TOWARD IMPROVING ENERGY SECURITY IN KENYA VIA HTLS CONDUCTORS AND LOAD BALANCING

CYNTHIA CHEREMA MKABANE: 148462

STRATHMORE UNIVERSITY: SCHOOL OF COMPUTING AND ENGINEERING SCIENCES

MASTER OF SCIENCE IN SUSTAINABLE ENERGY TRANSITIONS

Master's Project Dissertation submitted to the School of Computing and Engineering Sciences, Strathmore University, in partial fulfillment of the requirement of the award of Master of Science in Sustainable Energy Transitions.

April 2024

DECLARATION

This proposal is my original work and has not been presented for an award of any degree in any university.

Signature: ………………….. Date: 18/04/2024 …………………….

Admission no: 148462

APPROVAL

This proposal has been submitted to the School of Computing and Engineering Sciences for examination with my approval as the university supervisor.

Name: Dr. Dickson Owuor

Signature: ……………………… Date: 18 Apr, 2024 ……………………………...

ACKNOWLEDGEMENT

I would like to thank Dr. Dickson Owuor of the School of Computing and Engineering Sciences for his patient guidance, enthusiastic guidance, and useful critiques of this research work. I'd also like to thank him for his advice and help in keeping my progress on track. I would like to thank Dr. K.V. Rop on his assistance in data acquisition and also during analysis of the work.

A special thanks to DigSilent Powerfactory company for allowing me access to their software for analysis, and Kenya Power and Ketraco for their great input in terms of data acquisition and also analysis of the system.

A special thanks to my loving parents, Leonard and Phyllis Mkabane, whose words of encouragement and push for tenacity continue to ring in my ears. My heartfelt gratitude goes to my siblings Edwin Mkabane, Levis Mkabane, and Sandra Mkabane, who have never left my side and are very special to me.

Finally, I dedicate this dissertation to the Almighty God for allowing me to persevere through the difficulties of writing this dissertation.

ABSTRACT

The Industrial and Commercial sectors of the economy are rapidly growing and hence, energy consumption and transmission line loading are also increasing. This explains the major breakdowns related to transmission lines since the initially installed lines are not able to handle the increased energy requirements. Previous studies have been done replacing ACSR with ACCC conductors to reduce thermal line losses. The project aims to replace ACSR with ACCC conductors in short lines, analyze the length of the line in which the ACCC conductor will cease to be beneficial, and analyze the mechanical properties of the line. The Kenyan grid will be analyzed in its present state by performing a load flow analysis and a sag and tension analysis. The short lines will then be replaced by ACCC conductors and the load flow and sag and tension analysis of the new system done. The two systems will then be compared. The length of the line in which the ACCC conductor will no longer be beneficial for application will be determined. The analysis will be performed using PowerFactory DigSilent software.

Table of Contents

Table of Figures

Table of Tables

Abbreviations and Acronyms

AAAC All Aluminum Alloy Conductor

AAC Al Aluminum Conductors

ACCC Aluminum Conductor Composite Core

ACSR Aluminum Conductor Steel Reinforced

ACSS Aluminum Conductor Steel Supported

EHS Extra High Strength steel

GTACSR Thermal Resistant Aluminum Alloy Conductor Steel Reinforced

HTLS High Temperature Low Sag conductor

KPT Knee Point Temperature

SDG Sustainable Development Goals

SMIB Single Machine Infinite Bus

ZTACIR Super Thermal Resistant Aluminum Alloy Invar Reinforced

ZGTACR Super Thermal Resistant Aluminum Alloy Conductor Steel Reinforced

2A4G Two Area Four Generator system

Definition of Terms

i. **Conductor:** This is a substance or a material that allows the flow of electricity from one point to another.

ii. **Contingency:** It is an unexpected failure of a single principal component (e.g., a generator, transmission line, or capacitor) that causes the change of the system state, large enough to affect the grid security.(Roy & Jain, 2011)

iii. **Grid:** This is an interconnected network created for the purpose of electricity delivery from producers to consumers in a certain region.

Chapter One

1 Introduction

1.1 Background of Study

This subject has been extensively discussed in recent years, and it has become more broadened as an emphasis on energy efficiency and sustainability has grown. A system must be able to provide continuous energy supply at a reasonable cost in order to be considered safe. Short term and long-term energy security are the two main aspects of energy security.

Long term refers to the long-term investment required to provide energy in accordance with economic development and environmental needs. To increase energy supply to the grid, this is typically done in collaboration with governments or through Power Purchase Agreements(Mirza et al., 2009). The ability to respond quickly to changes in the demand-supply balance is referred to as short-term energy security. This is frequently done using contingency analysis to test the system's reliability.

According to (Griggs et al., 2017),one can solve energy security by focusing on the availability of energy, affordability, accessibility, and acceptability. Sustainable Development Goal (SDG7) deals with affordable, clean energy. However, accessibility is also important. Frequent analysis of power system models is needed to ensure stability and stability in the face of system changes. Contingency analysis simulates power systems to assess the effects of outages and calculate overloads.

It determines whether a power grid is safe from unexpected disturbances. This analysis is used to reduce the risk of blackouts and to ensure the power system's quality from source to end.

Transmission at high voltages could be one option to reduce line loss. Good conductors are essential to minimize losses.

It is crucial to select a conductor that offers the best mechanical, electrical, as well as cost attributes in order to maximize electricity transmission's benefits. Conductors that have a higher capacity for carrying electricity are essential as they play a significant role in reliability.

1.2 Problem Statement

Transmission and distribution infrastructure remain technical problems for electrical transmission utilities. The demand for electricity is increasing, so it's becoming more important to upgrade existing infrastructure and create new transmission lines.

It is possible to change the conductor in use to avoid any design changes to existing support structures. Thermal constraints affect the shortest lines. The current can cause them to become hot, and they will experience higher resistive losses at higher temperatures. These lines are more resistant to temperature increases. The amount of sag increases with an increase in temperature.(Tokombayev & Heydt, 2015)

In windy conditions, excessive sag can cause short circuits in the lines. Transmission with HTLS allows you to raise temperature and create the right sag conditions. A N-1 contingency assessment will help determine if the proposed HTLS Conductors have an improved carrying capacity and make the line as reliable possible.

1.3 Objectives

1.3.1 General Objective

To establish effect of adoption of HTLS load balancing and conductor strategy in Kenya for improving energy availability.

1.3.2 Specific Objectives

i. To analyze the performance of ACSR and HTLS conductors under full load for the Kenyan Power system.
ii. To propose a HTLS network with load balancing technique for the Kenyan Power system
iii. To model a HTLS network with load balancing technique for the Kenyan Power system
iv. To validate the proposed model using performance of the transmission lines.

1.4 Research Questions

1. What is the effect of changing the ACSR conductor to a HTLS conductor in the Kenyan Power System?
2. How does loadability impact the Kenyan Power System?
3. How does HTLS conductor impact loadability of the Kenyan Power System?
4. How does HTLS conductors improve loadability?

1.5 Justification of Study

For transmission lines shorter than 100 km, the greatest concern is thermal. Low resistive losses are important and conductors should transmit high currents at high working temperature. The conductor must have excellent thermal sag properties and tension properties. Conductors must be capable of operating at temperatures higher than ordinary bare overhead conductors and should not exceed the original maximum stretch. It shouldn't cause a significant increase in the initial maximum tension.

An aluminum conductor composite core is the best solution (ACCC conductor). The composite core shrinks significantly and has minimal thermal expansion coefficient. The conductor is lighter overall because the composite core is lighter than steel. Because the conductor has a higher tensile force, shorter spans and smaller structures are possible.

Because of the composite core's high strength and elastic conductor, it can withstand extreme wind loads. The length and cost of the ACCC conductor are both limited. There will be minimal losses as long as the line's length is limited by thermal and voltage limits. The cost of running the line should not be greater than the savings realized by using them.

1.6 Scope of Study

This study focuses only on High voltage transmission line of 132kV or more with a minimum length of 100km. These short transmission lines are prone to sag. Therefore, a solution is required to improve its performance and solve other issues within the Kenyan Power System.

Chapter Two

2 Literature Review

2.1 Introduction

The chapter focusses on the theoretical literature, empirical literature and the conceptual framework of using HTLS conductors and also the contingency analysis of various countries over the years.

2.2 Theoretical Literature

For more than a century, ACSR have been the primary conductors in the market for overhead transmission lines. ACSR and AAAC conductors are mainly used in the construction of overhead lines on occasion, primarily to provide additional corrosion protection for conductors. However, most designers around the world still prefer ACSR for transmission line construction. Thermal sag is regarded as one of the most significant drawbacks of ACSR. As the temperature rises, so does the conductor's expansion as a result of the increased current. The outer layer of ACSR conductors is Hard Drawn Aluminum, and the core layer is steel. Because 1350-H19 is not heat-treated aluminum, it cannot withstand increased temperature levels.(Kim et al., 2006)

The optimum continuous operating temperature that could be achieved with ACSR conductors is approximately 90ºC. If the conductor is used at temperatures higher than this, it is more prone to losing tensile strength over time. This is referred to as annealing. Lines will elongate as a result, and safety clearances will be violated. As a result, manufacturers developed another technology known as Low Loss Conductors, which can operate at higher temperatures such as 150ºC without annealing. .(Håkansson, 2013)

As a result, HTLS conductors are designed to resolve the current limitations and thermal elongation challenges presented with ACSR and Low Loss conductors. In order to improve current capacity and reduce thermal sag, various techniques are used in each type of HTLS conductor. As demand grows, new solutions for developing power transmission systems are required, while dealing with the issue of power system congestion. The possibility of solving the load growth is to add a number of parallel transmission lines for various sections, or to reconduct the transmission line and use conductors with higher current carrying capacity.

2.2.1 Conductor types used in Transmission Lines

Conventional Conductors

A) Aluminum Conductor Steel Reinforced (ACSR):

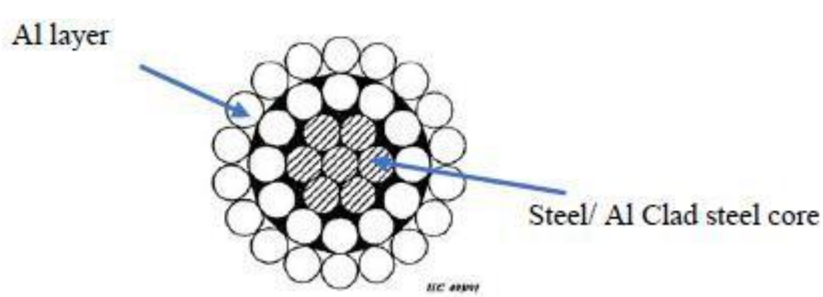
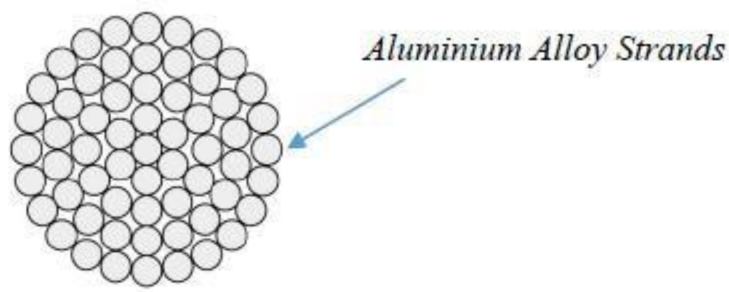


Figure 2-1: ACSR Conductor

ACSR is a conductor that is not homogeneous. It consists of 2 layers. The external layer is made of Hard Drawn Aluminum and serves as a conductor of electricity. The core layer is made of steel and provides tensile stability to the conductor. Because it is less expensive than copper, the conductor has generally been preferred. However, the conductor has several disadvantages, such as carrying too much weight. ACSR conductors cannot be used at temperatures above 75°C with a wind velocity of 0.6m/s since hard-drawn aluminum is indeed not heat treated. (Domínguez et al., 2014; Riba et al., 2020).



AACSR conductors are also widely used. Relative to ACSR conductors, they have concentrically stranded conductors made of stranded aluminum alloy wire and a high-strength coated steel core. Galvanized (zinc-coated) steel strands can be aluminized (aluminum-coated), or aluminum clad..(Transmission and Distribution Committee, 2013)

b) All Aluminum Alloy Conductor (AAAC):

Figure 2-2: Aluminum Alloy Strands

AAAC is a standardized conductor. Alloy aluminum improves the conductor's current load - bearing capacity as well as its mechanical strength. It carries slightly more current than an ACSR conductor of the same size. AAAC has greater corrosion resistance than ACSR, allowing it to be used in coastal areas. Heat treatment is also not used for alloy aluminum conductors. As a result, they are not suitable for use at higher temperatures.(Riba et al., 2020)

c) All Aluminum Conductors (AAC)

The composition of AAC conductors is almost pure aluminum wires, and they are primarily used in urban environments where support structures are near.. Their structure is similar to AAAC with a difference in the chemical composition of the conductors. AACs conductor mechanical strength is lacking as compared to the other conventional conductors i.e., AAAC, ACSR, and AACSR.

