- Have more space capacity to supply future connections

Many people living in the Townships have been disadvantaged because they did not have access to electricity. But with steady supply in townships, they can also enjoy the benefit of having a continuous supply at all times with minimum interruptions. During storms and heavy rains, there is always a chance that the supply will trip, but with the improvement of the network, the interruptions will be as low as possible. During the construction of the project, jobs will be created to the locals, and many people will benefit during the project.

A. Sizamile Township

Sizamile Township is one of the Townships based in Port Nolloth which is 150km from Springbok. The Township is supplied from Muisvlakte- Port Nolloth 11kV feeder coming from Muisvlakte Substation which is ±9km away from the Sizamile. There are ±520 customers in the township with 5 transformer zones. The Township consists of 4*200kVA transformers as well as one 50kVA Transformer.
Most of the customers connected in Muisvlakte- Port Nolloth 11kV Overhead line are prepaid customers. Sizamile was officially established in 1993 with the electrification project starting in the same year. The original network is still operating even today.

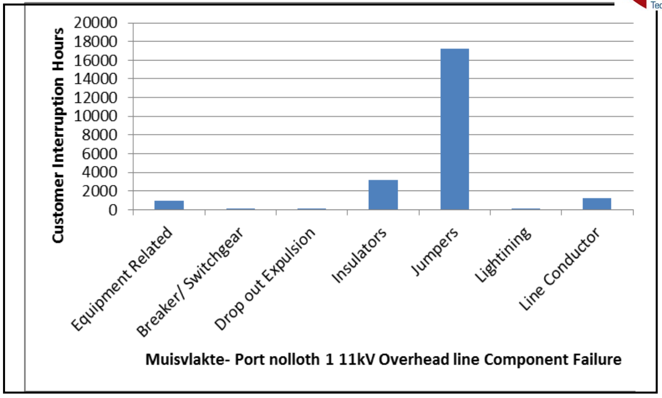


Fig .6. Muisvlakte- Port Nolloth 11kV OHL Component failure rate

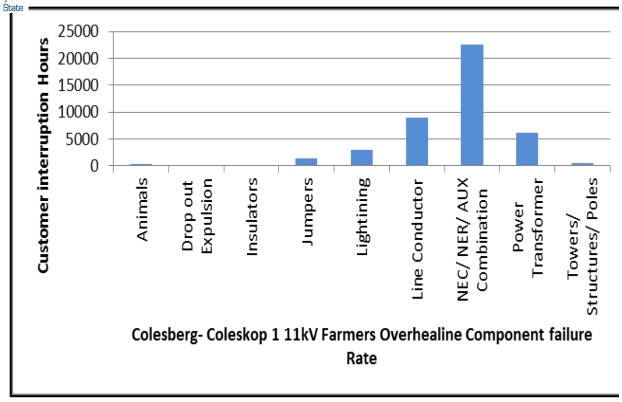


Fig .8. Colesberg- Coleskop 1 11kV Components failure rate.

Due to salty moist generated from the ocean, most of the components are exposed to rust. Muisvlakte- Port Nolloth 11kV feeder was constructed using different types of conductors with the different current rating. The information indicates how many times did the components fail on the line and how many customers were affected due to the specific component that failed. From both graphs, it can be observed that the highest contributor for both customer interruption hours and customers interrupted are jumpers, Followed by structures which are poles. Most of the jumper failures occur because of the rust on the joints which is due to most coming from the coast. Rust in this area affect most of the exposed components made of steel with an example shown in Fig.7. The picture was taken on the Recloser point just outside Muisvlakte Substation in Port Nolloth.

Fig .7.Stay which is affected by Rust in Sizamile.

B. Kuyasa Township

Colesberg Township (also known as Kuyasa) is situated in Colesberg and consists of 2603 customers. The township is fed by Colesberg – Coleskop Farmer 11kV which comes from Colesberg substation. Network consists of both MV and LV, in which LV is supplied by Aerial bundle conductor while MV is using both open and covered bare conductors.

The township is also considered as one of the biggest township in Colesberg area. Colesberg- Coleskop 1 11kV Overhead line was built in 1974 and was built as a radial network.

Colesberg- Coleskop 1 11kV Overhead line consists of two different networks which is three phase network as well as SWER (Single Wire Earth Return) network. SWER is usually used in the remote areas that consist of few customers. According to the graph above, most faults or interruptions occur on SWER transformers and Auto-Reclosers, and most of those faults are due to Earthing with corroded or broken earth rods. Fig. 8 also shows the failure rate of line conductor which mostly occur on the SWER conductor due to the type of conductor used. Most of the sections on this line make use of Squirrel type conductor which is a thin conductor used previously on the customers with lower load specifications. During hot conditions, the conductor stretches and increases the sagging of the conductor which affects the elastic strength of the conductor. Medium voltage transformers or pole mount transformers causes' interruption because of heat generated in the transformers due to load increase. During hot weather conditions, the ambient temperature can also affect the heat generated in the transformer. When the pole mount transformer is overloaded, the pressure in the tank increases and causes leakage of oil on the bushing and the tank itself as shown in Fig. 10.