High Temperature Low Sag Conductors

These conductors aim at solving issues related to the limited current carrying capacity and sagging when operating at high temperatures. The power transfer capability of short overhead transmission line i.e., less than 80km, is mainly limited by the conductors thermal rating. For lines which are $80km > x \leq 300km$, power transfer capability is limited by the voltage drop limits. Transmission lines which are longer than 300km, their steady state stability becomes a critical factor.

a) GTACSR/ZGTACR (Thermal/ Super Thermal Resistant Aluminum Alloy Conductor Steel Reinforced)

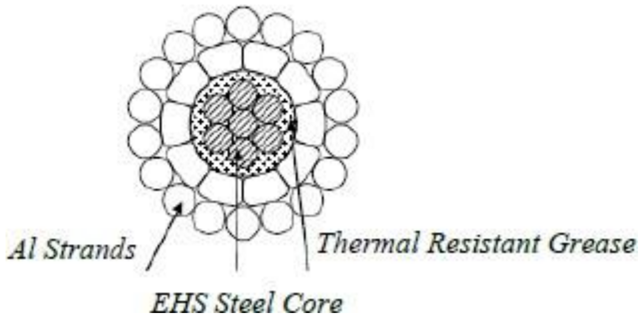


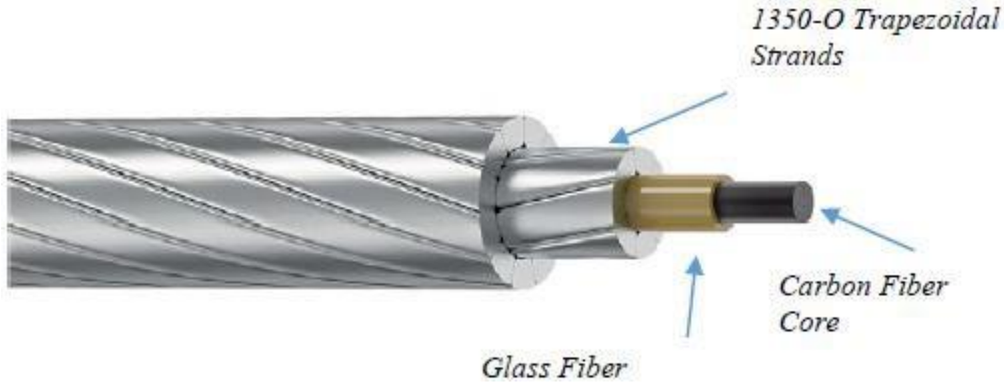
Figure 2-3:GTACSR/ZGTACR Conductor

This conductor is also called the Gap Conductor due to a space separating the outer and inner layers. The exterior layer is made of a hard drawn aluminum alloy doped with zirconium. The strands in the external layer are circular, while the strands in the layer below are trapezoidal. Thermally resistant grease is used to fill the annular gap. High strength steel is used for the inner core. Because of the presence of grease, the steel core and aluminum core can move independently of each other.*(Domínguez et al., 2014)*

GTACSR can operate at 150°C and ZGTACSR at 210°C. These conductors' stringing requirements differ from those of conventional conductors. Knee Point Temperature (KPT) is the temperature at which the steel core absorbs the entire conductor tension. The KPT of a gap conductor is comparatively low.(Riba et al., 2020)

b) <u>ACCC (Aluminum Conductor Composite Core)</u>

Figure 2-4: GTACSR/ZGTACR Conductor



This conductor's core is composed of a glass fiber composite core and hybrid carbon that employs a high temperature epoxy resin matrix to bind hundreds of thousands of individual fibers into a unified load bearing tensile member. To improve flexibility and toughness, the central carbon fiber core is surrounded by high grade boron free glass fibers. It also prevents galvanic corrosion between the carbon fiber core and the aluminum strands. Annealed Aluminum (1350-O) is used to make aluminum strands, which has a higher conductivity than Hard Drawn Aluminum. The shape of aluminum strands is trapezoidal.(Riba et al., 2020).

ACCC, like Gap conductors, has a very low Knee Point Temperature (KPT), which contributes to lower sag values with increasing temperature. When compared to other types of conductors, thermal expansion of the core is negligible. ACCC conductors can be used safely up to 180°C. These conductors, however, necessitate special installation techniques and careful handling.

c) **ZTACIR (Super Thermal Resistant Aluminum Alloy Invar Reinforced)**

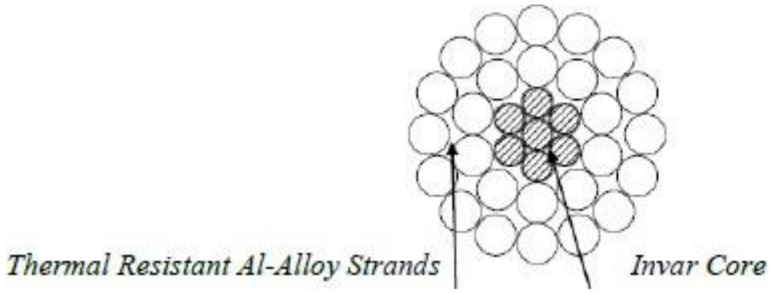


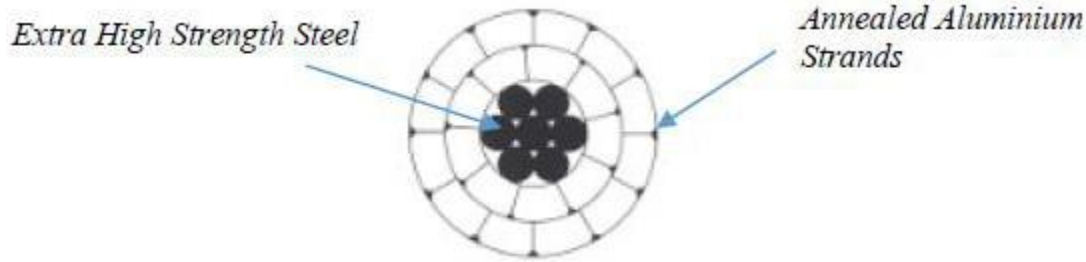
Figure 2-5: ZTACIR Conductor

The Invar Conductor is another name for this conductor. The shape is more like ACSR/AW. Unlike ACSR, the outer strands of Invar conductor are made of heat-treated annealed aluminum strands that can withstand high temperatures. The conductor's core is made of Aluminum Clad Steel with high strength and low thermal expansion value. These conductors can withstand temperatures of up to 210°C.

One advantage of Invar conductors is that their installation and spare parts requirements are more similar to those of ACSR. Because these conductors have a significantly higher KPT value, low sag performances cannot be expected at lower operating temperatures.

d) **ACSS (Aluminum Conductor Steel Supported)**

Figure 2-6: ACSS Conductor



The ACSS conductor's outer strands are made of trapezoidal-shaped heat-treated fully annealed aluminum. The conductor's core is made of extra-high strength steel (EHS). This conductor is very popular in the United States and some European countries. This conductor's tensile strength is not compromised when operated at 250°C. This conductor's stringing requirements are very similar to those of conventional conductors.

Transmission Lines

Overhead lines or underground cables transport electricity from generating stations to consumers. Overhead lines are used for long distances, whereas underground cables are used for under water crossings in urban areas.

a) Overhead lines

A transmission line is defined by four parameters: series resistance R caused by conductor resistivity, shunt conductance G caused by leakage currents between phases and ground, series inductance L caused by the magnetic field encompassing the conductors, and shunt capacitance C caused by the electric field between conductors.

b) Underground lines

The basic parameters of underground cables are the same as those of overhead lines: series resistance and inductance; shunt capacitance and conductance. However, the parameter values and thus the characteristics of cables differ significantly from those of overhead lines for the following reasons:

1. Cable conductors are much closer to one another than overhead line conductors.
2. Metallic bodies such as shields, lead or aluminum sheets, and steel pipes surround the conductors in a cable.
3. The insulating material in a cable is typically impregnated paper, low viscosity oil, or an inert gas.

Seeing as G and R are negligible, the characteristic impedance Z with losses ignored is commonly referred to as the surge impedance. The natural load or surge impedance load is the power delivered by a transmission line when it is terminated by its surge impedance (SIL).

2.3 Transmission Line Modelling

Transmission lines are divided into three main classes. The short lines, the medium lines and the long lines. The short lines are those below 100 km. The medium lines are between 100 and 250 km. The long lines are those above 250km.

In finding out the characteristics and performance of a transmission line, we model the transmission lines in form of a two-port network. The A B C D parameters relate the voltages and currents at the sending and receiving ends.

$$V_S = AV_R + BI_R \qquad (2.1)$$

$$I_S = CV_R + DI_R \qquad (2.2)$$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad (2.3)$$

The A B C D parameters depend on the resistance, inductance, capacitance and admittance of the lines. D and A are dimensionless while B's units are ohms and C's the units are siemens. Also, AD – BC = 1. (D.M. Larruskain, 2007)

For simplicity, we denote the impedances per unit lengths and total impedances as follows.

$$z = \gamma + j\omega L\ \Omega/m \quad (2.4)$$

$$y = G + j\omega C \frac{\Omega}{m} \quad (2.5)$$

$$Z = zl\ \Omega \quad (2.6)$$

$$Y = yl\ \Omega \quad (2.7)$$

G is the conductance. It takes into account actual power loss between conductors or between conductors and ground. It is overlooked because it is a minor component of shunt admittance.

2.3.1 Short Line Modeling

A short transmission line is represented as a simple series circuit. The effect of capacitance is minimal in the short lines.

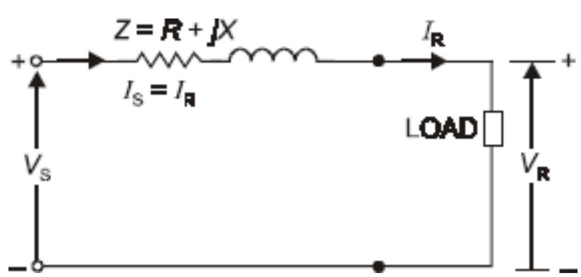


Figure 2-7: Equivalent circuit for a short line

From the figure above we find that:

$$V_S = V_R + IZ \quad (2.8)$$

$$I_S = I_R \quad (2.9)$$

The relationship between the sending and receiving ends is shown in the matrix below.

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad (210)$$

The phasor diagrams of loads with different kinds of power factor are shown below.

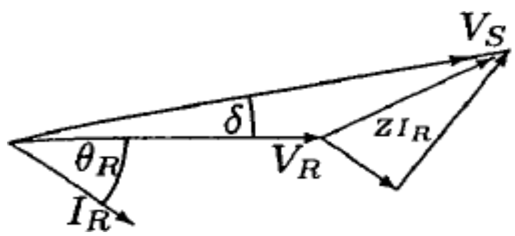


Figure 2-8: Phasor representation of a lagging power factor load.

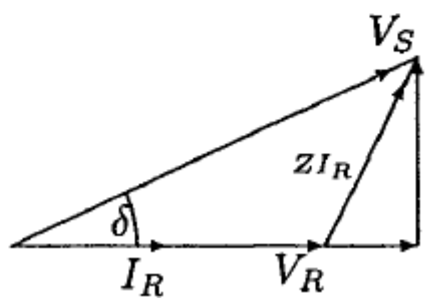


Figure 2-9:Phasor representation of a unity power factor load

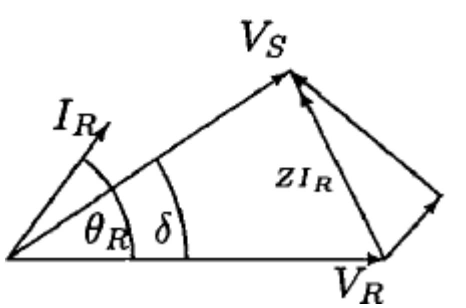


Figure 2-10:Phasor representation of a leading power factor load.

2.3.1.1 Voltage Regulation

Voltage regulation is defined as the percentage change in voltage in the receiving end of the line in going from no load to full load.(Kopsidas & Rowland, 2009)

$$= \frac{|V_R^{NL}| - |V_R^{FL}|}{|V_R^{FL}|} \times 100 \qquad (2.11)$$

V_R^{NL} = Receiving end voltage at no load.

V_R^{FL} = Receiving end voltage at full load.

At no load $I_R = 0$. From the matrix $V_R = AVs$ and $A = 1$. The percentage voltage regulation becomes:

$$\frac{|V_S| - |V_R|}{|V_R|} \times 100 \qquad (2.12)$$

Voltage regulation depends on the power factor. Current is poorer for the low lagging power factor. For leading power factor loads regulation may become negative where Vs is less than V_R as shown in the figures above.

2.3.1.2 Transmission Capability

A power line's capability is constrained by its thermal loading and stability limits. The rise in temperature, which causes expansion, causes the conductors to sag. At high temperatures, the lines may permanently stretch. The thermal limit of a line, according to the manufacturer's specifications, is:

$$S_{thermal} = 3V_{\emptyset rated} \times I_{thermal} \qquad (2.13)$$

During design the transmission lines are rarely operated at their theoretical optimum power. Usually, voltage regulation is also considered so that $V_R/V_S \geq 0.95$.

2.3.2 Medium Line Modelling

In these lines the line charging is significant; we therefore consider the shunt capacitance. Half of the shunt capacitance may be placed at either end of the line. (Geary et al., 2012).

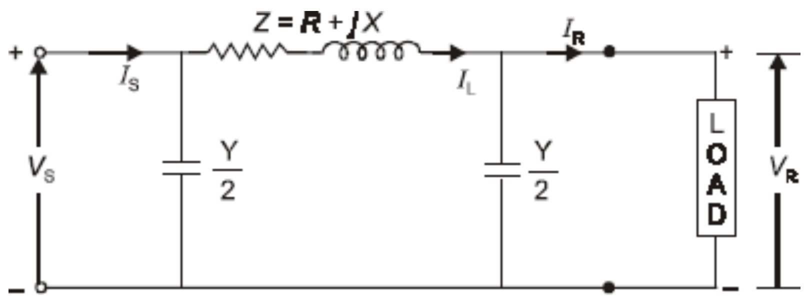


Figure 2-11:Corresponding circuit of a medium transmission line

$$\begin{bmatrix} \boldsymbol{V_S} \\ \boldsymbol{I_S} \end{bmatrix} = \begin{bmatrix} \left(\boldsymbol{1} + \frac{\boldsymbol{ZY}}{\boldsymbol{2}}\right) & \boldsymbol{Z} \\ \boldsymbol{Y}\left(\boldsymbol{1} + \frac{\boldsymbol{ZY}}{\boldsymbol{4}}\right) & \left(\boldsymbol{1} + \frac{\boldsymbol{ZY}}{\boldsymbol{2}}\right) \end{bmatrix} \begin{bmatrix} \boldsymbol{V_R} \\ \boldsymbol{I_R} \end{bmatrix} \qquad (2.14)$$

The ABCD constants for the line become:

$$A = \left(\boldsymbol{1} + \frac{\boldsymbol{ZY}}{\boldsymbol{2}}\right), \boldsymbol{B} = \boldsymbol{Z}$$

$$C = \boldsymbol{Y}\left(\boldsymbol{1} + \frac{\boldsymbol{ZY}}{\boldsymbol{4}}\right), \boldsymbol{D} = \left(\boldsymbol{1} + \frac{\boldsymbol{ZY}}{\boldsymbol{2}}\right)$$

2.3.3 Long Line Modeling

In short line and medium, we assume that the parameters are lumped. In long lines however the model with the parameters is distributed evenly along the line length. This diagram shows an equivalent diagram for a long line *l* km.

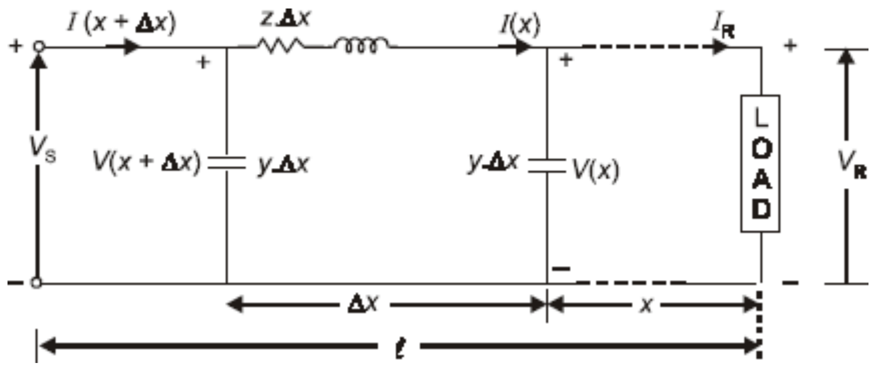


Figure 2-12: Equivalent circuit diagram of a long line

The parameters of the equivalent Ω becomes

$$Z' = Z_C \sinh(\gamma l) = \frac{Z \, . \sinh(\gamma l)}{\gamma l}$$

$$\frac{Y'}{2} = \frac{1}{Z_C} \tanh\left(\frac{\gamma l}{2}\right) = \frac{Y}{2} \frac{\tanh\,(\gamma l/2)}{\gamma l/2}$$

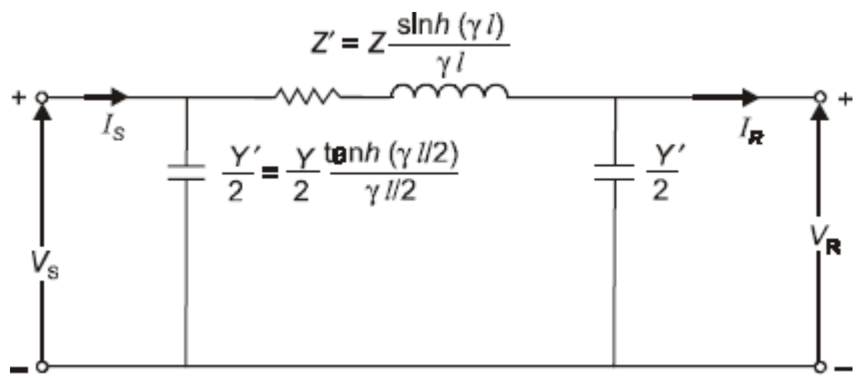


Figure 2-13:long line equivalent circuit with ABCD parameters.

2.4 Modelling Contingency Analysis

It is an effective tool for predicting which contingencies will cause system violations and ranking the contingencies based on their relative severity. Contingency analysis is divided into three stages:

i. Definition of the contingency
ii. Selection of the contingency
iii. Contingency evaluation

The contingency definition entails compiling a list of all potential contingencies that could occur in a power system. Contingency selection refers to the process of identifying the most severe contingencies from a contingency list that result in system violations in terms of power flow and bus voltage magnitude. As a result, the least severe contingencies are eliminated, and the contingency list is reduced. Contingencies are then prioritized based on the value of a scalar index known as the severity index or performance index.(Kundur et al., 2004)

The PI is a measurement of the system-wide impact of a contingency event. Contingency evaluation is the final step in contingency planning. This entails recommending the necessary corrective actions or control measures to be implemented in order to mitigate the effect(s) of the contingency.

2.4.1 Methods used in Contingency analysis

In DigSilent, a contingency analysis can be run using the following calculation methods:

1. AC Load flow calculation

   This method is used to give information on MVAR flows and bus voltages in the system. It determines the overloads and voltage limit violations accurately However, the time taken to perform this analysis is long and hence the Fast-Decoupled Power Flow is used during this calculation.

2. DC Load flow calculation

   This method is used to improve on the computational time and storage of data. It uses linearized DC load flow method to compute the active power flow per contingency.(Kanno et al., 1992; *UserManual_2023_en.Pdf*, n.d.). The DC load flow can be performed by neglecting simply any QV equation in the fast decoupled Newton Raphson power flow algorithm [12]. This gives as result a linear and non-iterative power flow algorithm. To achieve these simplifications, we simply assume that $|Vi| = 1$ pu for every bus i.

   And we have:

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \cdots \end{bmatrix} = [B'] \begin{bmatrix} \Delta\delta_1 \\ \Delta\delta_2 \\ \cdots \end{bmatrix}$$

The elements of matrixes B' are:

$$B_{ik}' = {}^{-1}/_{x_{ik}} \ (where\ xik\ is\ line\ impedance\ between\ buses\ i\ and\ k\ )$$

$$B'_{ii} = \sum_{k=1}^{n} \frac{1}{x_{ik}}$$

The terms of the matrix **B'** are described above by Eq. (2.2) and Eq. (2.3). The DC power flow is used only to calculate the real power flow (MW) of transmission lines and transformers. It gives no indication of the voltages or on the reactive power flow (Mvar) and apparent power (MVA).The power flow on each line using the dc power flow can be described by the following equation:

$$P_{ik} = \frac{1}{x_{ik}} (\ \delta_1 - \delta_k)$$

And

$$P_i = \sum_{k=nodes\ connected\ to\ i}^{n} P_{ki}$$

To compensate for the lack of losses in the DC solution, the total DC load is increased by the amount equal to AC losses. Hence, in the DC approach the estimated transmission system losses could be allocated to the bus loads. This requirement to first estimate the losses is usually not burdensome since the specified total control area "load" is actually the true load plus the losses.

3. AC Linearised calculation

This is a fast calculation method for contingency analysis, which represents the contingency case by using equivalent injections to reduce the flow through the faulted area to zero. The injections are calculated using a linearised estimate and the process avoids the need for a new load flow to be run for the contingency case. Where the algorithm detects that the linear method is not suitable for a particular contingency case it will revert to the standard method. The linearised method is faster than the traditional contingency analysis using a full load flow, but it does not consider the response of controllers and so is a more approximate method.(*UserManual_2023_en.Pdf*, n.d.)

4. Linearised screening +AC Load flow for critical cases

   The contingency analysis will perform two runs (if required). First it will use a linearised load flow method to calculate the active power flow per contingency case; if for certain contingencies loadings are detected to be above a certain threshold, then these cases will be recalculated using the iterative AC load flow method. The choice of screening method and the criteria (thresholds) to be used for the AC recalculation of critical cases are entered on the Screening page(*UserManual_2023_en.Pdf*, n.d.)

2.4.2 Contingency Ranking

Contingency ranking in power systems refers to the process of assessing and prioritizing potential system contingencies based on their impact on system reliability and security. Contingencies in power systems can include various events such as generator outages, transmission line failures, transformer faults, or sudden changes in load demand. Overall, contingency ranking is essential for maintaining the reliability and security of power systems by identifying and prioritizing potential risks and implementing appropriate mitigation measures to ensure the smooth operation of the grid.

The calculation of performance index using the NR load flow method yields a criterion for measuring the severity of possible contingencies in a power system. Based on the values obtained, the contingencies with the highest PIs (Perfomance Indices) are ranked first.(Alvarado et al., n.d.)

2.4.3 Remedial Action Scheme

These refer to the measures which the utilities need to take to get the system back to its normal operation after a contingency. Remedial Action Schemes (RAS) are also referred to as Special Protection Schemes (SPS) or System Integration Schemes (SIS). The RAS is designed to mitigate the effects of critical contingencies that initiate the actual system problems. Each critical contingency may require a separate arming level and different remedial actions. (Guide, 2006)

In the event of critical contingencies such as temporary faults during stressed operating conditions, automatic single-phase or three-phase recloser may prevent the system from undergoing catastrophic failure. This happens in most cases. However, appropriate RAS action may still be required if reclosing is unsuccessful.(Guide, 2006)

2.4.3.1 Types of Remedial Action

Corrective measures that are usually taken to mitigate the effects of contingency include:

- Shunt capacitor switching
- Generation Re-dispatch
- Load shedding
- Under load tap changing (ULTC) Transformer
- Distributed Generation
- Islanding

The effectiveness of the remedial actions has been demonstrated in where the IEEE 6 – bus system undergoing contingency analysis through computer simulation was able to return to normal operating state after power generation of one of the generators was minimized and load shedding was done.

2.4.4 Modeling of power system components

In carrying out contingency analysis for a transmission system, the major components under consideration are:

i. Generators

   It changes mechanical energy to electrical energy for distribution and transmission in the system network. Loss of generation could cause system instability hence contingency analysis is used to analyze whether the system can handle loss of a generator.

ii. Transformers

   Transformers transfer electricity between generator and the distribution primary circuit. They also are used to change AC voltages i.e., either step-up or step-down voltage levels.

iii. Transmission lines

   They carry electric current from one point to another. This can be either alternating current or direct current or both. Overloading by the transmission lines can lead to system instability. There is need to know the loading limit for every transmission line and ensure specific limits are not exceeded for better performance in times of a fault.

iv. Loads

2.5 Empirical Literature

Power outages are a serious problem, and preventing them is critical. Overloading of transmission lines, generators, and transformers, among other things, can cause blackouts. To avoid this, appropriate control strategies must be implemented to prevent an N-1 contingency, maintain load generation balance, and cascade to additional fault contingencies. Conducting a contingency analysis is important in Kenya for determining our energy security situation. (Tokombayev & Heydt, 2013; Wu et al., 2017)

(Roy & Jain, 2011) performed an analysis for contingency selection by considering two performance indices i.e., active power performance index and reactive power performance index, while considering a single transmission line outage. He incorporated both Fast Decoupled Load flow method and Radial Basis Function Neural network to rank the contingencies, taking note of the loading and generation levels in power systems. The networks considered were the IEEE 5-bus, IEEE 14-bus and IEEE 30-bus system. The proposed methods proved to be efficient in terms of accuracy and time. This analysis was done using MATLAB software.

An analysis of three 150kV High Voltage transmission lines in Sicily was performed to determine the line current carrying capacity using GIS and LiDAR technology. The current carrying capacity of each line was determined using both summer and winter atmospheric conditions. The current value of HTLS conductors from these three transmission lines was found to be superior to the current value of the traditional ACSR conductors used. ACSS and ZTACIR are the only high-temperature conductors currently installed in Italy.(Filippone et al., 2014)

(Rasool et al., 2021) analyzed the power system for Kurdistan Region to predict and evaluate voltage stability in case of a contingency occurrence on the transmission line to determine the most severe cases and manage them. The analysis was done using the Power System Simulator Software for simulation of the single transmission line outage.