Fig .10. Leaking Pole Mount Transformer due to Overloading

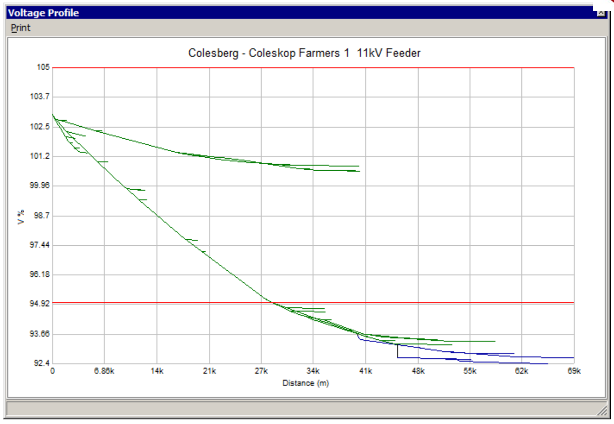


Fig .9. Colesberg- Coleskop 1 11kV Voltage Profile.

The total length of the line including all the T-offs is more ±300km as indicated on the background information. Due to the length of Colesberg- Coleskop overhead line, after ±27km from the source of supply, the feeder experiences a volt- drop which is below the limit of 95% as indicated in Fig. 9. Due to this voltage drop on the line, the line does not have enough capacity to connect new customers. The most affected customers due to the low voltages are further away customers and the customers supplied from SWER networks. All the cycles on the graph indicate the T-Offs from the main line.

C. Newtown Township

Newton Township is based in the Postmasburg area; it is serviced by Postmasburg CNC. The township is fed from Postmasburg Traction Substation which is approximately 4km from the substation. The name of the feeder feeding this township is Postmasburg-traction- Boichoko, it's an 11kV feeder and it also feeding Boichoko Township which is closed to Newtown Township. The Postmasburg Traction-Boichoko 11kV feeder itself has approximate ± 3596 customers with the majority of the customer's based.
Newtown and the other section now called White City. Newtown old section was first electrified in 1988 by the municipality and the second section which is White City was electrified in 2005.

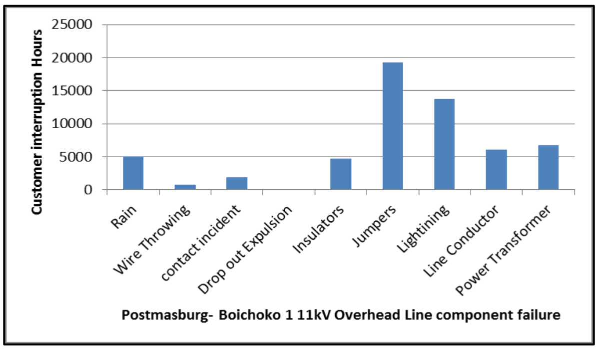


Fig .11. Postmasburg-Boichoko 1 11kV Component failure rate

The graph above shows the most contributors when it comes to customer interruption hours (CI). The data on the graph was recorded over a period of three years and most of the faults that caused the most interruption hours came from the MV network in the Township. The most significant contributor that affected most customers is the faults on the Reticulation network. Faults on Reticulation affected 26351 customers over the last 3 years.
Postmasburg area is highly affected by lighting which has a negative impact on the conductor and the jumpers on the line. Temperatures in Postmasburg Area range from 17º C in June to 32º C in January, with more rainfall happening during summer annually. As observed from Fig. 11, Jumpers fail because of the hotspot created over a certain period of time. When the current supplied on the conductor exceed the rated current of the conductor, excessive heat is generated causing the conductor to fail at some point. The cause of jumper failure on Fig. 11 is mostly due to the loose joint that connects the jumper to the main line, and in most cases, the size of the joint is not compatible to the size of the conductor used.

IV. CONCLUSION

The aim of this paper was to investigate the effects of the environment on the medium voltage components on the electrical network which might affect safety, quality of supply and performance of the networks in Semi-Urban areas. After analyzing the three electrical networks in the Townships, the results show that components such as jumpers, pole mount transformers and conductors fail due to the environment they are located in. The components that are located in the coastal areas turn to deteriorate much quicker than the components located inland. As the network ages, the material used on the components lose their strength and cannot operate according to their designed specifications. Accelerated ageing of components due to environment, over utilization of components increases failure rate of the components on the network and decrease the reliability of the network. The network optimization or network performance study was not discussed in this paper. More studies relating to the thermal loading on the medium voltage networks will be covered later on in the investigation. The results obtained from this study will assist with preventative initiatives and recommendations have safe, reliable networks in our Semi-Urban areas.

REFERENCES

[1] D. Malzbender, "Domestic Electricity Provision in the Democratic South Africa By," 2005.

[2] T. Harris, "Insights into the links between electricity access and household dynamics in South Africa between 2008 and 2012," University of Cape Town, 2016.

[3] S. A. W. P. A. (SAWPA), "Wooden piling or foundation poles used for permanent buildings," *Guid. Note*, no. November, pp. 1–2, 2015.