2.6 Conceptual Framework

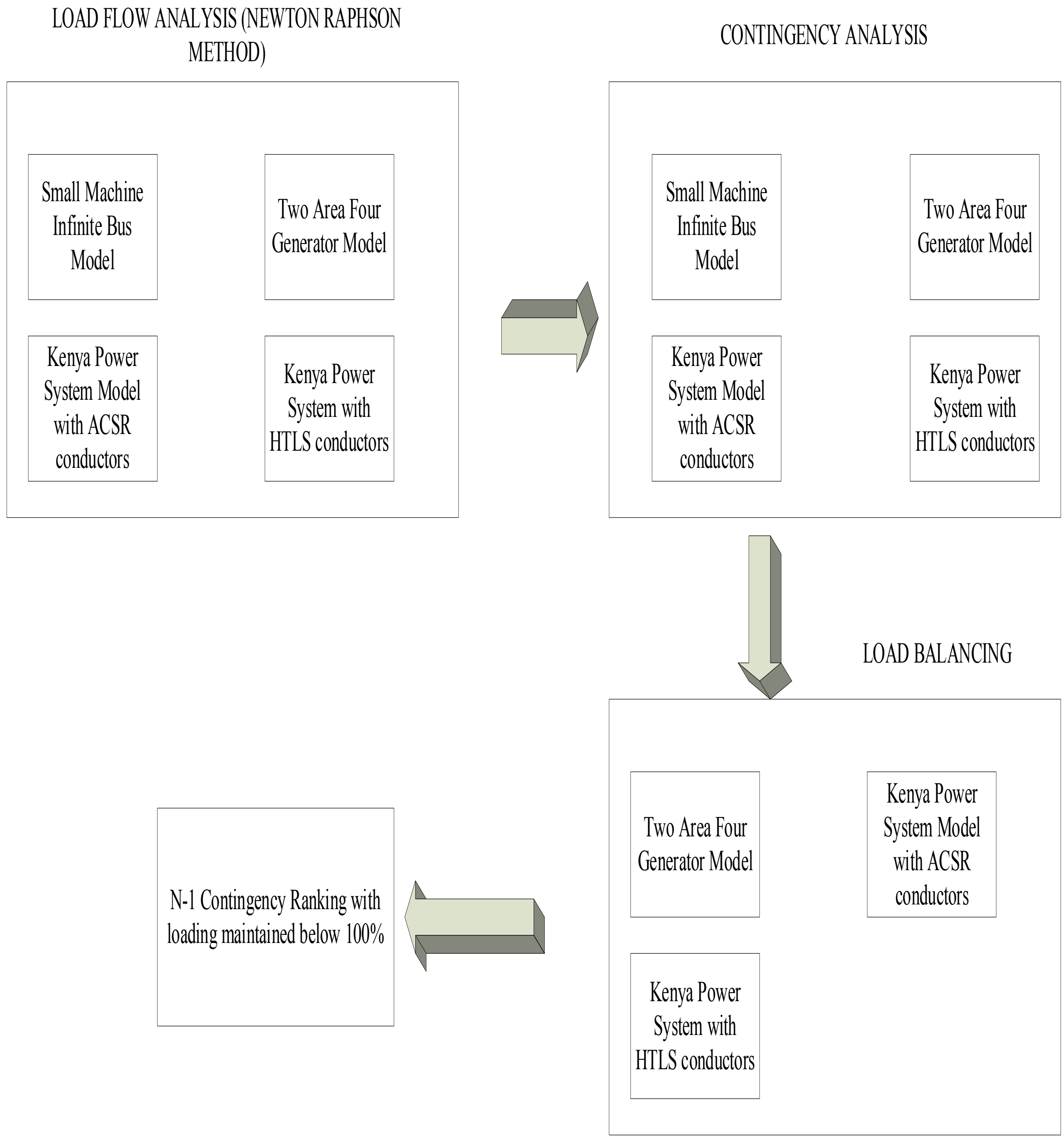


Figure 2-14:Conceptual framework for analysis of the project

Chapter Three

3 Research Methodology

3.1 Introduction

In order to address the rising concerns on energy security, there have been significant increase in connected domestic and commercial consumers to the National Grid. There has also been a rise in the energy plant installation around the country that has improved availability of the energy to the consumers as a whole. However, the recent load shedding experienced in the country is greatly connected to transmission lines being load constrained. Hence there is a need for a contingency analysis to be conducted to ensure that the lines do not surpass their thermal limit as well as their loading.

The whole grid will be analyzed because some sections of the grid are mesh connected while other are radially connected. The scope however will be limited to short transmission lines i.e., below 100km in length.

3.2 Experimental Model

The Kenyan Power transmission system will be modelled using Powerfactory DigSilent software. The system has ACSR conductors hence a load flow analysis of the system will be done to check for power system overloads on the transmission line being analyzed. The short transmission line will then be replaced with HTLS conductors and the load flow of the system will be done. A contingency analysis will be performed for all the systems to analyze the reliability of the system.

This system will be modeled as follows focusing on short transmission lines above 132kV:

1. A model of the current power system will be done and a load flow done to determine its operating conditions i.e., loadability of the line.
2. A contingency analysis will be performed to determine the security level of the system i.e., N-1 security.
3. A model of the power system with HTLS conductors for the short transmission lines will be done to determine its operating conditions.
4. A contingency analysis will be performed to determine the security level of the system i.e., N-1 security.
5. Load balancing of the system with HTLS conductors will be performed.

3.3 Research design

The data required for the analysis is to be collected from Kenya Power control center. The transmission line data required for analysis includes: Resistance and reactance values for all sequences, Voltage profiles, generations data etc. The data will be used while modelling and to provide a more accurate analysis of the state at which Kenya is. The model will be done using DigSilent software as it provides a complete suite of functions for studying large interconnected power systems and addressing their emerging needs.

3.4 Sampling Frame

The Kenyan Power system will be used for analysis using DigSilent software. The sample under study will be reduced to short transmission lines which are below 100km in length for study. The short transmission lines are prone to short circuit due to rise in temperature during current transfer. The short transmission lines considered will be for all voltage levels in the system, and will consider the effect of N-1 contingency on the system.

Chapter Four

4 Results

4.1 Introduction

This chapter presents results of the research questions that guided the investigation, that are listed as follows:

1. What is the effect of changing the ACSR conductor to a HTLS conductor in the Kenyan Power System?
2. How does loadability impact the Kenyan Power System?
3. How does HTLS conductor impact loadability of the Kenyan Power System?
4. How does HTLS conductors improve loadability?

The research questions were addressed through analysis using Powerfactory DIGSILENT software.

4.2 Data collection methods

The data that was used for these analyses was obtained from Kenya Power and Kenya Electricity Transmission Company Limited (Ketraco) for 2022. The data was mainly secondary data and entailed generator data, transmission line data, busbar information, load data and reactive elements in the Kenyan transmission system.

The information collected is updated yearly, taking into considerations the upgraded and the new installed transmission lines as well as generations. The data collected includes renewable energy technologies like wind energy and solar energy that have been introduced in the system.

The data sets were obtained from both online platforms and the companies listed above for better accuracy of the data.

4.3 Data preparation techniques

The data set collected was large hence data cleaning was done to remove the data not required for the analysis. This was done using Microsoft Excel, reducing the data to generation (P, Q, pf), transmission line parameters (R, L, C, km), and voltage levels in the network. The data that was not required was deleted e.g., Make of the machine, open circuit saturation factor etc. The data sets provided were well labelled hence relabeling and removal of outliers or missing values was not required.

4.4 Data analysis techniques

The data collected was used to model a single line diagram for the Kenyan Power system using the DigSILENT PowerFactory 2023 software. A load flow analysis was done to determine the power flow through the various elements in the system. It was also used to check the loading capability of the line during normal operating conditions.

A contingency analysis was done on the transmission lines to determine the reliability and security of the lines in cases of an outage, a fault or disturbances in the power system that can cause a blackout in a section of the grid or on the whole grid. The analysis will also help in planning and analyzing the growth level in terms of load of a section in the grid and its effect on the grid.

4.5 Results

4.5.1 Kenya Power Grid

A load flow analysis was run to determine the overview and summary of the grid as shown in the figure below:

Total System Summary

1 Summary Grid

1.1 Overview

Number of Voltage Levels	Number of Connected Grids	No. of Substations	No. of Busbars	No. of Terminals	No. of Lines
6	0	0	169	0	178
No. of 2-w Trfs.	No. of 3-w Trfs.	No. of 4-w Trfs.	No. of syn. Machines	No. of asyn. Machines	No. of Static Generators
37	0	0	28	5	0
No. of PV Systems	No. of Loads	No. of SVS	No. of Shunts/Filters	No. of Other Elements	No. of Isolated Areas
0	96	0	17	0	8
No. of Unsupplied Isolated Areas					
6					

1.2 Power Summary

Generators, Active Power MW	Generators, Reactive Power Mvar	Generators, Apparent Power MVA
1774.8	-185.1	1784.4
Generators, Nominal Active Power MW	Generators, Nominal Reactive Power Mvar	Generators, Nominal Apparent Power MVA
3328.1	2149.6	3962.0
Generators, difference between maximum and actual active power MW	Generators, difference between maximum and actual reactive power Mvar	
1970.6	3680.6	
Loads, Active Power MW	Loads, Reactive Power Mvar	Loads, Apparent Power MVA
1708.7	990.5	1975.0

Figure 15: Total system summary for the Kenyan Power System

The load flow analysis was run using the Newton Raphson method to determine the active and reactive power, the voltage levels and also the loading at each node. These parameters assist in assessing the network stability, optimizing operation through generation dispatch, impact of various contingencies as well as assisting in planning and expansion activities for the grid.

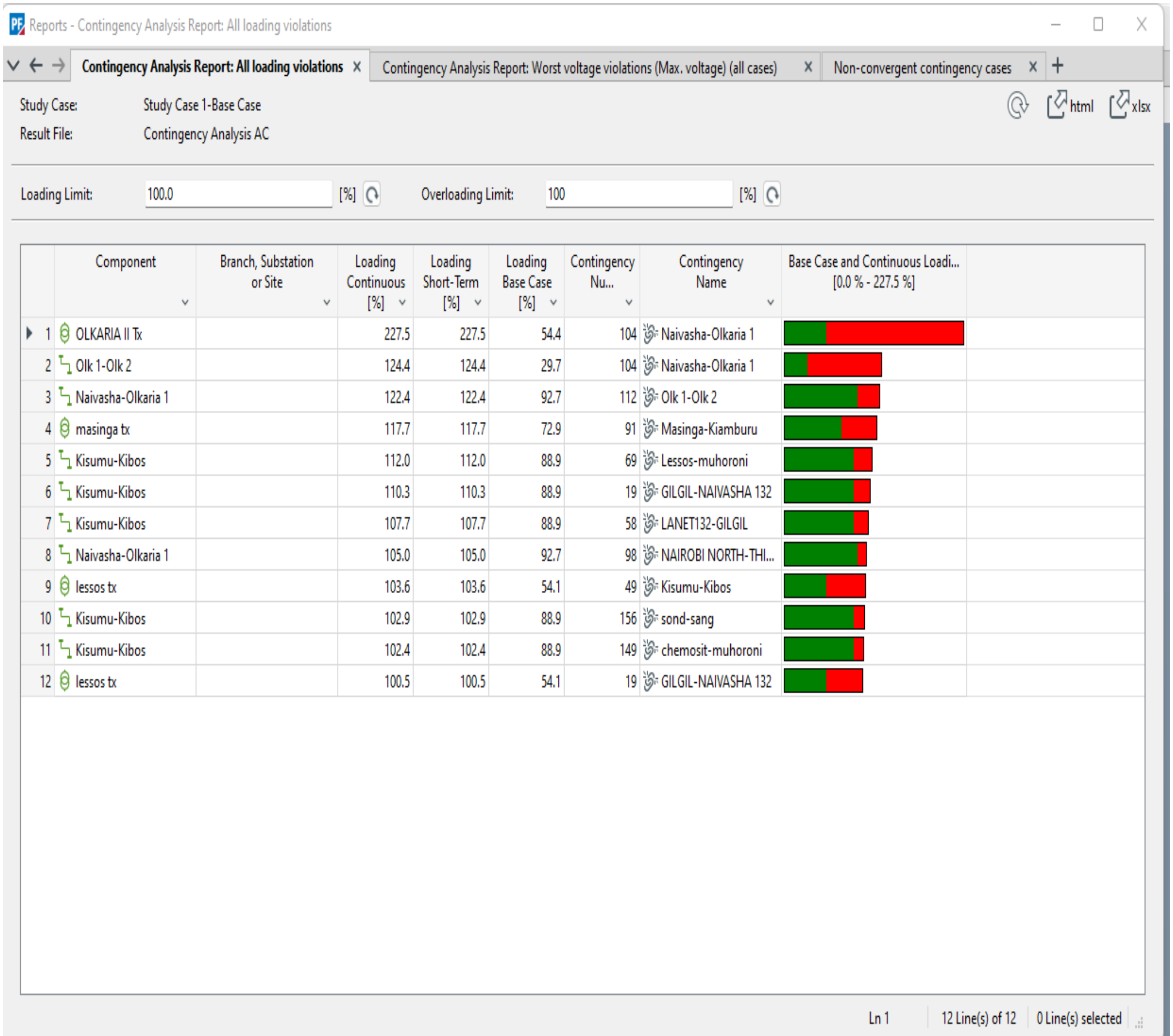
4.5.2 Analysis of the system with ACSR conductors

The system transmission lines are currently ACSR. According to Kenya Power and Ketraco records, the following lines are critical and under consideration due to the blackouts caused in cases of overloading or in an event of a short circuit:

1. Kisumu- Muhoroni
2. Muhoroni- Chemosit
3. Naivasha-Olkaria 1AU
4. Juja- Dandora
5. Suswa – Nairobi North
6. Masinga- Kamburu

The contingency analysis considered the above listed lines. During the analysis, 181 fault cases were created considering the N-1 contingency of transmission lines. The contingency analysis was done for a scenario of 100% loading to test the actual conditions on the ground, as close to 90% of the transmission lines are loaded in the upper quarter i.e., they are 75% to 90% loaded. A static contingency analysis was done using AC load flow method to be able to get both the loading violations and voltage violations of the system.

Table 4.1: All loading violations for ACSR system



Reports - Contingency Analysis Report: All loading violations

Contingency Analysis Report: All loading violations | Contingency Analysis Report: Worst voltage violations (Max. voltage) (all cases) | Non-convergent contingency cases

Study Case: Study Case 1-Base Case

Result File: Contingency Analysis AC

Loading Limit: 100.0 [%] Overloading Limit: 100 [%]

	Component	Branch, Substation or Site	Loading Continuous [%]	Loading Short-Term [%]	Loading Base Case [%]	Contingency Nu...	Contingency Name	Base Case and Continuous Loadi... [0.0 % - 227.5 %]
1	OLKARIA II Tx		227.5	227.5	54.4	104	Naivasha-Olkaria 1	
2	Olk 1-Olk 2		124.4	124.4	29.7	104	Naivasha-Olkaria 1	
3	Naivasha-Olkaria 1		122.4	122.4	92.7	112	Olk 1-Olk 2	
4	masinga tx		117.7	117.7	72.9	91	Masinga-Kiamburu	
5	Kisumu-Kibos		112.0	112.0	88.9	69	Lessos-muhoroni	
6	Kisumu-Kibos		110.3	110.3	88.9	19	GILGIL-NAIVASHA 132	
7	Kisumu-Kibos		107.7	107.7	88.9	58	LANET132-GILGIL	
8	Naivasha-Olkaria 1		105.0	105.0	92.7	98	NAIROBI NORTH-THI...	
9	lessos tx		103.6	103.6	54.1	49	Kisumu-Kibos	
10	Kisumu-Kibos		102.9	102.9	88.9	156	sond-sang	
11	Kisumu-Kibos		102.4	102.4	88.9	149	chemosit-muhoroni	
12	lessos tx		100.5	100.5	54.1	19	GILGIL-NAIVASHA 132	

Ln 1 | 12 Line(s) of 12 | 0 Line(s) selected

Table 4.2: Non-convergent cases for contingency analysis

Reports - Non-convergent contingency cases

Contingency Analysis Report: All loading violations | Contingency Analysis Report: Worst voltage violations (Max. voltage) (all cases) | **Non-convergent contingency cases**

Study Case: Study Case 1-Base Case

Result File: Contingency Analysis AC

	Contingency Nu...	Contingency Time Phase [min.]	Contingency Name
1	24	-1	ISHIARA WEST-MERU
2	35	-1	KIGANJO -PROP OTH...
3	45	-1	Kamburu-Ishiara West
4	55	-1	Kutus T1-Kutus
5	56	-1	Kutus Tee2-Kutus
6	92	-1	Masinga-Kutus
7	120	-1	PROP OTHAYA- KUTUS

Ln 1 | 7 Line(s) of 7 | 0 Line(s) selected

Table 4.3: Maximum or worst voltage violations

Reports - Contingency Analysis Report: Worst voltage violations (Max. voltage) (all cases)

Contingency Analysis Report: All loading violations | **Contingency Analysis Report: Worst voltage violations (Max. voltage) (all cases)** | Non-convergent contingency cases

Study Case: Study Case 1-Base Case

Result File: Contingency Analysis AC

html | xlsx

Max. voltage threshold 1.100 [p.u.] Max. Voltage Limit: 1.05 [p.u.]

	Component	Branch, Substation or Site	Voltage Max. [p.u.]	Voltage Step [p.u.]	Voltage Base [p.u.]	Contingency Nu...	Contingency Name	Base Case and Post Voltag... [1.303 p.u. - 1.360 p.u.]
1	LOIYANGALANI(1)		1.360	0.010	1.350	98	NAIROBI NORTH-THI...	
2	LOIYANGALANI(1)		1.359	0.009	1.350	33	Juja-Mangu	
3	LOIYANGALANI(1)		1.355	0.004	1.350	1	Olk 3- Olk4	
4	LOIYANGALANI(1)		1.352	0.002	1.350	166	BAMBURI-RABAI	
5	LOIYANGALANI(1)		1.352	0.002	1.350	172	KISUMU 132-KISUMU...	
6	LOIYANGALANI(1)		1.352	0.002	1.350	128	RABAI-NEW BAMBURI	
7	LOIYANGALANI(1)		1.352	0.001	1.350	83	MSA CEMENT-KILIFI	
8	LOIYANGALANI(1)		1.352	0.001	1.350	91	Masinga-Kiamburu	
9	LOIYANGALANI(1)		1.351	0.001	1.350	11	ELDORET- ELDORET ...	
10	LOIYANGALANI(1)		1.351	0.001	1.350	151	kisumu-sondu	
11	LOIYANGALANI(1)		1.351	0.001	1.350	57	LAMU-GARSEN	
12	LOIYANGALANI(1)		1.351	0.001	1.350	179	PROP MBARAKI(1)	
13	LOIYANGALANI(1)		1.351	0.001	1.350	12	Eldoret-Lessos	
14	LOIYANGALANI(1)		1.351	0.001	1.350	97	Musga-webuye	
15	LOIYANGALANI(1)		1.351	0.001	1.350	53	Konza-Machakos	
16	LOIYANGALANI(1)		1.351	0.001	1.350	111	OTHAYA-PROP OTHA...	
17	LOIYANGALANI(1)		1.351	0.001	1.350	158	sotik-bomet	
18	LOIYANGALANI(1)		1.351	0.001	1.350	123	RABAI-KIPEVU 1	
19	LOIYANGALANI(1)		1.351	0.000	1.350	87	Mangu-Gatundu	
20	LOIYANGALANI(1)		1.351	0.000	1.350	125	RABAI-KIPEVU 3	
21	LOIYANGALANI(1)		1.351	0.000	1.350	127	RABAI-MTWAPA	

Ln 1 | 167 Line(s) of 167 | 0 Line(s) selected

4.5.2.1 Results after load balancing

Table 4.4: All loading violations after adding a line to Kisumu-Kibos

Reports - Contingency Analysis Report: All loading violations

Contingency Analysis Report: All loading violations | Contingency Analysis Report: Worst voltage violations (Max. voltage) (all cases) | Non-convergent contingency cases

Study Case: Study Case 1-Base Case

Result File: Contingency Analysis AC

Loading Limit: 100.0 [%]   Overloading Limit: 100 [%]

	Component	Branch, Substation or Site	Loading Continuous [%]	Loading Short-Term [%]	Loading Base Case [%]	Contingency Nu...	Contingency Name	Base Case and Continuous Loadi... [0.0 % - 227.5 %]
1	OLKARIA II Tx		227.5	227.5	54.4	104	Naivasha-Olkaria 1	
2	Olk 1-Olk 2		124.4	124.4	29.8	104	Naivasha-Olkaria 1	
3	Naivasha-Olkaria 1		122.4	122.4	92.7	112	Olk 1-Olk 2	
4	masinga tx		117.7	117.7	72.9	91	Masinga-Kiamburu	
5	Naivasha-Olkaria 1		105.0	105.0	92.7	98	NAIROBI NORTH-THI...	
6	lessos tx		103.6	103.6	53.7	49	Kisumu-Kibos	

Ln 1   6 Line(s) of 6   0 Line(s) selected

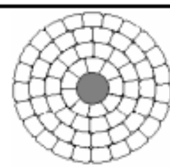
4.5.3 Analysis of the system with HTLS conductors

According to (*Accc-Midal-Dataeuropean-Sizes.Pdf*, n.d.), we used the properties of the HTLS conductors used in other countries for our case study. We used the cables used in Madrid as a reference due to the characteristics of the cable i.e., rated current, AC resistance, weight of the cable and its current carrying capacity. The figure 16 below shows the properties of the overhead transmission line that were used during the design process.

Lay ratio - Outer layer of Aluminum wires : Min.10 Max.13		Lay Direction of outer layer	Right Hand
- Inner layer of Aluminum wires : Min.10 Max.16		Surface finish	Standard or Non Specular
Prefered Lay of outer layer	420 mm	Max. single length /Drum	2640 m

Stranding configuration	
No. & Diameter of CTC Core	1 x 9,78 mm
No. of Aluminum Layers	4 N°
No. & equivalent Dia. of Trapezoidal wires in first layer	8 x 4,69 mm
No. & equivalent Dia.of Trapezoidal wires in second layer	12 x 4,74 mm
No. & equivalent Dia. of Trapezoidal wires in third layer	16 x 4,77 mm
No. & equivalent Dia. of Trapezoidal wires in fourth layer	20 x 4,78 mm

Individual Aluminum wires	
Minimum conductivity	63 %IACS
ASTM minimum Tensile Strength	58,6 MPa
Composite Core	
Conductivity	Nil
Rated Breaking Load	162,1 kN



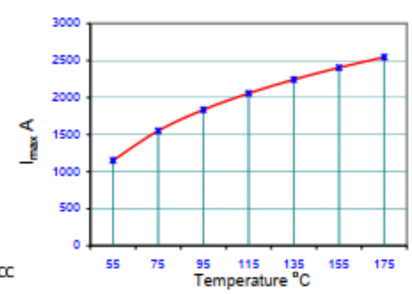
Trapezoidal Wires		
	height	3,55 mm
Area :	Layer-1	17,3 sqmm
	Layer-2	17,68 sqmm
	Layer-3	17,87 sqmm
	Layer-4	17,98 sqmm

Coefficient of thermal expansion		Modulus of elasticity	
above thermal knee point	$1,61 \times 10^{-6}$ /°C	above thermal knee point	118,6 GPa
below thermal knee point	$20,51 \times 10^{-6}$ /°C	below thermal knee point	71,5 GPa

Max. allowable continuous operating temp. (surface)	175°C
Rated current at max. temperature ^	2546 Amp.
AC Resistance at max. operating temp.	0,04808 Ω/ km
Calculated max. current at 120 Deg.C ^	2106 Amp.
Calculated AC Resistance at 120 Deg.C	0,04189 Ω/km
Geometric Mean Radius(GMR)	14,88 mm
Inductive Reactance @0,3m radius at 50Hz	0,18975 Ω/km
Capacitive Reactance @0,3m radius at 50Hz	0,15865 MΩ.km

^ Current calculated at 25 Deg.C ambient, wind velocity 0,6m/s solar radiation: 1000W/sq.m emissivity coefficient: 0,5 & absorptivity: 0,5

* Extreme Load Saftety Strength of Conductor =185 kN
(Applicable if sustained load over 80% RTS expected for prolonged periods. For further information please refer to ACCC Technical note TN-750-001.)



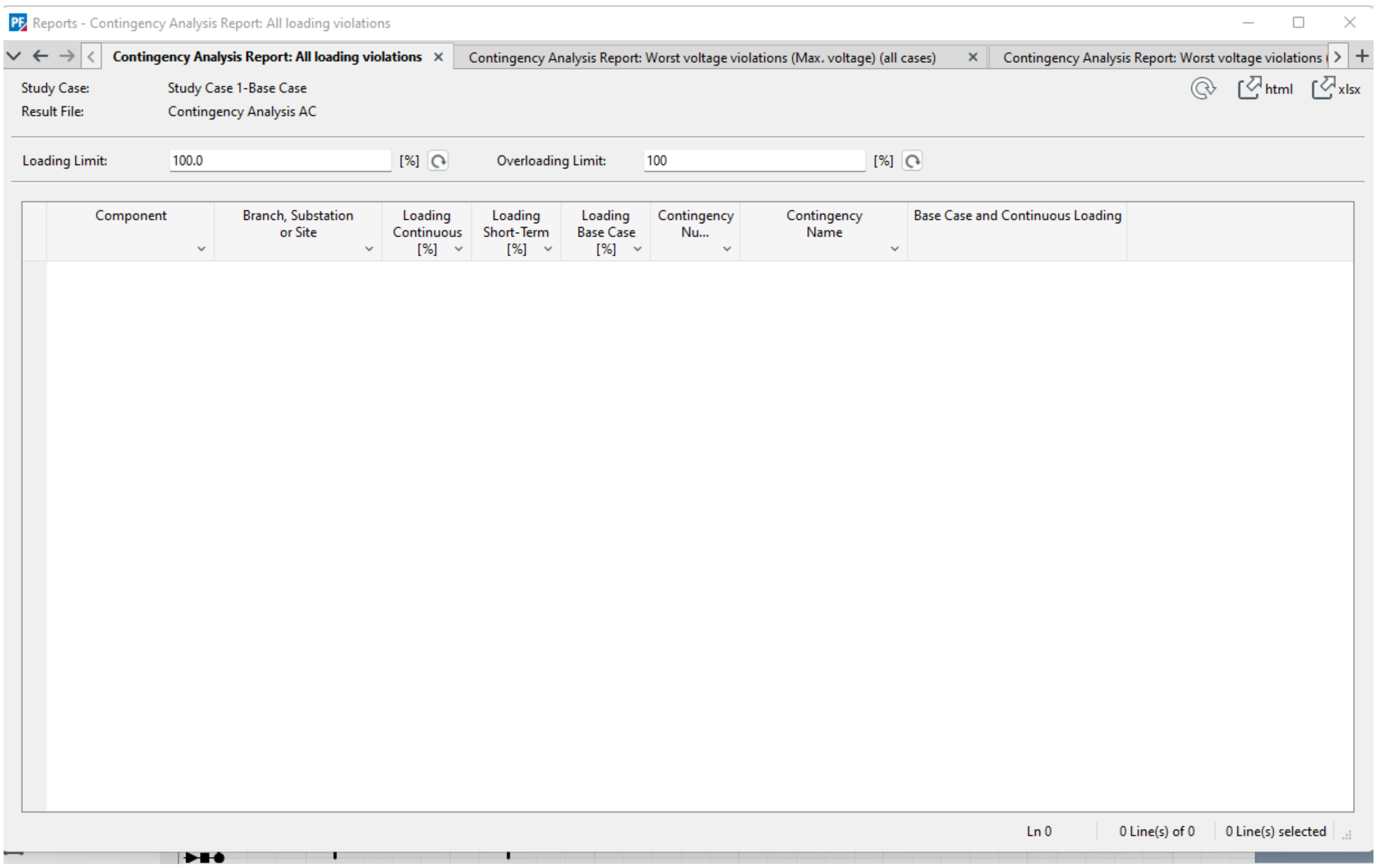
General Specification Standard : ASTM B 857
Document version : Preliminary

Manufactured under license from CTC CABLE CORPORATION

Figure 16: HTLS Conductor properties for a transmission line in Madrid

The Kenyan power system was redesigned incorporating the above ratings of HTLS transmission lines for132kV lines and 220kV lines. A load flow analysis was run to determine the loading capability of the line. Most of the lines increased the carrying capacity as can be seen when the contingency analysis is run. There were no loading violations nor non-convergent cases as seen from the table below

Table 4.5: Loading violations of the Kenyan Power System with HTLS transmission lines



Component	Branch, Substation or Site	Loading Continuous [%]	Loading Short-Term [%]	Loading Base Case [%]	Contingency Nu...	Contingency Name	Base Case and Continuous Loading

5 Discussion

5.1 Introduction

In this Chapter, an analysis of the results obtained in chapter 4, where a comparison of the loading and voltage violations are considered in the research. It as well explains how the results achieved meet the research objectives of the research study.