[4] R. of S. A. National Treasury, "Intergovernmental Fiscal Review," no. April, pp. 1–202, 2001.

[5] B. H. Chudnovsky, *Electrical Power Transmission and Distribution- Aging and Life Extention Techniques*. Boca Raton: CRC Press, 2013.

[6] M. Mamdouh Abd El Aziz, S. Member, D. Khalil Ibrahim, and H. Araby Kamel, "Estimation of the Lifetime of Electrical Components in Distribution Networks," *Online J. Electron. Electr. Eng.*, vol. 2, no. 23, pp. 269–273, 2007.

[7] X. Zhang and E. Gockenbach, "Assessment of the actual condition of the electrical components in medium-voltage networks," *IEEE Trans. Reliab.*, vol. 55, no. 2, pp. 361–368, 2006.

[8] S. Refsnæs, L. Rolfseng, E. Solvang, and J. Heggset, "Timing of Wood Pole Replacement Based on Lifetime Estimation," no. January, p. 9, 2015.

[9] F. L. R. Vidor, M. Pires, B. A. Dedavid, P. D. B. Montani, and A. Gabiatti, "Inspection of wooden poles in electrical power distribution networks in Southern Brazil," *IEEE Trans. Power Deliv.*, vol. 25, no. 1, pp. 479–484, 2010.

[10] B. Wareing, *Wood Pole Overhead Lines*, First Addi. London: IET Power and energy series no.48, 2005.

[11] V. Singh and M. N. Bailey, "Document Classification : Controlled Disclosure Title : Distribution Guide – Part 19 : SEPARATIONS AND CLEARANCES FROM POWER Unique Identifier : Document Type : Revision : Total pages : Review date : BUILDING LINE RESTRICTIONS , SERVITUDE Unique Identifie," Johannesburg, 2011.

[12] T. A. Short, "Overhead Lines," in *Electrical Power Distribution Equipment and Systems*, no. C, Taylor and Francis, Ed. CRA Press, 2004, pp. 1–58.

[13] S. T. Jan, R. Afzal, and A. Z. Khan, "Transformer Failures , Causes & Impact," *Int. Conf. Data Mining, Civ. Mech. Eng.*, pp. 49–52, 2015.

[14] T. S. D. E. and N. E. David Eccles, "Asset Management Plan: Pole Mount Transformers- Distribution," 2013.

[15] E. N. Association, "Danger of death: Network essentials one," *Energy Networks Association (ENA)*, London, p. 2, Oct-2007.

[16] Q. O. F. Supply, "ELECTRICITY SUPPLY — QUALITY OF SUPPLY Part 2 : Voltage characteristics , compatibility levels , limits and assessment methods," 2003.

[17] R. Godina, E. M. G. Rodrigues, J. C. O. Matias, and J. P. S. Catalão, "Effect of Loads and Other Key Factors on Oil-Transformer Ageing: Sustainability Benefits and Challenges," *energies*, pp. 12147–12186, 2015.

[18] A. Nowbakht, M. Ahrarinouri, and M. Mansourisaba, "Presenting a new method to estimate the remaining life of aerial bundle cable network," *23rd Int. Conf. Electr. Distrib.*, vol. 112, no. June, pp. 15–18, 2015.

[19] A. Reyers, "An Introduction to Medium and Low Voltage Cables in Distribution Networks as support of Smart Grids," *Brussels*, no. June, p. 17, 2014.

[20] S. A. Nagy, I. S. Ibrahim, M. K. Ahmed, A. S. Adail, and S. Soliman, "Network Reconfiguration for Loss Reduction in Electrical Distribution System Using Genetic Algorithm," vol. 46, no. 1, pp. 78–87, 2013.

ANNEXURE B: SAIDI and SAIFI calculations

The performance of the network is regulated by NERSA by means of customer interruptions [80]. The most important key performance indicators that are widely known are SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) [80]. Distribution networks supply different types of customers including prepaid customers and small power users such as schools, churches, malls and farms. However, most of the customers are usually prepaid customers. The electrical utilities are assessed by the number of customers affected by loss of supply.

Good performance of the network is determined by the reliability of the network. The more reliable the network is, the better the performance of the network will be. Reliable networks typically include different sources of supply, auto-reclosers at different points on the network and well-maintained networks. Although there are many indicators that are measured on distribution networks, this study focused on SAIDI and SAIFI. SAIDI and SAIFI can be mathematically expressed as follows [80]:

$$\text{SAIDI} = \frac{\sum \text{Customer Interruption Duration p.a}}{\text{Total number of customers served}} \tag{9}$$

SAIDI improvement can be improved by sectionalizing the network into different zones so that one can only control how many customers are interrupted per outage or fault [80].

$$\text{SAIFI} = \frac{\text{Total number of customers interrupted p.a}}{\text{Total number of customers served}} \tag{10}$$

SAIFI can be improved by reducing the frequency of customer interruption that may be due to faults that occur on the network or frequent outages to conduct replacements on the network [80].