5.2 Kenyan Power System with ACSR conductors

5.2.1 Loading Violations

According to table 4-1, the N-1 contingency analysis shows the effect of loss of some of the transmission lines on the system as a whole. The contingencies were ranked from the most severe to the least severe. The Naivasha- Olkaria 1 is the most sever line with a loading of 227.5% for the Olkaria II Tx and loading of 124.4%.

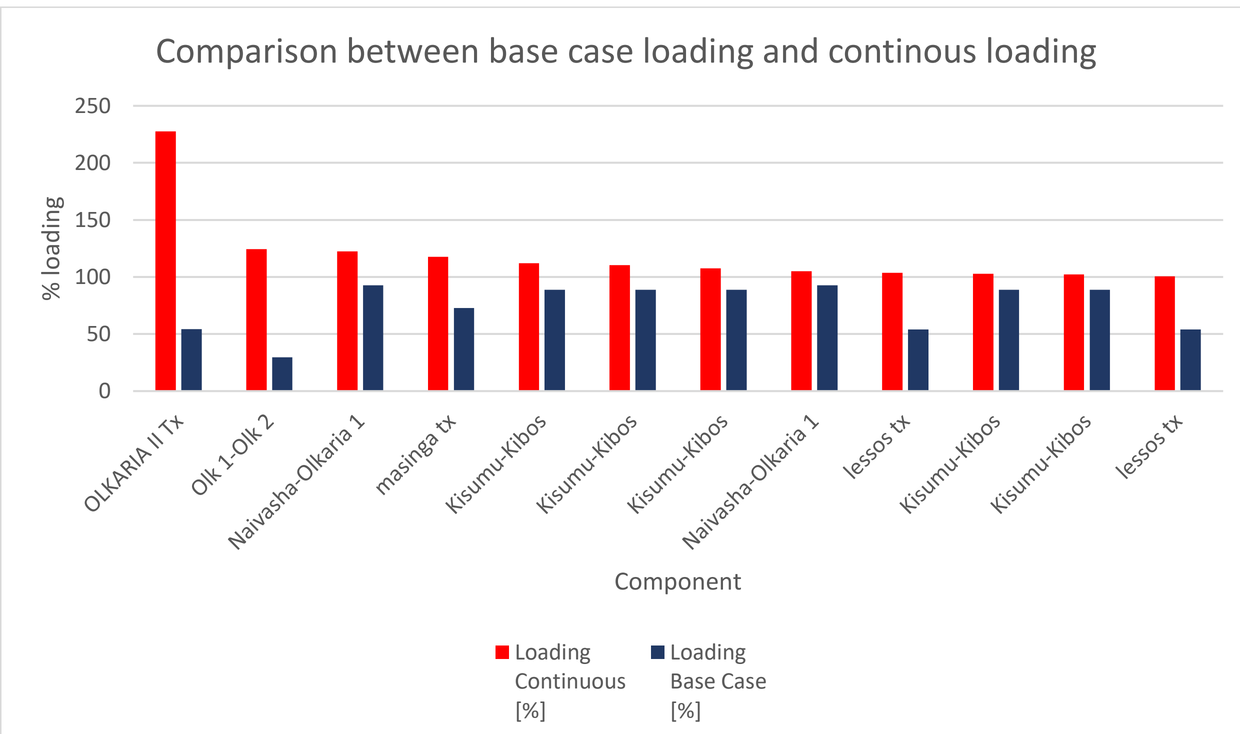


Figure 17: Comparison between base loading and continuous loading of the lines

This is because all the power generated by the Olkaria I AU is directed towards that line and transformer. The Naivasha-Olkaria 1 transmission line has also not been made redundant to assist in the event of a security case. Adding another line in parallel between the two busbars creates a redundant connection that ensures load shedding is not experienced with some customers.

The Masinga- Kamburu line is also a major line of concern to Ketraco and Kenya Power. The loss of this line affects the Masinga transformer. This is because loss of the line makes the Masinga generator the only supply for the loads, overloading the transformer. Addition of a line in parallel from Masinga- Kamburu will ensure the transformer is not overloaded as well reduce on any instance of load shedding.

The loss of chemosit-muhoroni transmission line causes an effect on the Kisumu-Kibos line. This is because loss of the line causes the Olkaria II generator to increase on its generation to be able to supply some of the affected loads. Redirection of power causes an overload on the Kisumu-Kibos line making it overloaded by 102.4%. Addition of another parallel transmission line between Kisumu and Kibos busbars allows for division of power transferred hence the making the line be stable.

Redundancy of most of the equipment is because, in normal operation, most of them are loaded close to three-quarter of the current carrying capacity of each line.

5.2.2 Voltage violations.

Table 4-3 shows the voltage violations of 166 transmission lines. Loss of all this line affects the the Loiyanagalani busbar. This is because the length of the loiyangalani line could cause Ferranti effect on the bus bars where the receiving voltage is more than the sending end voltage. Addition of a R-L shunt reactor, with a power rating of 100MVAr, at the Loiyangalani bus removes the effect as of the voltage stabilizes.

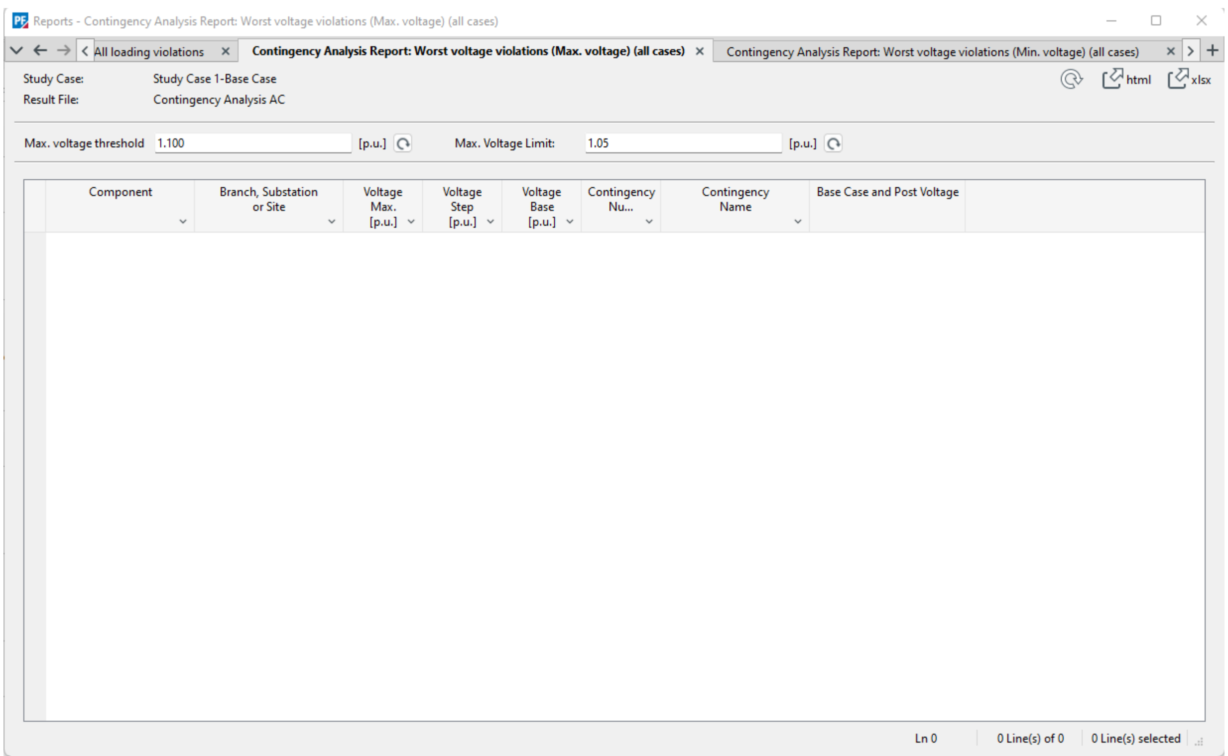
5.2.3 Non-convergent cases

Table 4-2 shows the non-convergent cases during the performance of the contingency analysis. This shows that non-convergence of this line affects both the loading and voltage limits of the system. Stabilization of this transmission lines through addition of redundant parallel lines improves in both the loading violations and the voltage violations.

5.3 Kenyan Power System with HTLS conductors

Table 4-5 show the results when a contingency analysis is run with incorporation of the HTLS conductors. There were no loading violations nor non-convergent cases. However there were voltage violations with the loss of 174 transmission lines that affected the Loiyangalani busbar. This is due to the Ferranti effect caused by the long transmission line from Loiyangalani to Suswa 220 busbar. Additon of an R-L, 100MVAr reactor on the Loiyngalani busbar stabilized the voltage violations as shown in the table below:

Table 5.1: Voltage violation of the Kenyan Power system after addition a shunt reactor



6 Conclusion and Recommendation

6.1 Conclusion

The research determined that there are weaknesses in the system due to overloading. Major causes would be overloading of equipment, aging of some of the equipment, and lack of constant maintenance of the system. Contingency analysis done in the system has shed light on the security challenges of the system by conducting an N-1 analysis for transmission lines. This has shown the weakness in a major part of the system in terms of overloading and voltage violations that affect the stability of the system.

The analysis was done with incorporation of the renewable energy technologies hence incorporating all their intermittency qualities. The analysis provides insights on the vulnerabilities of the systems and potential disruptions on the Kenya Grid and in the midst allows for proper planning on maintenance and upgrades to the equipment in the system.

In addition, the results obtain in the analysis of HTLS conductors in the system i.e., in the 132kV and 220kV transmission lines shows the capability of the system. The system was able to withstand both N-1 and N-2 contingency analysis of the system without being overloaded or exceeding the voltage limits shown. This has led to major discoveries on the need to upgrade our system even as the economy grows and be beneficial to areas interested in power security and stability.

6.2 Recommendation

The proposed system was developed to solve the challenge of system insecurity in the Kenyan Power System Grid. The analysis of the system was successful in maintaining both a N-1 and N-2 contingency analysis for lines and cables. However, the analysis did not incorporate the small renewable plants below 1MW and the IPP's. With this, it is advisable that the proposed system be implemented in a live scenario to check the security of the system in a real-time scenario.

6.3 Further work

The analysis of both generator and cable/ transmission line, N-1 contingency is important as the real time scenario has very many cases and will assist in an advised planning process by the authorities. Further research is needed on the static security of the Kenyan power system using contingency analysis for other operating scenarios such as during the dry seasons when generation from hydro power plants is low. Also, a dynamic security assessment of the system should be done in the future.

7 References

Accc-midal-dataeuropean-sizes.pdf. (n.d.).

Alvarado, A., Asqui, J., Plazarte, J., & Urquizo, J. (n.d.). *Analysis of contingencies through the sensitivity factors of the National Electricity Interconnected System. A case study in Ecuador*.

Domínguez, A. H., Escobar, A., & Gallego, R. A. (2014). *Transmission expansion planning considering conductor proposals with different wire size and technology*. 1–6.

Filippone, G., Ippolito, M., Massaro, F., & Puccio, A. (2014). *On the roadmap to Supergrid in Sicily: LIDAR technology and HTLS conductors for uprating the 150 kV lines*. 1–5.

Geary, R., Condon, T., Kavanagh, T., Armstrong, O., & Doyle, J. (2012). Introduction of high temperature low sag conductors to the Irish transmission grid. *CIGRE B2*, *104*.

Griggs, D., Nilsson, M., Stevance, A., & McCollum, D. (2017). *A guide to SDG interactions: From science to implementation*. International Council for Science, Paris.

Guide, R. A. S. D. (2006). *Western Electricity Coordination Council (WECC), Remedial Action Scheme Subcommittee*. Technical report.

Håkansson, E. (2013). *Galvanic Corrosion of High-Temperature Low-Sag (HTLS) High Voltage Conductors: New Materials—New Challenges*.

Kanno, J., Mori, H., & Tsuzuki, S. (1992). A New DC Load Flow Method for Power System Contingency Analysis. *IEEJ Transactions on Power and Energy*, *112*(9), 773–778.

Kim, S.-S., Kim, B.-G., Jang, T.-I., Kang, J.-W., Lee, D.-I., & Min, B.-U. (2006). Change of Properties by Environment Conditions in Aged ACSR Overhead Conductor. *Journal of the Korean Institute of Electrical and Electronic Material Engineers*, *19*(3), 287–291.

Kopsidas, K., & Rowland, S. M. (2009). A performance analysis of reconductoring an overhead line structure. *IEEE Transactions on Power Delivery*, *24*(4), 2248–2256.

Kundur, P., Paserba, J., Ajjarapu, V., Andersson, G., Bose, A., Canizares, C., Hatziargyriou, N., Hill, D., Stankovic, A., & Taylor, C. (2004). Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions. *IEEE Transactions on Power Systems*, *19*(3), 1387–1401.

Mirza, U. K., Ahmad, N., Harijan, K., & Majeed, T. (2009). Identifying and addressing barriers to renewable energy development in Pakistan. *Renewable and Sustainable Energy Reviews*, *13*(4), 927–931.

Rasool, A. A., Abbas, N. M., & Sheikhyounis, K. (2021). Contingency Analysis and Ranking of Kurdistan Region Power System Using Voltage Performance Index. *UKH Journal of Science and Engineering*, *5*(1), 73–79.

Riba, J.-R., Bogarra, S., Gómez-Pau, Á., & Moreno-Eguilaz, M. (2020). Uprating of transmission lines by means of HTLS conductors for a sustainable growth: Challenges, opportunities, and research needs. *Renewable and Sustainable Energy Reviews*, *134*, 110334.

Roy, A. K., & Jain, S. K. G. (2011). *Contingency analysis in power system*.

Tokombayev, A., & Heydt, G. T. (2013). *High temperature low sag (HTLS) technologies as upgrades for overhead transmission systems*. 1–6.

Tokombayev, A., & Heydt, G. T. (2015). High temperature low sag upgrades and payback for the economic operation improvement of power transmission systems. *Electric Power Components and Systems*, *43*(3), 345–355.

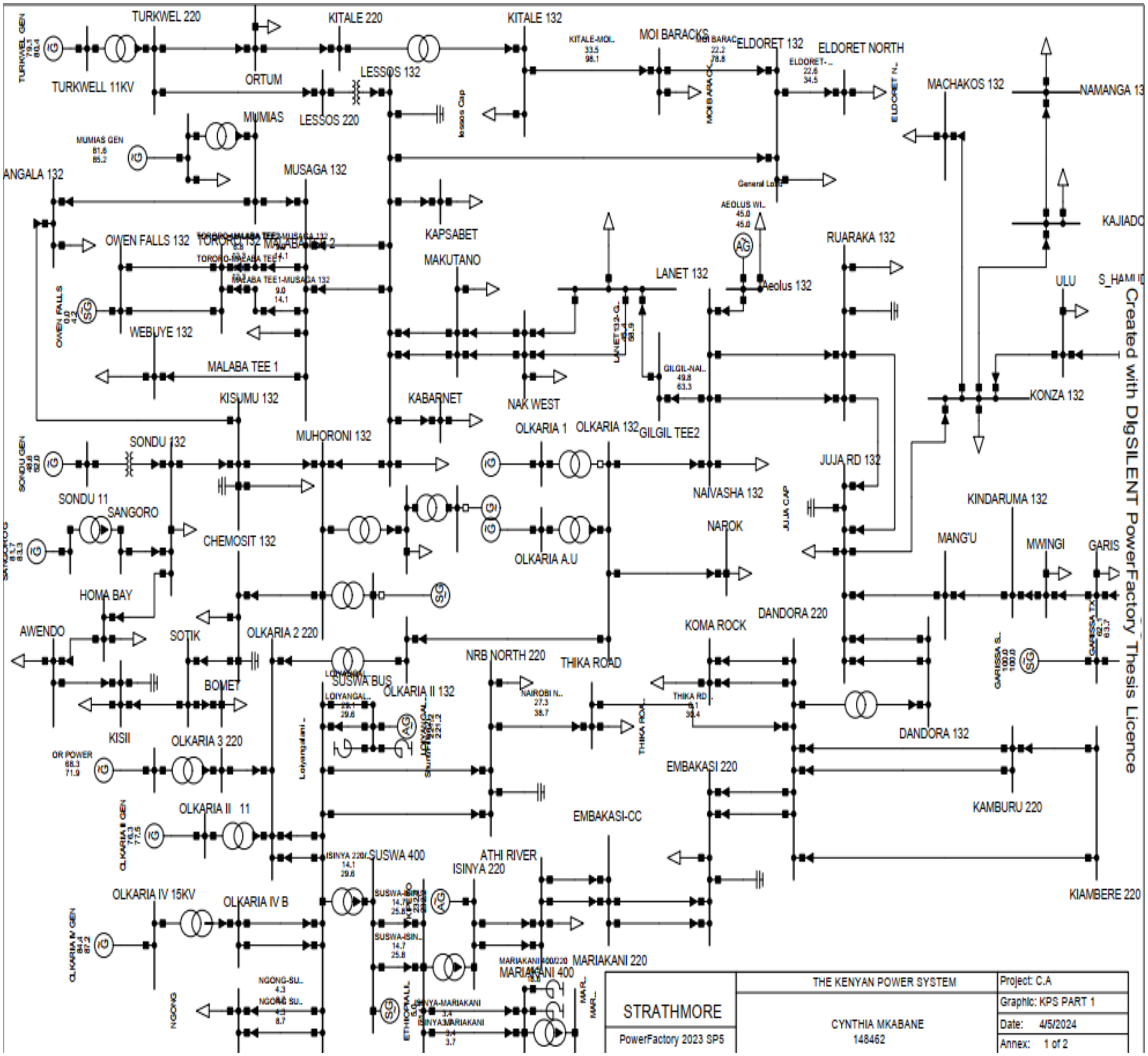
Transmission and Distribution Committee. (2013). IEEE guide for determining the effects of high-temperature operation on conductors, connectors and accesories. *IEEE Power and Energy Society*.

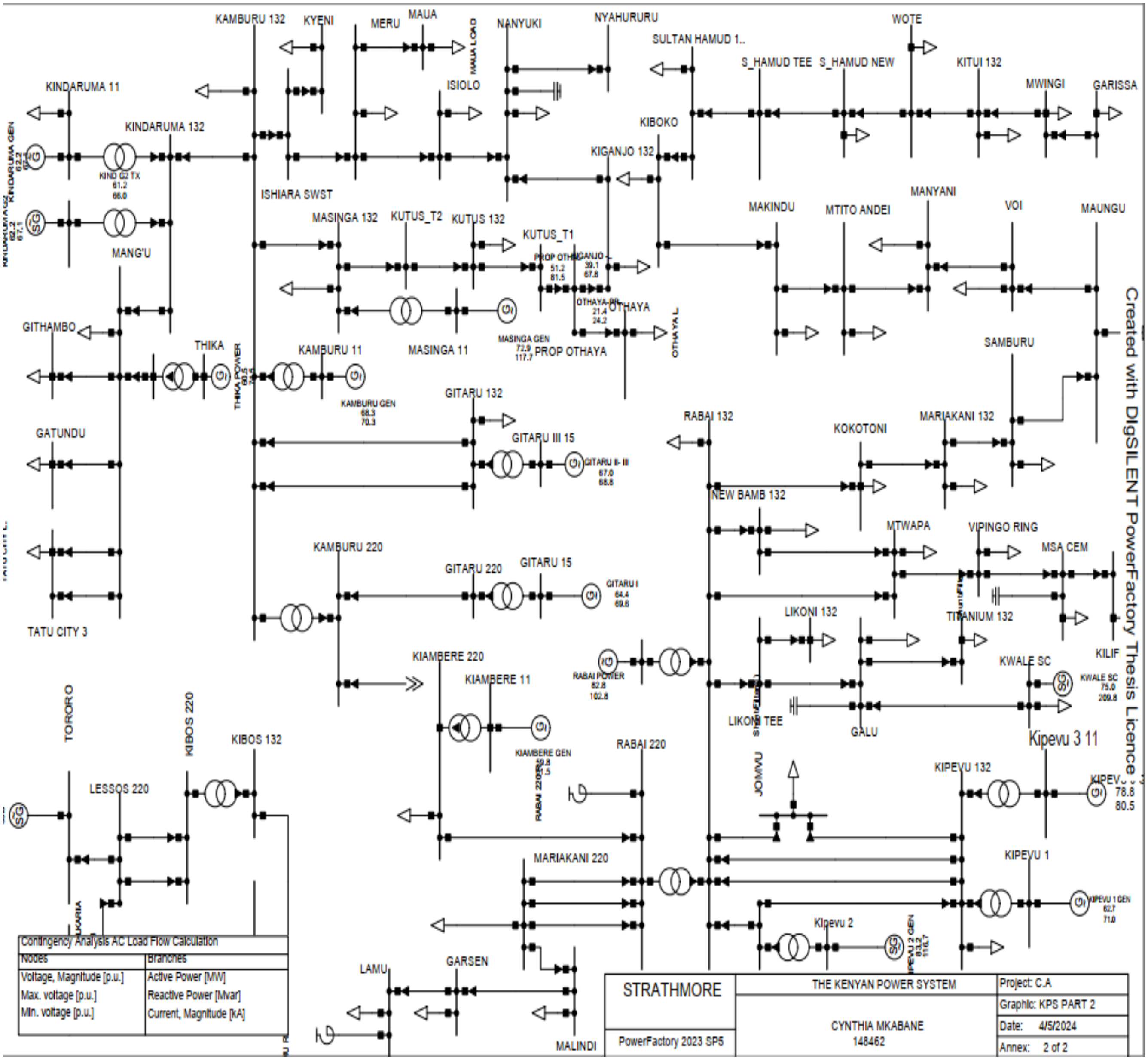
UserManual_2023_en.pdf. (n.d.).

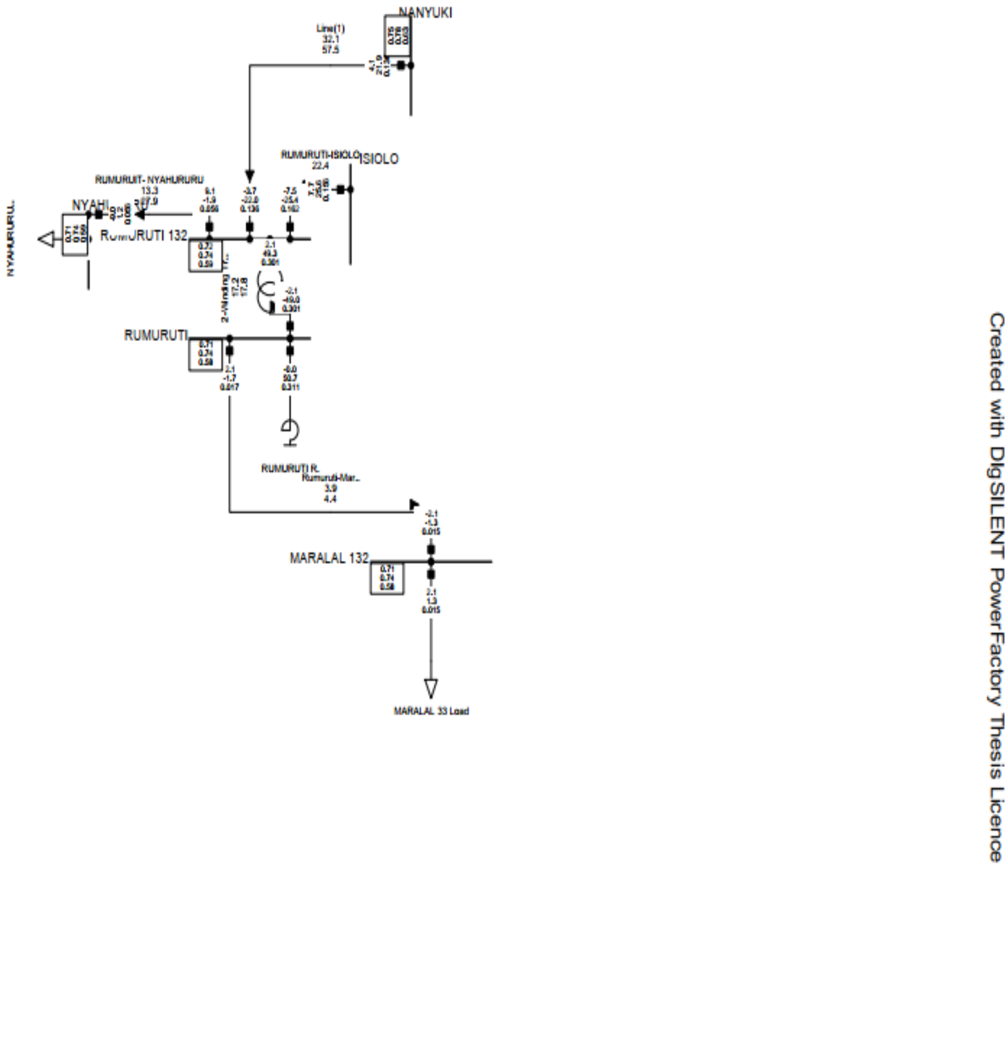
Wu, Y.-K., Chang, S. M., & Hu, Y.-L. (2017). Literature review of power system blackouts. *Energy Procedia*, *141*, 428–431.

8 APPENDIX

8.1 Kenya Transmission system



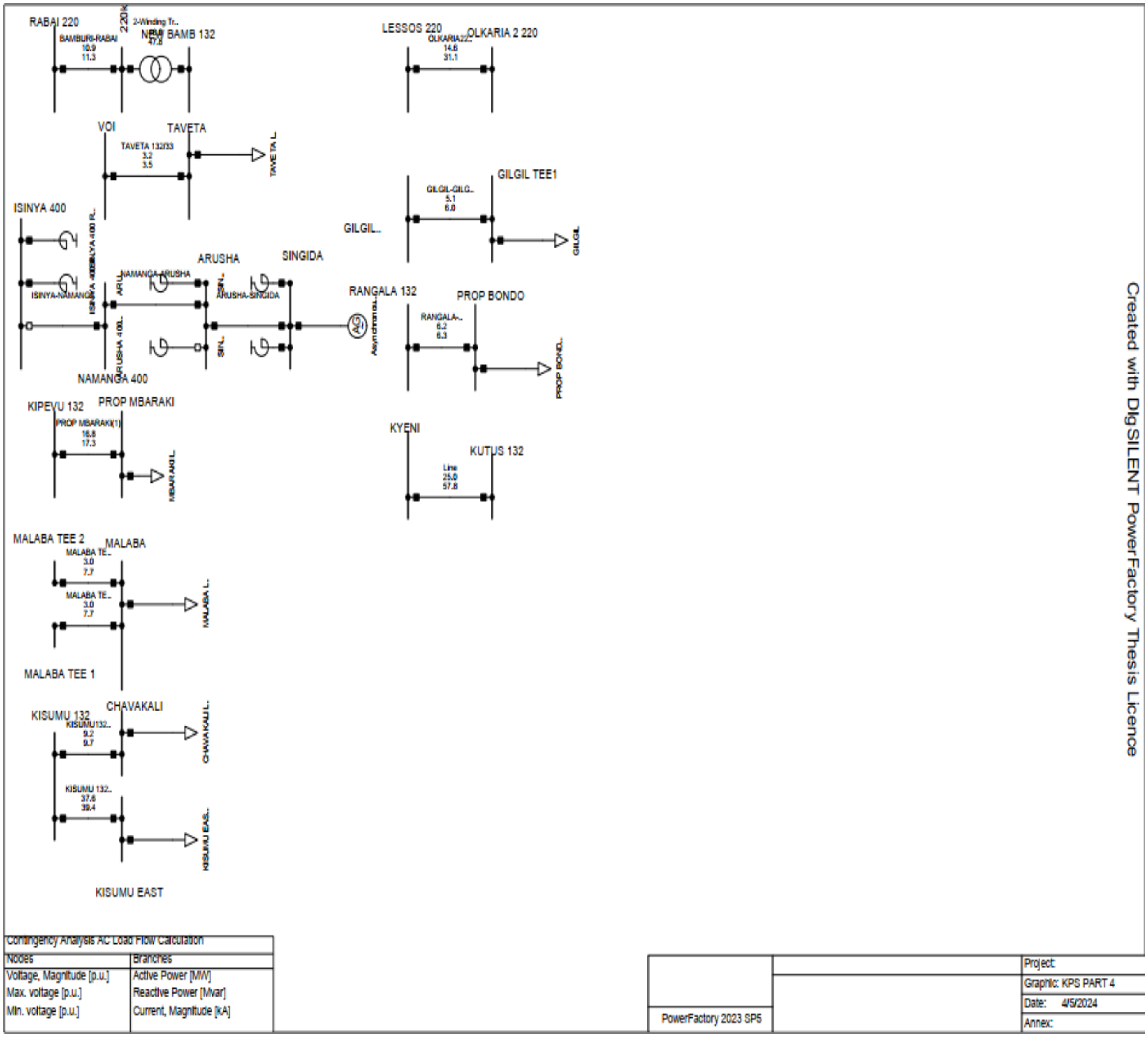

KAMBURU 132
KYENI
MERU
MAUA
NANYUKI
NYAHURURU
SULTAN HAMUD 1..
WOTE
S_HAMUD TEE
S_HAMUD NEW
KITUI 132
MWINGI
GARISSA
KINDARUMA 11
KINDARUMA 132
ISIOLO
KIBOKO
KIGANJO 132
ISHIARA SWST
MASINGA 132
KUTUS_T2
KUTUS 132
KUTUS_T1
MAKINDU
MTITO ANDEI
MANYANI
VOI
MAUNGU
MANG'U
GITHAMBO
THIKA
KAMBURU 11
MASINGA 11
PROP OTHAYA
OTHAYA
SAMBURU
GITARU 132
GITARU III 15
RABAI 132
KOKOTONI
MARIAKANI 132
GATUNDU
NEW BAMB 132
MTWAPA
VIPINGO RING
MSA CEM
KAMBURU 220
GITARU 220
GITARU 15
LIKONI 132
TITANIUM 132
TATU CITY 3
KIAMBERE 220
KIAMBERE 11
KWALE SC
KILIF
LIKONI TEE
GALU
Kipevu 3 11
TORORO
KIBOS 220
KIBOS 132
RABAI 220
KIPEVU 132
LESSOS 220
KIPEVU 1
MARIAKANI 220
Kipevu 2
LAMU
GARSEN
MALINDI
Contingency Analysis AC Load Flow Calculation
Nodes
Branches
Voltage, Magnitude [p.u.]
Active Power [MW]
Max. voltage [p.u.]
Reactive Power [Mvar]
Min. voltage [p.u.]
Current, Magnitude [kA]
STRATHMORE
THE KENYAN POWER SYSTEM
Project: C.A
Graphic: KPS PART 2
CYNTHIA MKABANE
148462
Date: 4/5/2024
PowerFactory 2023 SP5
Annex: 2 of 2
Created with DigSILENT PowerFactory Thesis Licence



Contingency Analysis AC Load Flow Calculation	
Nodes	Branches
Voltage, Magnitude [p.u.]	Active Power [MW]
Max. voltage [p.u.]	Reactive Power [Mvar]
Min. voltage [p.u.]	Current, Magnitude [kA]

PowerFactory 2023 SP5

Project:
Graphic: KPS PART 3
Date: 4/5/2024
Annex:


RABAI 220
BAMBURI-RABAI
10.9
11.3
2-Winding Tr..
NEW BAMB 132
LESSOS 220
OLKARIA2..
14.6
31.1
OLKARIA 2 220
VOI
TAVETA
TAVETA 132/33
3.2
3.5
TAVETA L
GILGIL TEE1
GILGIL-GILG..
5.1
6.0
GILGIL..
GILGIL
ISINYA 400
ARUSHA
SINGIDA
NAMANGA-ARUSHA
ISINYA-NAMANGA
ARUSHA-SINGIDA
RANGALA 132
PROP BONDO
RANGALA-..
6.2
6.3
PROP BOND..
NAMANGA 400
ARUSHA 400L
KIPEVU 132
PROP MBARAKI
PROP MBARAKI(1)
16.8
17.3
MBARAKI L
KYENI
KUTUS 132
Line
25.0
57.8
MALABA TEE 2
MALABA
MALABA TE..
3.0
7.7
MALABA TE..
3.0
7.7
MALABA L
MALABA TEE 1
KISUMU 132
CHAVAKALI
KISUMU132..
9.2
9.7
CHAVAKALI L
KISUMU 132..
37.6
39.4
KISUMU EAS..
KISUMU EAST
Created with DIgSILENT PowerFactory Thesis Licence
Contingency Analysis AC Load Flow Calculation
Nodes
Branches
Voltage, Magnitude [p.u.]
Active Power [MW]
Max. voltage [p.u.]
Reactive Power [Mvar]
Min. voltage [p.u.]
Current, Magnitude [kA]
PowerFactory 2023 SP5
Project:
Graphic: KPS PART 4
Date: 4/5/2024
Annex:

8.2 DigSilent Licence Contract

DIgSILENT PowerFactory Licence Contract

LC2023-01977

between

Cynthia Mkabane
City Square
00200 Nairobi
Kenya

hereinafter the Licensee

and

DIgSILENT GmbH
Heinrich-Hertz-Str. 9
72810 Gomaringen
Germany
Tel: +49 (0) 7072 - 9168-0
Fax: +49 (0) 7072 - 9168-88
E-mail: mail@digsilent.de

hereinafter the Licensor

DIgSILENT PowerFactory Licence Contract

Licensee:	Cynthia Mkabane, Nairobi, Kenya
Product:	DIgSILENT *PowerFactory*
Version:	*PowerFactory* 2023
Product Description:	The software with the below listed functions is delivered according to the "**PowerFactory Product Specification**" of the corresponding Version, which is available at https://www.digsilent.de/product-specification
Licence Agreement:	The usage of the software must be in accordance with the "**DIgSILENT Licence Agreement**" valid by the date of this contract, which is available at https://www.digsilent.de/licence-agreement
License IDs:	The licenses under this contract are listed in the appendix of this document
Total Price:	free of charge thesis licence
Maintenance:	until 12.10.2024 The scope of the maintenance and support services is defined in the document "**Maintenance & Support Services**" available at https://www.digsilent.de/maintenance-support
Company Credentials:	Company ID: THX Company Password: THXJxWCu (for user registration)
Support Centre:	https://www.digsilent.de/de/support.html
Hotline:	tel. +49 (0)7072 / 9168-50 – German tel. +49 (0)7072 / 9168-51 – English

Gomaringen, 28.08.2023
DIgSILENT GmbH

This document was issued electronically and is therefore valid without signature.

Applicable appendix: List of licences

Licence ID:	2023-1012-0031918
Licence Model:	Temporary Licence (12.10.2023 - 12.10.2024)
	1 x Base Package
	1 x Contingency Analysis
	1 x Cable Analysis
	1 x Transmission Network Tools
	1 x Reliability Analysis Functions
	1 x Economic Analysis Tools
	1 x Small Signal Stability (Eigenvalue Analysis)
Number of Nodes:	500
Licence Type:	PF4T
Software-Edition:	Single User
Licence Technology:	UFC Softkey
	The conditions of the distinct software editions, licence technologies, and licence types are defined in the document "**PowerFactory Software Editions and Licensing**" available at https://www.digsilent.de/licence-types
USB Key-ID:	N.A.
Activation Key:	TTFVD-DFHD8-6EMFN-HWVY8-NDSXM
Further Agreements:	Time-limited thesis licence with restricted use, destined for your non-sponsored bachelor/master/PHD thesis only, not for commercial use.
	Replacing Licence Contract No. LC2023-01874

8.3 Transmission line data

Table 8.1: Transmission Line data

Name	Rated Voltage (kV)	Positive sequence R1 (Ω/km)	X1 (Ω/km)	B1 (S/km)
400_3CONDOR	400	0.024507	0.271653	4.23E-06
400_QUADLARK	400	0.036511	0.253579	4.52E-06
220_CANARY	220	0.07649	0.44	2.63E-06
220_GOAT	220	0.10838	0.4468	2.58E-06
220_300/50_RMGL	220	0.096008	0.431305	2.68E-06
220_CANARY_MNTL	220	0.063498	0.398546	2.89E-06
220_3CONDOR	220	0.024507	0.271653	4.23E-06
220_2500Al	220	0.01698	0.16036	1.01E-04
132_GOAT	132	0.10824	0.41275	2.81E-06
132_LYNX	132	0.18994	0.430656	2.69E-06
132_WOLF	132	0.22014	0.435329	2.66E-06
132_CANARY	132	0.07634	0.405987	2.87E-06
66_WOLF	66	0.2194	0.341755	3.31E-06

8.4 Similarity report check

Cynthia Mkabane Dissertation.pdf

ORIGINALITY REPORT

22%	20%	11%	10%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	citeseerx.ist.psu.edu Internet Source	3%
2	Submitted to Tshwane University of Technology Student Paper	2%
3	erepository.uonbi.ac.ke Internet Source	2%
4	www.erb.org.zm Internet Source	1%
5	dokumen.tips Internet Source	1%
6	ljs.academicdirect.org Internet Source	1%
7	dergipark.org.tr Internet Source	1%
8	H. B. D. Yasaranga, W. D. A. S. Wijayapala, K. T. M. U. Hemapala. "Techno Economic Analysis of the Use of High Temperature Low Sag (HTLS) Conductors in the Sri Lanka's	1%

8.5 Ethical approval

Strathmore
UNIVERSITY

8th September 2023

Ms Mkabane Cynthia Cherema,
cynthia.mkabane@strathmore.edu

Dear Ms Mkabane,

RE: Toward Improving Energy Security in Kenya via HTLS Conductors and Load Balancing

This is to inform you that SU-ISERC has reviewed and **approved** your above **SU-masters** research proposal. Your application reference number is **SU-ISERC1840/23**. The approval period is from **8th September 2023 to 7th September 2024.**

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by SU-ISERC.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to SU-ISERC within 72 hours of notification.
iv. Any changes anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to SU-ISERC within 72 hours.
v. Clearance for the export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to the expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days of completion of the study to SU-ISERC.

Before commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology, and Innovation (NACOSTI) https://research-portal.nacosti.go.ke/ and obtain other clearances needed.

Yours sincerely,

Mr Ambrose Rachier,
Chairperson; SU-ISERC

STRATHMORE UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICAL REVIEW COMMITTEE
(SU-ISERC)
08-Sep-2023
Email:ethicsreview@strathmore.edu
P.O BOX 59857-00200
NAIROBI-KENYA

Ole Sangale Rd, Madaraka Estate. PO Box 59857-00200, Nairobi, Kenya. Tel +254 (0)703 034000
Email admissions@strathmore.edu www.strathmore.edu

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **756597**

Date of Issue: **16/September/2023**

RESEARCH LICENSE

This is to Certify that Miss.. Cynthia Cherema Mkabane of Strathmore University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nairobi on the topic: Toward Improving Energy Security in Kenya via HTLS Conductors and Load Balancing for the period ending : 16/September/2024.

License No: **NACOSTI/P/23/29603**

756597

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions