UNIVERSITY OF NAIROBI

DEPARTMENT OF MECHANICAL & MANUFACTURING ENGINEERING

MSC (ENERGY MANAGEMENT)

VOLTAGE STABILITY IMPROVEMENT BY CONSTRUCTION OF PARALLEL TRANSMISSION LINES (CASE STUDY – WESTERN KENYA REGION)

RICHARD OCHIENG OBUMBA

Registration No: F56/12088/2018

A Project Report submitted in partial fulfillment of the degree of Master of Science in Energy Management of the University of Nairobi

Supervisors

Dr. Peter Moses Musau

Sign: Date**:** 17th November 2020

Dr. Abraham Nyete

Sign: … . Date:18/11/2020..

DECLARATION

This project report is my original work and has to the best of my knowledge not been presented before.

Signature

Date 17/11/2020

Name: Richard Ochieng Obumba

Reg No: F56/12088/2018

UNIVERSITY OF NAIROBI

Declaration of Originality Form

This form must be completed and signed for all works submitted to the University for examination.

Name of Student RICHARD OCHENG OBUMBA

Registration Number F56/12088/2018

College ARCHITECTURE AND ENGINEERING

Faculty/School/Institute ENGINEERING

Department MECHANICAL AND MANUFACTURING ENGINEERING

Course Name MASTER OF SCIENCE ENERGY MANAGEMENT

Title of the work

VOLTAGE STABILITY IMPROVEMENT BY CONSTRUCTION OF PARALLEL TRANSMISSION LINES (CASE STUDY – WESTERN KENYA REGION)

DECLARATION

1. I understand what Plagiarism is and I am aware of the University's policy in this regard
2. I declare that this Project (Thesis, project, essay, assignment, paper, report, etc) is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work, or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.
3. I have not sought or used the services of any professional agencies to produce this work
4. I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her own work
5. I understand that any false claim in respect of this work shall result in disciplinary action, in accordance with University Plagiarism Policy.

Signature

Date 12/06/2020

DEDICATION

“Do not be anxious about anything, but in everything by prayer and petition with thanksgiving, present your request to God”…. Philippians 4:6. Special thanks go to my mother Elizabeth Obumba and my siblings for their love and constant support. I wish to convey my gratitude to Dr. Peter Musau, Dr. Abraham Nyete, Celestine Kavindu and Professor Cyrus Wekesa for their support and encouragement during execution of my research. Lawrence Oduor of Kenya Power and Lighting Company (K.P.L.C) has also been very helpful towards furnishing me with data necessary for simulation of the research project.

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AC – Alternating Current……1

B/C Analysis - Benefit/Cost analysis……4

COUE – Cost of Unserved Energy……91

DC – Direct Current……1

DG – Distributed Generation……25

EIA – Environmental Impact Assessment……33

ESIA - Environmental and Social Impact Assessment ……33

FACTS – Flexible Alternating Current Transmission Systems……17

FVSI – Fast Voltage Stability Index……28

GA – Generic Algorithm……29

HVDC – High Voltage Direct Current……29

IEEE – Institute of Electrical and Electronics Engineers……54

IPSO – Improved Particle Swarm Optimization ……29

KenGen – Kenya Electricity Generating Company……47

KETRACO - Kenya Electricity Transmission Company……38

KPLC – Kenya Power and Lighting Company……35

kV – Kilo Volts……2

kWH – Kilo Watt Hour……47

LCPDP - Least Cost Power Development Plan……24

LLF - Loss Load Factor……91

LRMC - Long Run Marginal Cost……………………………………………………...91

MUSD – Million United States Dollar………………………………………………….36

MVA – Mega Volt Ampere…………………………………………………………..39

MVAr - Mega Volt Ampere (Reactive)………………………………………………...55

MW – Mega Watt…………………………………………………………………….39

O & M – Operations and Maintenance……...……………………………………..……..91

PPA – Power Purchase Agreement………………………………………………….47

pu – Per Unit…………………………………………………………………………48

RTO – Regional Transmission Organization…………………………………………...22

SCADA – Supervisory Control and Data Acquisition………………………………….....35

SIL – Surge Impedance Loading…………………………………………………45

SPEA - Strength Pareto Evolutionary Algorithm…………………………………………27

SSSC – Static Synchronous Series Compensator…………………………………………17

STATCOM – Static Synchronous Compensator…………………………………………18

SVC – Static Var Compensator………………………………………………………27

TCSC – Thyristor Controlled Series Capacitor…………………………………………27

UPFC – Unified Power Flow Controller……………………………………………….20

UVLS – Under Voltage Load Shedding……………………………………………...17

VSA – Voltage Stability Assessment…………………………………………………...29

WKR - Western Kenya Region……………………………………………………………4

ABSTRACT

An integrated power system in any given economy is anticipated to provide steady and reliable power sufficient for peak loads. Several challenges have been witnessed in diverse power grids, despite research having been widely done to augment stability and enhancement. Transmission line infrastructures or lack thereof contribute largely towards these challenges. Majority of past works have focused on inclusion of Flexible Alternating Current Transmission Systems (FACTS) devices as a means of improving voltage stability and reliability. Western Kenya Region (WKR) among other locations globally have previously experienced voltage instabilities, whereby some led to voltage collapse. This research involved studying the status of transmission lines in West Kenya region and analysis of construction of parallel transmission lines along the main transmission path into Western Kenya Region to improve regional voltage profile. Surge Impedance Loading calculations and Benefit/Cost analysis were also done to predict the maximum loading of the transmission lines and investigate the economic benefit with respect to capital cost of the project respectively. The existing transmission system of Western Kenya Region and the parallel transmission lines were modelled on an IEEE 39 Bus System and simulated using the DigSilent Powerfactory software. The results revealed that simulation of parallel transmission lines improved the bus voltages and reduced the loading of the transmission lines, therefore improving to the possibility of increasing loads into the network, which was simulated at maximum demand. Parallel transmission lines improved the region's voltage profile, where the lowest bus voltage of all the scenarios improved from 0.887pu to 0.942pu translating to an improvement of 6.2%. Power transfer capability also improved by 45.27%. The excess energy available for generation would also be put to its desired use. When loads in the future increase beyond magnitudes that present a voltage drop excessive of the threshold by over 6%, installation of capacitor banks with a minimum of 130MVAr or a suitable FACTS device would be appropriate at the bus having the weakest voltage levels, since loading of the transmission line had been significantly reduced.

Keywords:

Voltage Stability, Transmission Lines, IEEE 39 Bus System, FACTS Devices.

TABLE OF CONTENTS

Contents

CHAPTER ONE: INTRODUCTION

1.1. Background

A tremendous increase in global population has caused relative increase in power demand, whereas Transmission and Generation systems' growth have not been synchronous with this advancement. Consequently, the voltage stability is affected while augmenting losses in the system. There are several methods of refining voltage stability. Some the major methods include putting up FACTS devices and synchronous condensers, generation power plants, connecting DG systems to customers and building parallel transmission power lines to increase power transfer capabilities as well. Maintaining voltage levels for stability purposes is important because deviating voltage values may result in malfunction or damage of critical electrical equipment [65].

Transmission can be either through DC technology or AC technology. AC technology is preferable because it is easier to transform the voltages from either higher to lower values, or lower values to higher values; switching is possible due to zero current values at every half cycle; construction of tee-offs in DC technology is not possible, whereas execution of such operations in AC technology is possible and cheaper transfer of Energy for bulk Energy [49], [50].

Transmission of Electrical power certainly leads to energy losses. A sudden failure of a generation plant may deprive the system essential reactive support, and this would easily lead to voltage instability or voltage collapse [53]. The system control Engineer can use reactive power resources to increase amount of power transfer capability and maintain voltage levels at all buses within the ranges $0.95p.u \leq V \leq 1.05p.u.$ It is prudent to maintain higher voltages because this phenomenon increases the likelihood of avoiding a Voltage Collapse [53]. System sturdiness is determined by the capability of an infrastructure to function in balanced and irregular conditions, and this can be determined by the status of either the region's generation or transmission capacity. Voltage stability is the capability of power infrastructure to sustain suitable voltage magnitudes at every node within the grid. When uncontrollable decline of voltage is experienced within a system it can be said to be experiencing voltage instability [16]. A remedy against unstable voltage is to temporarily transfer the burden to the customers through load shedding [52].

Two or more transmission lines in proximity on a similar way leave route are in parallel. There is mutual capacitance or inductance between the circuits. Voltages are generally high during off peak periods, and relatively low during peak periods [29]. It is worth noting that transmission lines that are not loaded are capacitive in nature. This capacitance is distributed along the line, as opposed to the lumped cases seen in capacitor banks [63].

There are two major scenarios that may arise when addressing the issue on stability of voltage. The first one is transient voltage stability, with a very short occurrence of zero to ten seconds. For intense voltage dips, the demand of reactive power of induction motors increase, leading to voltage collapse which can be tripped by protection of relays. Integrating HVDC into a power system experiencing weak voltages contribute to transient voltage stability challenges. The second one is longer-term voltage stability, with an occurrence of two to three minutes. This scenario has a high magnitude of disturbance and massive loads, especially imports from remote generation plants. Load tap changing transformers and regulators help restore distribution power at the distribution level. This causes further voltage decay, hence causing adjacent generators to be overexcited, calling for the need of more generators to provide reactive power, which is inefficient [16].

System instability is reached when there is increase in demand of power, or a major disturbance occurs. Many at times, the system becomes incapable of meeting the reactive power demand. The aspects of voltage stability include transmission characteristics, generation profile, load characteristics and reactive compensation device characteristics. Determination of the shortest distance to instability and continuous power flow is also important [5].

There have been several instances of voltage dips, which are well documented in Kenya Power's National Control Center. Most of these cases were and are still addressed through load shedding (Appendix K) or requesting for more generation from respective generation power plants to enhance reactive power being injected into the grid. Inductive and capacitive reactor banks have been installed at strategic points in transmission substations to control voltage stability within the networks. On the 29th day of February 2020, Western Kenya Region experienced voltages of up to 116.3 kV, deviating from nominal voltage by 12%. Voltage deviation should not at any point exceed 6%. Load shedding customers was the last resort solution adopted to stabilize the voltage. There are several instances of low voltages experienced, whereby some lead to Voltage Collapse. These incidents are depicted in Table 1.1 as found in [40], [41], [42], [43] and [44].

Table 1.1: Incidents of Voltage Instability and/or Collapse

Country	**Affected Load (MW)**	**Duration of the collapse**	**Date**	**Comments**
France	9,000	7 minutes	12/01/1987	System did not collapse, but recovered by shedding off 1,500MW
Brazil and Paraguay	24,436	68 Seconds	11/11/2009	Voltage collapse after a blackout the previous day that affected 67 million people
Sweden and Denmark	6,550	-	23/09/2003	4 Million people affected
USA and Canada	63,000	39 Minutes	14/08/2003	50 million people affected, and over $4 Billion lost.
France	29,000	26 Minutes	19/12/1978	Over $200 Million lost
Greece	5,000	30 Minutes	12/07/2004	-
Japan	8,168	20 Minutes	23/07/1978	-
Chile	2,000	30 Minutes	May 1997	-
Israel	3,140	19 Minutes	08/06/1995	-
New Jersey, USA	-	3 Hours	06/07/1999	Low Voltage Condition

1.2. Problem Statement

The evacuation of growing power generation capacity has been a challenge during peak hours in many parts of the world with respect to increasing population. This has caused several homesteads to be subjected to Under Voltage Load Shedding, and industrial customers to frequently use expensive alternative sources of energy like diesel generators, which not only decreases profit of their businesses, but also contributes to negative environmental effects. The challenge of evacuating this power is majorly due to insufficient transmission line infrastructure, causing congestion on the transmission network, thus resulting in instances of voltage instability, and potentially voltage collapse. This could be because of high loading of the transmission line, long distance between the generation and consumption centers, low reactive power compensation or poor generation voltages. During peak hours, WKR faces the challenge of experiencing low voltages deviating by up to 12% from the nominal voltage of 132 kV due to overloading on the transmission line thoroughfare into the Western Kenya Region, whose total line rating is 146MVA. This means that the maximum power transferable from Nairobi Region through Naivasha is 146MVA, whereas the maximum demand of the region stands at 444MW. Generation in WKR is incapable of meeting the region's maximum demand. The existing transmission lines are indeed bottlenecks which can be resolved by expanding the transmission system infrastructure. Construction of parallel transmission line systems is beneficial in terms of improving the regional voltage profile, by lowering transmission line impedance and increasing power transfer capabilities to the region, to sufficiently supply peak loads.

1.3. Objectives

1.3.1. Main Objective

The main objective of the project was to analyze parallel construction of transmission lines as the best solution for enhancing both voltage stability and optimizing power transfer capabilities.

1.3.2. Specific Objectives

i) To investigate and analyze the capacities of present-day generation sources in Kenya.
ii) To find the Surge Impedance Loading of the long transmission lines connected in Western Kenya Region.
iii) To calculate the Benefit/Cost analysis of constructing a parallel transmission line that would improve voltage profile in Western Kenya.
iv) To analyze the voltage profile of the existing transmission lines connected to Western Kenya and the inclusion of parallel transmission lines.

1.3.3. Research Questions

i) Are present day sources of generation adequate to enable power transfer to Western Kenya Region?
ii) Is Surge Impedance Loading reflective of ample supply of power to consumers?
iii) Is implementation of the building additional transmission lines economically viable?
iv) Are the bus voltage levels of the existing transmission system in Western Kenya within acceptable voltage thresholds? How does this compare additional parallel transmission lines?

1.4. Justification of the Research

Voltage stability and availability of sustainable power in any given economy is very essential, hence calling into the need of developing solutions that would alleviate instances of voltage instability. According to IEEE, instability of voltage can cause a massive voltage collapse to a significant section of the system. Any given system may enter such a state where there is significant increase in the load or due to faulty equipment in the system.

Voltage instability can be experienced either at the transmission, generation, or the distribution level [27]. Voltage collapse has recently been on the rise in major grids, causing unnecessary damages, hence triggering system collapse in the affected areas. Losing some generation units for diverse reasons could be a contributing reason towards the collapse. Load shedding has been a traditional and bias method of trying to stabilize the system voltage. It was therefore important to conduct a research that would cushion all customers from experiencing unnecessary outages.

There are several regions in different parts of the world that experience these challenges. A good example is the Western part of Kenya, which has a few counties. Population in this region has increasingly been on the rise like several other devolved units since Promulgation of the 2010 constitution of Kenya. Due to population growth, the demand for power also increased. Kenya's power sector is divided into four regions namely Mt. Kenya, Western Kenya, Coast and Nairobi region. Power in Western Kenya, which includes North Rift, West Kenya, Central Rift and South Nyanza portrays the highest level of instability and unreliability in Kenya. They have been facing different challenges from the other regions in Kenya mentioned above. The first challenge was found to be power instability due to lack of sufficient transmission line infrastructure. This has been causing the existing transmission line to be overloaded during peak periods, triggering reactive power to be absorbed by the line, thus causing voltage to drop. The second challenge was found to be sporadic availability of Muhoroni Gas Turbine Power Plant due to technical challenges. The third challenge was found to be over-reliance on Turkwell, Sondu Miriu and Sangoro Hydroelectric Power Plants which have been incapable of producing sufficient energy when hydrology is low. The challenges above therefore informed the decision on the need to study the best alternatives of improving voltage stability which in this case was introduction of parallel transmission lines to the existing ones connected to the Western Region.

1.5. Scope of the Research Project

In this research project, the transmission bus voltages, line ratings and lines' loading were analyzed in a modified IEEE 39 bus system. The entire transmission network of WKR totaling to 864 kms was modelled and simulated using the DigSilent Powerfactory Software. Three schedules of excitation were independently designed to investigate the performance of the region's transmission system in terms of voltage and loading of the transmission line. Each schedule comprised of six scenarios, where each scenario was analyzed separately, and results tabulated for every schedule. The six scenarios considered partial and complete inclusion and exclusion of reactive compensators, and addition of parallel transmission lines with and without reactive compensation. Voltage profile of each schedule was also plotted against the respective buses.

Schedule 1

Schedule 1 had energy generation connected to the grid from Olkaria 1, Turkwell, Uganda interconnector, Sondu and Sang'oro Power stations. The energy from Olkaria 1 contains a mix of energy from Nairobi's grid, and energy generated from Olkaria as well. The simulation gave results and loading of the transmission lines were tabulated in Table 4.1, whereas bus voltages were tabulated in Table 4.2.

Schedule 2

Schedule 2 represented generation from Olkaria 1, Turkwell, Sondu and Sang'oro. In this case, power was not being dispatched from Uganda interconnector. The simulation gave results and loading of the transmission lines were tabulated in Table 4.3, whereas bus voltages were tabulated in Table 4.4.

Schedule 3

The last schedule had Olkaria 1, Uganda interconnector, Sondu and Sangoro producing energy to the electrical grid. In this case, Turkwell power station was switched off. The simulation gave results and loading of the transmission lines were tabulated in Table 4.5, whereas bus voltages were tabulated in Table 4.6.

1.6. Organization of the Project Report

This research project consists of Five chapters. Chapter One provides the introduction, by introducing the aspect of voltage stability in general, highlighting the challenges experienced in the past. Objectives, Justification of the Research Project, and Scope of the research are also covered in this Chapter.

Chapter Two covers theory of transmission lines and transmission systems adequate for improvement of voltage, advantages and disadvantages of placement and inclusion of DG systems and its theory. The work done by previous researchers have also been extensively captured, by highlighting the scopes, methods used, and gaps identified.

Chapter Three highlights the method used in the research, formulae adequate for addressing the specific objectives and sources of data crucial for execution of the project.

Chapter Four presents the results obtained from the simulation, addresses the specific objectives by using respective formulas for Surge Impedance Loading and Benefit/Cost analysis and graphs for Voltage profile, respectively. The results are further discussed in this Chapter.

Chapter Five gives the Conclusion, Contribution and Recommendations for further work in line with the voltage stability improvement.

CHAPTER TWO: LITERATURE REVIEW

2.1. Transmission Systems for Voltage Improvement

Transmission lines consist of infrastructure that carry electric power from power producing plants to substations that deliver power to the load, while a generation power plant is an industrial facility with one or more generators that convert mechanical power into electrical power [4], [10]. The electrical transmission system can be said to be self-regulating, in the sense that if load is more than generation, then the load must reduce significantly, to take care of the transmission losses. When power production is more than the consumers' usage, the power flows to areas with lower generation. There are three major factors that contribute towards the limitation of transferring power to load areas. These are [5]:

i) Overhead line thermal capability

The functions affecting the thermal capability include weather conditions like the wind and ground clearance. It is imperative to therefore design projects based on loss evaluation. Several approaches like uprating the transmission line conductors or adding another circuit could be adapted to address such eventualities.

ii) Dielectric Capability

The nominal voltage rating of a line should not exceed 10%. Care therefore must be taken, which means that power cannot be transferred in extreme conditions. FACTS technology may be adapted to increase the transfer capability.

iii) Stability

Stability issues that limit the transmission capability include:

  i) Voltage collapse
  ii) Transient stability
  iii) Frequency Collapse
  iv) Dynamic stability
  v) Steady state stability

Power system stability indicates the capability of a power system to regain a state of equilibrium after being subjected to a physical disruption, with maximum binding of variables to maintain system integrity [61].

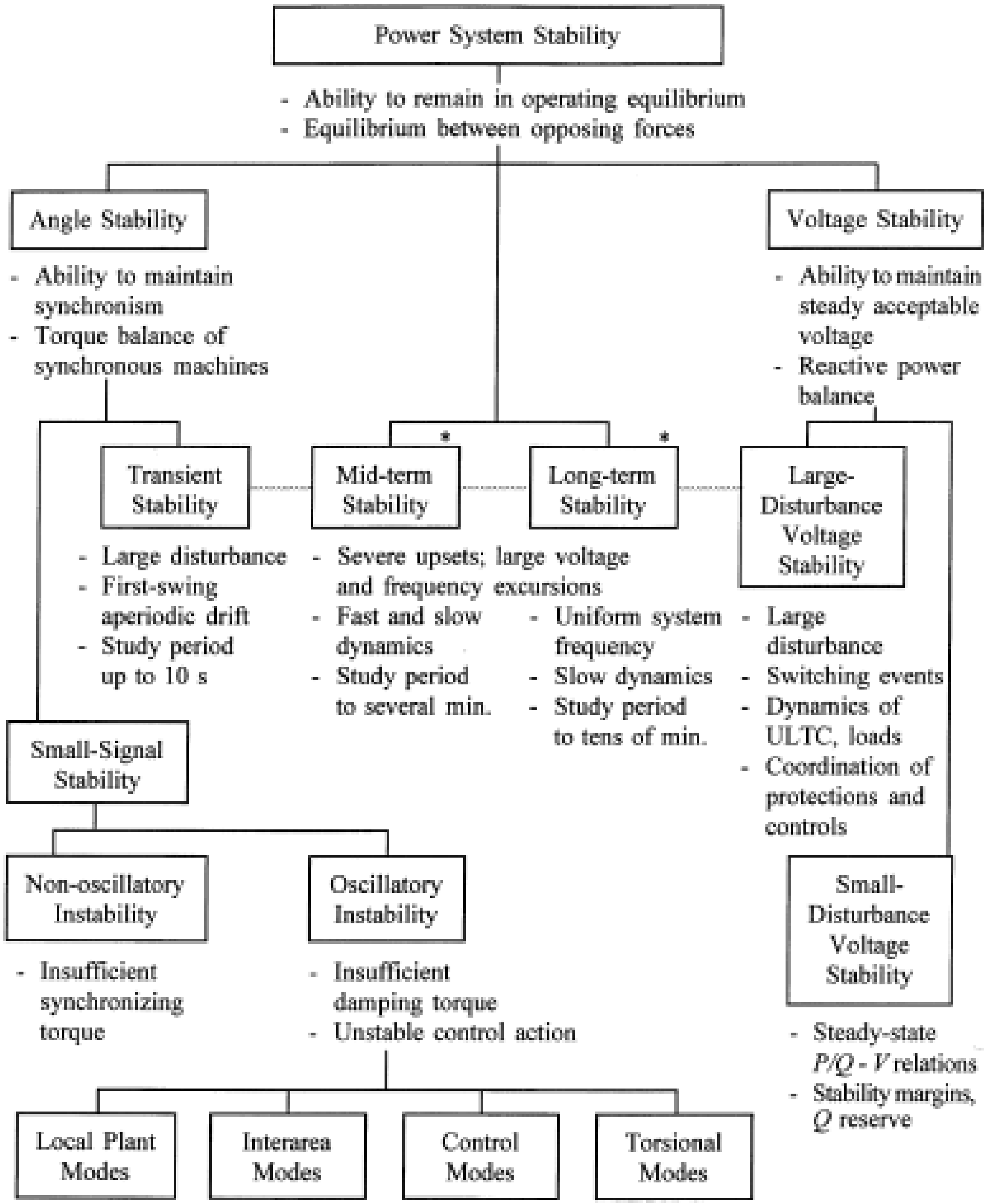


Figure 2.1: Power System Stability Classification [5]

Execution of transmission line projects are vital in the sense that they not only provide system reliability by increasing power transfer capabilities, but also spur economic development regions in question [29].

Transmission interconnections are vital in the sense that load diversity can be well addressed, and increased source options is made possible. For many expansion capacity needs, building of new transmission lines may be necessary [66]. Parallel transmission lines share the same pylons and wayleave route. The voltages of these circuits can be similar or not [36]. The reactance in a transmission line can be reduced by introducing more transmission lines in parallel [30].

Transmission line distances can be represented by specific lumped parameters and classified as either Short Transmission lines, Medium range transmission lines or long transmission lines. If a line has a significantly low value of shunt capacitance, the line may be described as a short line. Lines which are about 80 kms long or less are short lines, whereas transmission lines having a distance that range between 80 kms and 240 kms are considered medium-length lines. Transmission lines longer than 240 kms are referred to as long transmission lines, which require calculations as distributed constants for high degrees of accuracy [31].

Transmission lines possess four main characteristics. These are *series resistance*, in the form of conductor resistivity; *shunt conductance* in the form of leakage currents between phases and ground and corona effect; *series inductance*, L in the form of magnetic field around every conductor, and *shunt capacitance* in the form of electric fields between the conductors [5].

Figure 2.2 represents the basic flow of alternating current in transmission lines. The transmission characteristics of interest are the load power, load voltage and injected reactive power. Overhead transmission lines are predominantly inductive, thus analysis done using reactance, X and load angle, δ [5].

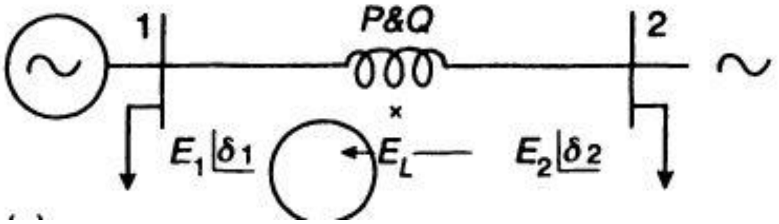


Figure 2.2: Basic transmission line System

The real current component at the generation end is given by:

$$I_{P1} = \frac{E_2}{Z_{LN}} Sin\delta \tag{2.01}$$

The reactive current component at the generation end is given by:

$$I_{Q1} = \frac{(E_1 - E_2 Cos\delta)}{Z_{LN}} \tag{2.02}$$

Active Power therefore becomes

$$P_1 = E_1 \times I_{P1} = E_1 (\frac{E_2}{Z_{LN}} Sin\delta) \tag{2.03}$$

Similarly, the reactive power is given by:

$$Q_1 = E_1 \times I_{Q1} = E_1 \frac{(E_1 - E_2 Cos\delta)}{Z_{LN}} \tag{2.04}$$

The receiving end equations can also be expressed in terms of either active or reactive components. The active component of current at the load end is given by:

$$I_{P2} = \frac{E_1}{Z_{LN}} Sin\delta \tag{2.05}$$

The reactive component of current at the load end is given by:

$$I_{Q2} = \frac{(E_2 - E_1 Cos\delta)}{Z_{LN}} \tag{2.06}$$

Active Power therefore becomes

$$P_2 = E_2 \times I_{P2} = E_2 (\frac{E_1}{Z_{LN}} Sin\delta) \tag{2.07}$$

Similarly, the reactive power is given by

$$Q_2 = E_2 \times I_{Q2} = E_2 \frac{(E_2 - E_1 Cos\delta)}{Z_{LN}} \tag{2.08}$$

From the expressions, it is ideally clear that the generated power is equal to power at the load end, since it is assumed that there are no transmission losses. It may be given by:

$$P = P_1 = P_2 = E_1\left(\frac{E_2}{Z_{LN}} Sin\delta\right) \tag{2.09}$$

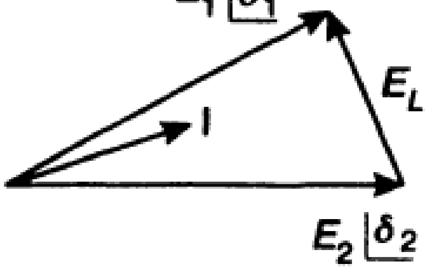


Figure 2.3: Flow of current perpendicular to the Source Voltage

The value of Z_{LN} in equations (2.04), (2.08) and (2.09) can be manipulated to give a desired output of reactive generation power, reactive load power or generation power respectively. The value of Z_{LN} is inversely proportional to both active and reactive power and can be expressed as in equation (2.10) and (2.11).

$$Z_{LN} = E_2 \frac{(E_2 - E_1 Cos\delta)}{Q_2} \tag{2.10}$$

$$Z_{LN} = E_1\left(\frac{E_2}{P} Sin\delta\right) \tag{2.11}$$

Having transmission lines in parallel lowers the impedance significantly and can be expressed mathematically. Total impedance, Z_T of n number of transmission lines is given by:

$$Z_T = \left[\sum_{k=1}^{n} \left\{\frac{1}{Z_k}\right\}\right]^{-1} \tag{2.12}$$

Figure 2.4 is a representation of a simple radial transmission system, depicting the power, current and voltage at the receiving end. These parameters are represented as functions of load demand [5]. The parameters of importance are generated power (P_R), reactive power injected (Q_I) and most importantly, receiving end Voltage (V_R) [5].

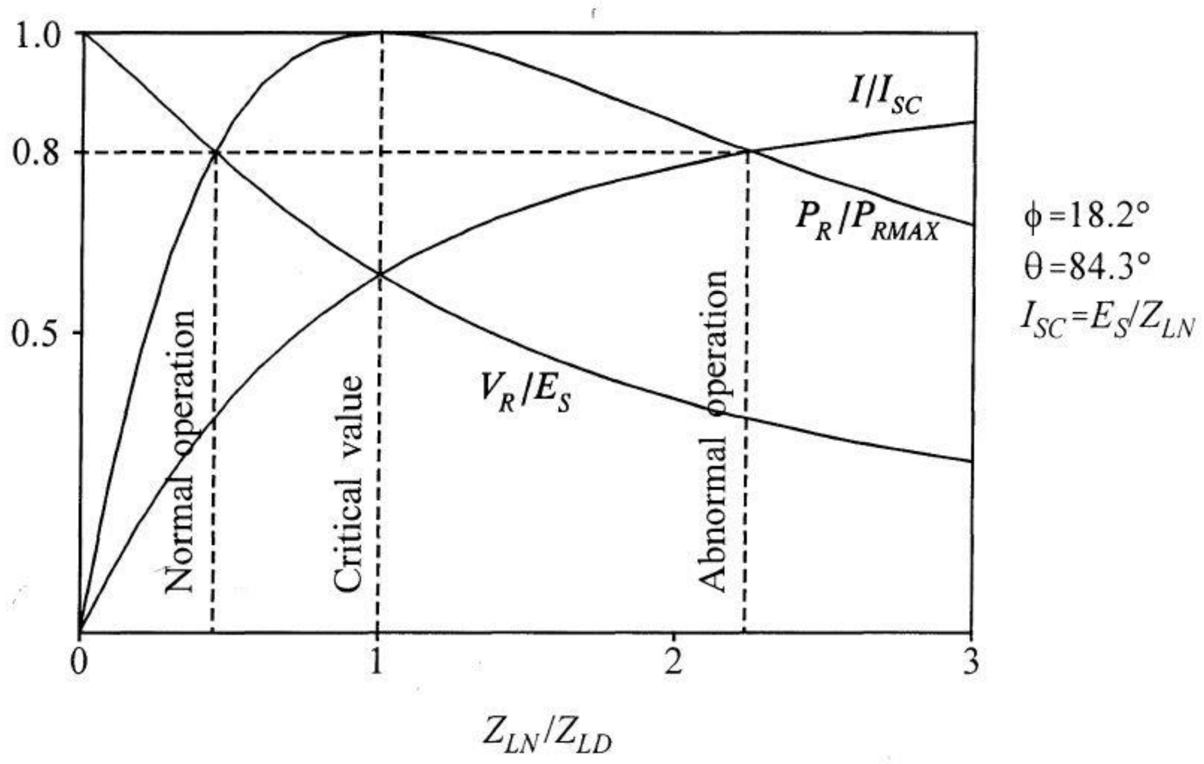


Figure 2.4: Simple Radial System [5]

For a two terminal transmission system with a source voltage, E_S, series impedance Z_{LN} and load Z_{LD}, Figure 2.4 refers.

The current, I, flowing through the network is given by

$$I = \frac{1}{\sqrt{F}}\frac{E_S}{Z_{LN}} \qquad (2.13)$$

Where F is a constant, given by

$$F = 1 + \left(\frac{Z_{LD}}{Z_{LN}}\right)^2 + 2\left(\frac{Z_{LD}}{Z_{LN}}\right) Cos(\theta - \emptyset)$$

Receiving end voltage is given by

$$V_R = Z_{LD}.I = \frac{Z_{LD}}{\sqrt{F}}\frac{E_S}{Z_{LN}} \qquad (2.14)$$

The power at the load is therefore expressed as

$$P_R = V_R . I . Cos\emptyset = \left[\frac{Z_{LD}}{\sqrt{F}} \frac{E_S}{Z_{LN}}\right] . \left[\frac{1}{\sqrt{F}} \frac{E_S}{Z_{LN}}\right] Cos\emptyset$$

$$P_R = \left(\frac{Z_{LD}}{F}\right)\left(\frac{E_S}{Z_{LN}}\right)^2 Cos\emptyset \qquad (2.15)$$

Parallel transmission lowers the line impedance, Z_{LN}, to increase the voltage for stability purposes. From the graph in Figure 2.4, the value of Z_{LN} should be less than Z_{LD}, which decreases gradually as well, but due to increase in load demand. Construction of Parallel transmission lines has been considered preferable in this research. The coupling in Transmission lines is very important and should be considered when calculating series impedance and shunt admittance. Figure 2.5 represents a single line diagram of a double circuit transmission line.

Once the neutral voltage drop is lumped into voltage drops across live conductors, the live conductor voltage drop, E_P may be expressed as

$$\begin{pmatrix} E_P \\ E_P \end{pmatrix} = Z_p \begin{pmatrix} I_{P1} \\ I_{P2} \end{pmatrix} \qquad (2.16)$$

Where I_{P1} and I_{P2} are the line current vectors of line 1 and line 2.

Equation (2.16) is therefore resolved as

$$\begin{pmatrix} I_{P1} \\ I_{P2} \end{pmatrix} = Z_P^{-1} \begin{pmatrix} E_P \\ E_P \end{pmatrix} = \begin{pmatrix} [Y_A + Y_B] \\ [Y_C + Y_D] \end{pmatrix} E_P \qquad (2.17)$$

$$[I_{P1} + I_{P2}] = [Y_A + Y_B + Y_C + Y_D] E_P \qquad (2.18)$$

$$E_P = Z_{PEQ} \, [I_{P1} + I_{P2}] \qquad (2.19)$$

$$Z_{PEQ} = [Y_A + Y_B + Y_C + Y_D]^{-1} \qquad (2.20)$$

Where Z_{PEQ} is the equivalent 3 x 3 series phase impedance matrix of the double circuit line. Y_B and Y_C give an account of inductive coupling between the circuits.

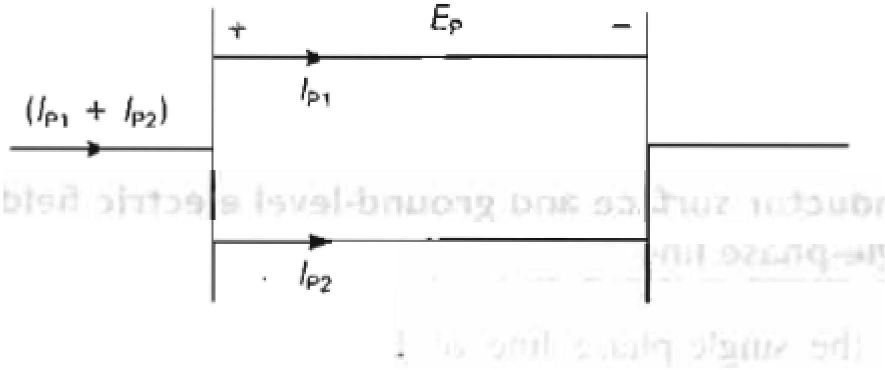


Figure 2.5: Single Line Diagram of a Double Circuit Transmission Line [29]

Transmission line loadabilty is defined as the degree of line loading, expressed as a percentage of SIL, permissible within the given the thermal voltage drop and stability limits. H. P. St. Claire introduced this concept in 1953, covering voltages between 34.5kV and 330kV. The curve shown in Figure 2.6 has been instrumental for Transmission Planning. Use of bundled conductors also contribute largely towards improving line loadability because of the concept of increasing shunt Capacitance, C, and increasing series inductance, L, which ultimately reduces the Characteristic Impedance, Z_c [5].

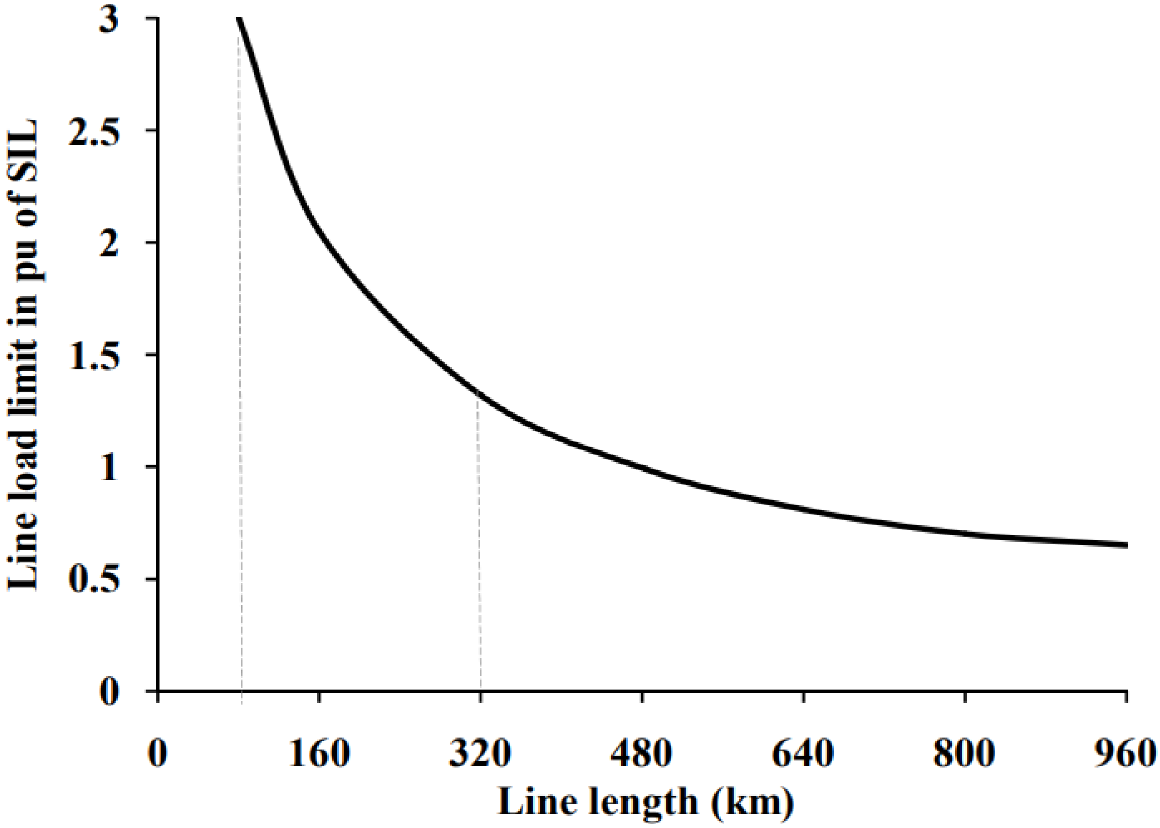


Figure 2.6: St. Clair Loadability Curve [5]

Construction of Transmission lines is a public sector project, which is defined as a system owned by the citizens in a given country, under the Government [3]. B/C analysis was initially developed by the United States Congress to introduce objectivity, and in that case commend the Food Control Act in 1936. [3].

Poor voltage performance is mostly experienced in unstable cases of angle and voltage stability. Having a transient behaviour where voltage trajectories are maintained to a certain level is important, because unnecessary triggering of protection devices is minimized [38]. Different transmission systems can be used to stabilize the voltage profile of a region. One of the systems would be construction of additional transmission lines in parallel, to ensure the line is not loaded below SIL. This strategy falls under transmission system reinforcement [45].

Capacitor series compensation can be used to diminish reactive inductance which is higher in overhead transmission lines than underground cables. Series Capacitors are in most cases installed at the transmission line terminals or intermediate points and tend to have little effect on lightly loaded lines. In this case, shunt capacitors would be ideal. On the other hand, shunt compensators are in most cases installed at the bus in the substations nearer to the load [12], [16].

Shunt reactors, which should have dedicated forms of protection, are connected to the transmission line mainly to compensate for capacitive reactance, and limit transient and steady state voltages. Shunt capacitors on the other hand are critical for voltage augmentation by providing a source of reactive power supply. Series capacitors are used on the transmission lines to improve power transfer capability, while series reactors are used to lower fault current that may occur on the transmission line [36], [67]. In summary, it is worth noting that compensation in transmission lines may involve use of capacitors to reduce undesirable effects of inductance or inserting inductors to reduce the capacitive effects [24].

Some analytical tools available for carrying out voltage stability assessment include long term dynamic simulation, AC contingency analysis, Optimal Power Flow, Power Voltage (P-V) and Reactive (Q-V) curves [37]. Some of the solutions necessary for ensuring voltage collapse is avoided are as follows [5]:

i) Use of reactive power compensation devices.
ii) Proper coordination of protection and control devices with respect to the system needs.
iii) Control of transformer tap changing.
iv) UVLS.
v) Automatic network Voltage control.

Static var compensators and synchronous condensers are other key elements used in voltage regulation for stability purposes. The operation and initial cost for the synchronous condensers are however not cost effective, thus making the static var compensator a viable option between the two [16]. FACTS are widely used nowadays to boost power system performance and address the need of increased transmission line capacity, hence improving the voltage levels. Instead of constructing new transmission lines, FACTS can be installed onto the existing transmission lines, either in series or shunt [2]. The shunt FACTS are SVC and STATCOM, while the series FACTS devices include SSSC and TCSC. UPFC is a mixture of both shunt and series compensators. TCSC is a thyristor-based FACTS that uses silicon to control them by managing series connection of capacitors with a given transmission line. The device can be easily turned on but cannot be manually turned off. The current must first be reduced to zero, and then fired at a particular firing angle.

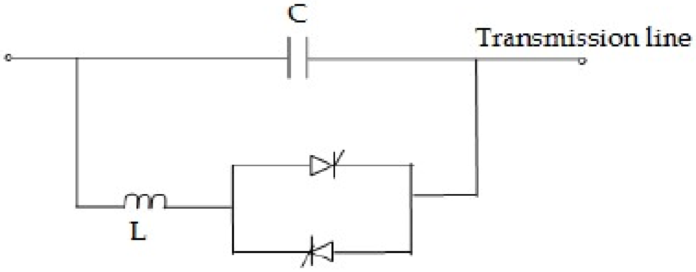


Figure 2.7: TCSC Basic Circuit [2]

SSSC is DC capacitor Voltage source-based FACTS that has an ability of injecting an almost perfect voltage sine wave in series with the transmission line, that could either be inductive or capacitive.

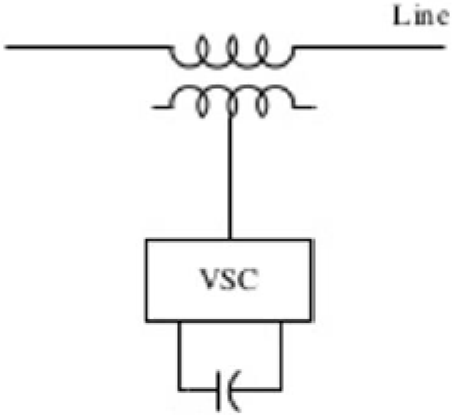


Figure 2.8: SSSC Basic Structure [2]

STATCOM is also a voltage source convertor-based FACTS device used to improve a system with poor regulation of voltage and low power factor. The device has a high response speed, and conveniently small in nature, with low harmonic pollution. The voltage source is based on a DC capacitor, hence low capability of active power. Its ability to be used in voltage stability is premised on its constant current characteristics, which can hardly be affected, regardless of the voltage magnitude.

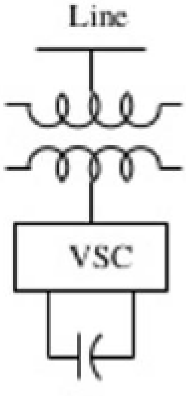


Figure 2.9: Basic STATCOM Structure [2]

Static VAR compensator is a thyristor-based FACTS consisting of a thyristor switch monitoring the reactor and/or shunt capacitor bank.

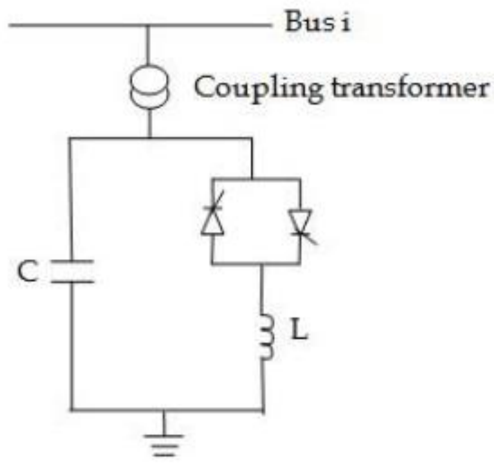


Figure 2.10: SVC Basic Circuit [2]

UPFC is a composite voltage source-based FACTS device consisting of both SSSC and STATCOM. It has the ability of providing real time monitoring of transmission line characteristics like line impedance, phase angle and the nodal voltages. They are unique and powerful, but also very expensive.

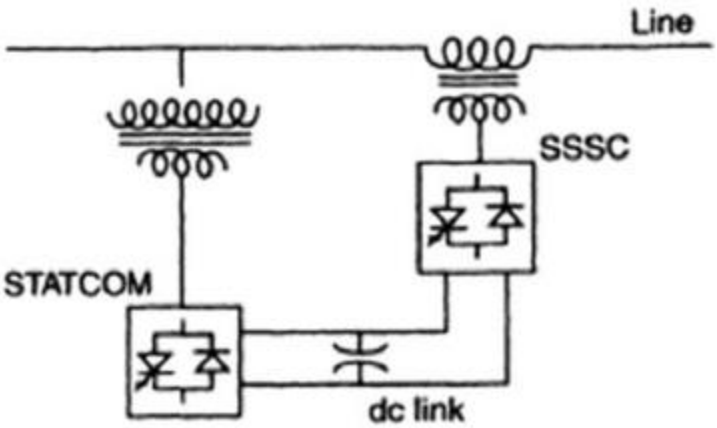


Figure 2.11: UPFC Basic Design [2]

Series compensation raises the effective SIL, while shunt compensation effectively lowers the SIL. A transmission line can have both series and shunt compensation, so that imaginary power can be balanced either by augmenting or reducing the SIL [16]. The natural load ${P_0}'$ can be derived as:

$${P_0}' = P_0\sqrt{\frac{1-K_{sh}}{1-K_{se}}} \tag{2.21}$$

Where

K_{sh} is shunt compensation degree and K_{se} is series compensation degree.

Natural load, ${P_0}'$ and Characteristic impedance, ${Z_0}'$ of an ideal line are directly proportional, and the line angle, θ and the phase constant, β are in direct proportion as well. The line angle is expressed as:

$$\theta' = \theta(\sqrt{1-k_{se}})(\sqrt{1-k_{sh}}) \tag{2.22}$$

The performance of a transmission line is decided by the Characteristic Impedance, Z_0, line distance, *l* and line angle, θ. Compensation helps to modify these parameters so as to get a desired voltage profile and power transfer characteristics. In an ideal situation or conventional transmission line, assuming zero losses and no compensation, the following expressions would suffice [46], [72].

$$Z_0 = \frac{\sqrt{L}}{\sqrt{C}} = \frac{\sqrt{x_L}}{\sqrt{b_C}} = \frac{\sqrt{X_L}}{\sqrt{B_C}} \tag{2.23}$$

and

$$\theta = \beta l$$

$$\beta = \omega\sqrt{LC} = \sqrt{x_L b_C} = \frac{\sqrt{X_L B_C}}{l}$$

Where

L = Series Inductance per unit length

C = Shunt Capacitance per unit length

b_C = Shunt Capacitive Susceptance per unit length

X_L = Total Series inductive Reactance

B_C= Total Shunt Capacitive Susceptance

l = Transmission line length

β = phase constant

Z_0 of a transmission line is described in terms of SIL or ideal loading. SIL is the power loading at which imaginary power is neither generated nor absorbed or generated power is equivalent to consumed power. The current and voltage should be uniform and not out of phase anywhere along the line. For a uniformly distributed series capacitive compensation of c_{se} per unit length, the effective series reactance is given by: -

$$x_L' = x_L - \frac{1}{\omega c_{se}} = x_L - x_{Cse} = x_L(1 - k_{se}) \tag{2.24}$$

Where $k_{se} = \frac{x_{Cse}}{x_L}$

The effective values of Z_0 and phase constant with series compensation are related to the uncompensated values as shown in Equation (2.25) and Equation (2.26).

$$Z_0{}' = Z_0\sqrt{1 - k_{se}} \tag{2.25}$$

And $\beta' = \beta(\sqrt{1 - k_{se}})$ (2.26)

When considering having both series and shunt compensation, the equations are therefore expressed as shown in Equation (2.27) and Equation (2.28).

$$Z_0{}' = \frac{Z_0\sqrt{1-k_{se}}}{\sqrt{1-k_{sh}}} \qquad (2.27)$$

and

$$\beta' = \beta(\sqrt{1-k_{se}})(\sqrt{1-k_{sh}}) \qquad (2.28)$$

For a uniformly distributed shunt compensation having a susceptance of b_{sh} per unit, the effective shunt susceptance is expressed as

$$b_C' = b_C - b_{sh} = b_C(1-k_{sh}) \qquad (2.29)$$

Where $k_{sh} = \frac{b_{sh}}{b_C}$

The effective values of Z_0 and phase constant with shunt compensation are related to the uncompensated values as shown in equations (2.30) and (2.31).

$$Z_0{}' = \frac{Z_0}{\sqrt{1-k_{sh}}} \qquad (2.30)$$

And $\beta' = \beta(\sqrt{1-k_{sh}})$ (2.31)

SIL is expressed as shown in equation (2.32).

$$P_0 = SIL = \frac{V_{LL}{}^2}{Z_0} \qquad (2.32)$$

Where V_{LL} is the voltage between two phases of the transmission line.

Each Transmission System Operator (TSO) in Germany must ensure Voltage stability in their controlled area involving Transmission and all the critical electrical components within specific boundary areas [69]. Transmission planning is nowadays more complicated, and therefore an RTO approach is a potential process to adapt when such a need arises. Figure 2.12 depicts an overview of this process where recognition of the purpose should be the initial step, ensued by a detailed analysis of the current energy situation of the region. This step provides a platform upon which potential problems and their solutions are addressed. The third and fourth steps involve forecasting of expected circumstances many years into the future and finding transmission problems that might occur. Steps 5 and 6 evaluate a couple of alternatives that could resolve the issues highlighted above. Some of the alternatives are transmission line related, while some are not. Risk assessment is also done at that level. The seventh step abstracts the outcome of the analysis carried out in the prior steps and commends certain projects to investigate the transmission challenges discussed in step 4 [1].

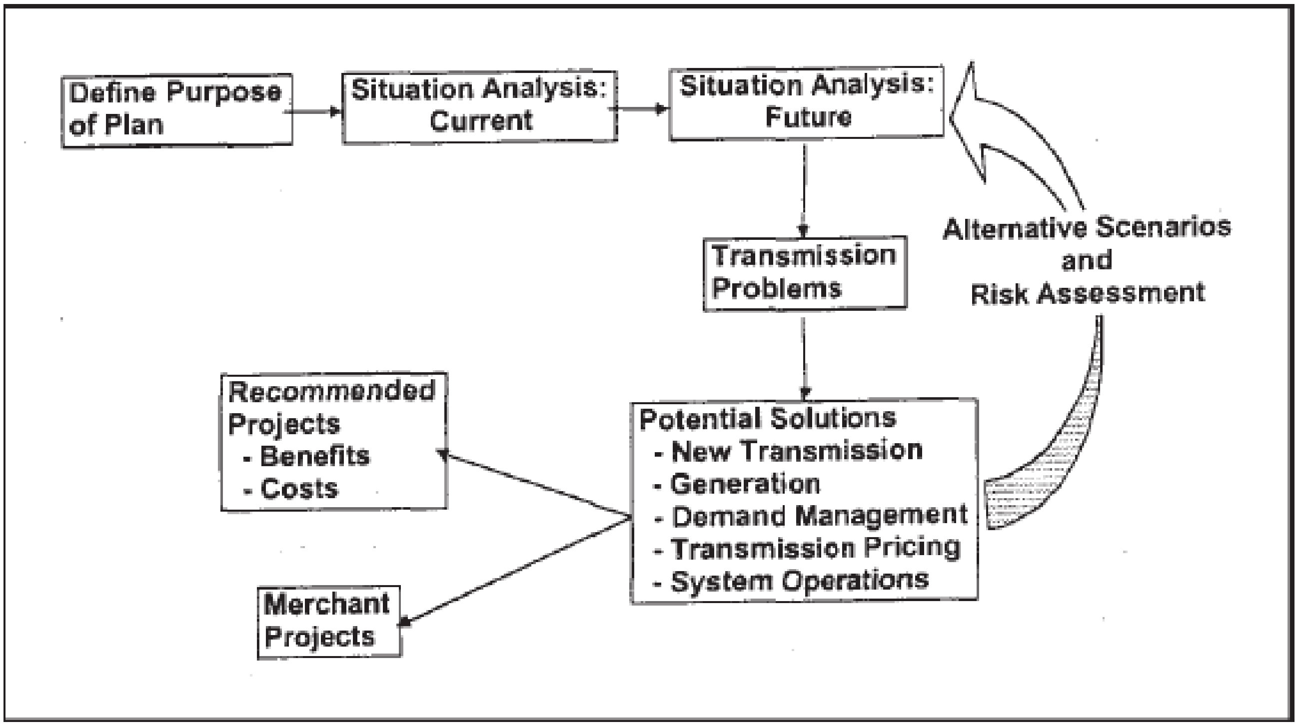


Figure 2.12: Outline of a Proposed Transmission Planning Process [1]

The technique used to compare two mutually exclusive alternatives is known as incremental B/C analysis. Public sector projects, including electrical utility projects are meant to serve the public at zero profit. There is also a possibility of analyzing the B/C for a single project. B/C analysis has an aspect of objectivity, hence reducing possibilities of political interference. If the B/C ≥ 1.0, then the project is viable economically, whereas if B/C < 1.0, then the project is unjustified [3], [60]. The B/C Analysis for a single project is expressed by: -

$$B/C = \frac{benefits - disbenefits}{costs} \tag{2.33}$$

Kenya’s transmission plan (Updated LCPDP) prepared by Lahmeyer International, who is an international consultant, took into consideration the importance of system requirements and reliability [8]. The quality of power source must meet some minimum values with respect to level of reliability and constancy of voltage and frequency. Power system controls help an operator restore a system to its normal state if the system has been disturbed [5].

Control of Real power is closely related to frequency control, and control of reactive power is closely related to voltage control [5], [69]. The frequency must be the same for suitable operation of a system. The control of voltage levels is obtained from controlling the production, absorption, and flow of imaginary power at all levels in the system [5].

Extreme system instabilities may result in cascading power black outs causing frequency decline. To prevent under frequency operation, load shedding strategies are used to lower the connected load to a level that can be simply supplied by the generation plants [5].

The prime cause of low power factor in Induction motors is due to having numerous of them running whilst not being fully loaded [6]. System capacity improvement courtesy of power factor correction permits additional loads like Motors and lighting, without causing system overload [7]. Power factor correction has several benefits like reducing electricity bills, increasing system capacity, improving system operating characteristics in terms of voltage gain and line loss reduction.

In the 1990’s, challenges in centralized supply of electrical energy emerged primarily due to exponential growth of power consumption. Pollution posed danger to the environment, due to over-reliance of fossil fuel, estimated to have contributed about 70% [16].

Energy losses are normally experienced between the generation point and consumption centers. The annual growth of demand was high, therefore initiating the need of constructing more transmission lines, which would evacuate excess energy from the available generation sources to all the load centers. The challenge was later faced by the global recognition of decentralized generation, which was renowned to contribute clean sources of energy [16].

2.2. Distributed Generation for Voltage Improvement

Distributed Generation is described as the utility of small-scale technologies to supply power to customers as depicted in Figure 2.13. Depending on the country, e may be regarded as embedded or dispersed, dependent upon the voltage levels or the capacity of the plant [10].

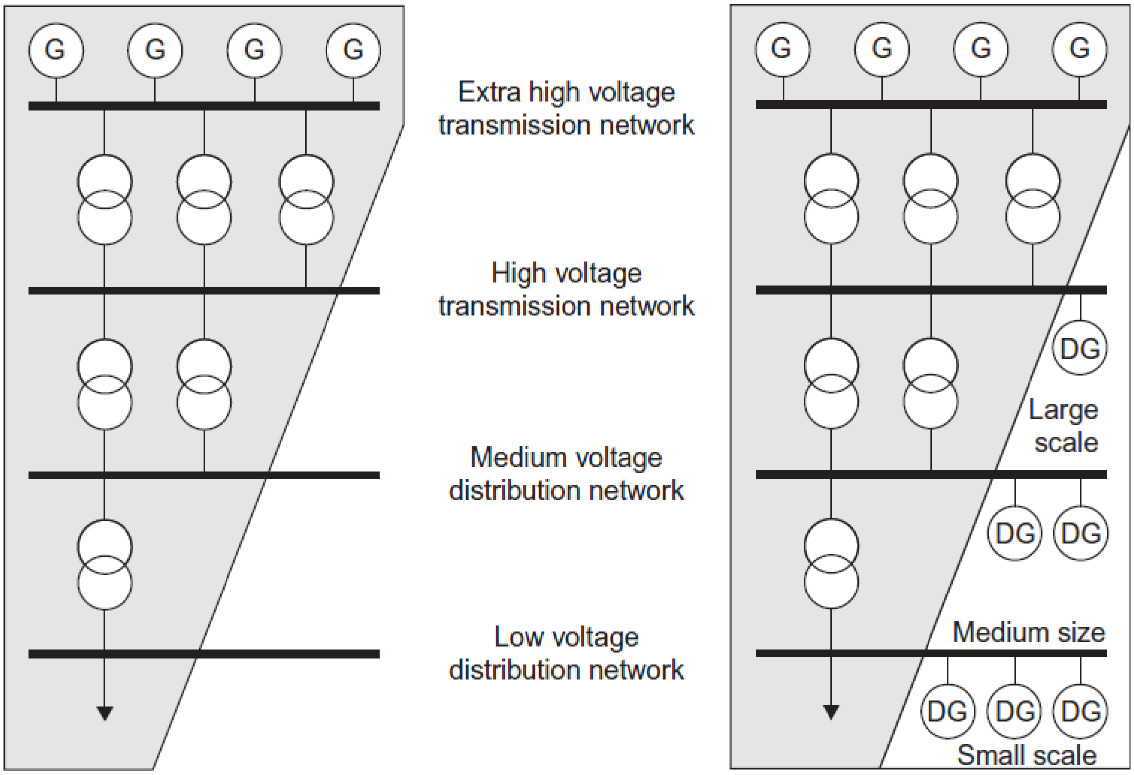


Figure 2.13: Distributed Generation Network [10]

DG can be connected to voltages ranging between 120V to 150kV. The key aspects to be looked at when considering a DG are voltage harmonic distortion and transient voltage variations. Given any scenario, the voltage quality may either decrease or increase in magnitude. In the event of a fault that may cause decrease of voltage levels, a DG over-speeds to ensure the internal protection unit operates [10]. Some studies have revealed that avoiding Transmission systems and settling for DGs would significantly resolve voltage concerns. Other studies have however revealed that additional DGs in form of renewable sources of energy like Solar Photo Voltaic would deviate frequency, due to increased sources of energy that lack rotational inertia, critical for frequency stability [73].

DG integration addresses several other challenges like mitigation of environmental pollution, improvement of power quality, enhanced reliability and protection and line loss reduction. The DGs are however very low in capacity, and consequently, the penetration levels are significantly low, between 1 to 5% [27].

Construction of Transmission lines is capital intensive in nature, and experiences losses along the line. DGs can be used as an alternative to construction of Transmission lines because it is cheaper and does not experience as much losses as transmission lines, since they are located near the consumers.

Renewable sources of energy are increasingly being used as DG systems to stabilize voltage, due to long term cost of investment and need to reduce pollution of the environment. The higher the penetration levels to the system by the DG, the higher the voltage applicable to all the buses [27]. The main disadvantages of DG networks include extreme high cost of storage to allow optimum use of power harnessed and intermittent nature of existence.

Several utility companies around the World lack adequate managerial and financial capacity. Unacceptable Voltage drops are experienced in most of these countries. These companies also shy away from investing in rural areas because the business idea does not seem lucrative for them. Due to these challenges among others, technological advancements have been developed, and several players have shown interest in entering the Renewable Energy space. One of the key dimensions of electricity supply is to ensure reliability, by checking that the systems do not deviate from acceptable voltage and frequency levels [9].

2.3. Survey of Previous Works

Several researchers have been involved in addressing the challenge of voltage instability in power systems. Most of the research work was based on compensation devices as a means of stabilizing voltage, thus providing reliable supply of power.

J.Vivekananthan and R.Karthick (2013) [11] used an IEEE 30 bus system to study Voltage improvement and reduction of power losses using the Bacterial Foraging Optimization Model, through application of three FACTS devices. A limited number of FACTS devices were considered, and an alternative of constructing a new transmission line was not considered.

P. Pavani and S. N. Singh (2014) [18] used a search-based algorithm to find the best location of a DG, to reduce losses and therefore improve reliability. Resolution of stability at the distribution level did not address transmission line voltage stability in any way, thus customers metered at high transmission voltages would remain affected.

S. Shreejith and S. P. Simon (2014) [19] conducted a B/C analysis and performance between SVC and UPFC in a Dynamic Economic Dispatch (DED). The research was limited to two FACTS devices, yet there are several FACTS devices and construction of transmission lines that could also be analyzed to justify economic viability of pursuing the project.

H. Kianersi and H. Asadi (2015) [20] used IEEE 14 bus system to simulate the voltage stability index for all the buses and SPEA algorithm for placement of TCSC and SVC. The research was limited to thyristor-based FACTS devices, without analyzing placement of parallel transmission lines stability improvement or voltage source-based FACTS devices.

A. K. Mohanty and A. K. Barik (2011) [21] highlighted the use of FACTS devices in introducing stability to heavily loaded Transmission lines. The research failed to acknowledge that additional transmission lines may improve power transfer capability and enhance stability.

S. Sonwane and P. Ghutke (2019) [22] used MATLAB simulink to design UPFC for power oscillation stability caused by load non-linearity. The study did not clearly indicate the bus system used for the simulation model.

Raihan Al-Masud et al (2019) [24] used series FACTS devices as a technique for increasing power transfer, hence improving voltage stability. The scope of compensation ranged between 10% and 85%. The research emphasized on the possibility of increasing compensation in a transmission line but did not indicate the maximum limit of compensation.

V. Komoni et al (2014) [26] used steady state voltage stability index critical in optimal DG placement with a 3-bus system for loss reduction and voltage stability. The PSS/E software used in the research was used to simulate the effect of DG installed on three buses, and a system without DG on the voltage profile of a real distribution system. The study did not consider using IEEE standards to carry out the analysis.

Mostafa et al (2016) [27] used FVSI and varying ability of the loads with two types of DG sources. FVSI reveals that the further the line and bus values are from 1 per unit, the more sensitive they are. This means that the weakest bus was selected for incorporation of the DG. Further to that, the research compares a power system without DG, one with wind power and another one with Solar PV. The researchers acknowledged that transmission also experiences voltage instabilities, yet analysis was not done at the transmission level.

S. Oketch et al (2012) [39] used the modal analysis and VQ sensitivity methods to study voltage stability in Nairobi’s distribution network. The study depicted a stable network, but the smallest eigenvalues proved that the network was not far from voltage instability. An alternative for this research gap was not given in the study.

R. M. Larik et al (2016) [52] used UVLS scheme to improve Voltage stability. A 3 machine 9 bus test system was used. This scheme had a huge demerit of not supplying peak loads. Transmission line analysis was not conducted in this research as well.

Kumaraswamy et al (2014) [54] used IEEE 6 Bus and 9 bus systems to simulate the power flow analysis of a system without inclusion of DG, and another with DG included. The PSAT software was used to analyze both scenarios and gave results. Analysis of the voltages at the transmission level was not conducted.

T. V. Muni et al (2004) [57] used the concept of simulating parallel ac and dc transmission lines, using the MATLAB simulation tool. The results displayed showed that parallel transmission improved power stability, as opposed to ac transmission alone. The research did not pursue a cost benefit analysis of parallel transmission.

C. J. Kilonzi (2014) [58] used a hybrid of GA and IPSO to optimize the location of DG by considering both real and reactive power losses in the analysis, following previous research work that has ignored the reactive components. The research work had a main objective to reduce power system losses and improve voltage profile. The research did not carry out a simulation at the transmission level.

A. Singhal and V. Ajjarapu (2017) [59] superimposed analysis of Transmission VSA and Distribution VSA, to establish which of the two contributes towards system voltage collapse. The researchers proposed the need for realistic co-simulation approach because the results revealed erroneous loadability assessments of up to 200%. Carrying out a study at the transmission level alone opts to resolve the stability issue from the source, before cascading to the distribution level.

S. Nascimento and M. M. Gouvêa (2016) [62] used the Evolutionary algorithm to optimize manipulation of variables and automation of FACTS devices to enhance voltage stability. Virtual reactive power was not analysed via inclusion of parallel transmission lines.

T. V. Cutsem et al (2002) [70] proposed a combinatorial method which performs load shedding to the most minimal level using an optimization approach. The research failed to recognize the importance of ensuring that power should sufficiently meet peak demand.

M. S. H. Lipu and T F Karim (2013) [71] used FACTS technology and HVDC as reliable methods for improving voltage stability and enhancing power transfer capability. The researchers did not consider transmission line enhancement, neither did they carry out a B/C analysis to justify the adoption of these technologies.

H. F. Khan et al (2020) [75] used MATLAB Simpower System to carry out transient and voltage stability of an IEEE 9-bus system. The research paper only analysed the response of the system whenever subjected to a fault. The voltage stability remedy was not captured in the paper.

I. Kitta et al (2019) [77] used Load flow simulation software to obtain the voltages and power losses in six scenarios. The first scenario involved simulation of the existing conditions without any additions. The second and third scenario involved addition of 275kV and 150kV, respectively. Scenario 4, 5 and 6 included 150kV transmission line and varying capacitor banks on different buses. The research paper did not touch on the loading of the transmission line.

Table 2.1: Summary of Previous Works on Stability Studies

Ref No.	**Author**	**Contribution**	**Method(s) Used**	**Research Gap**
[11]	J.Vivekananthan and R.Karthick	Used an IEEE 30 bus system to study Voltage Improvement	Bacterial Foraging Optimization Model through application of FACTS devices	Few FACTS devices were studied in the research, and transmission line design was not incorporated.
[18]	P. Pavani and S. N. Singh	Identifying the best DG location for enhanced reliability	Knowledge based Search algorithm	Non-DG customer concerns were not addressed e.g large power customers
[19]	S.Shreejith and S.P. Simon	Comparing SVC and UPFC in DED	ABC Algorithm incorporating SVC and UPFC	Limitation to two FACTS devices, without studying inclusion of more lines,
[20]	H.Kianersi and H. Asadi	Optimal placement of SVC and TCSC FACTS	Simulating IEEE 14 bus system for voltage stability index and SPEA for placement of UPFC and SVC.	The location magnitudes did not indicate the SI units of measure. The study did not consider parallel transmission lines.
[21]	A. K. Mohanty and A. K. Barik	Explanation of Thyristor based and Voltage source-based FACTS devices	Application and Technical advantages of FACTS	The economic advantages were not considered in the research paper
[22]	S.Sonwane and P. Ghutke	Simulation of voltage injection and Power flow	Using MATLAB Simulator to investigate performance of UPFC	Possibility of reviewing construction of transmission lines not analyzed.

Ref No.	Author(s)	Contribution	Method(s) Used	Research Gap
[24]	R. Al-Masud et al.	Controlling Transmission line impedance using series compensation, and increasing power transfer capability (Case Study in Bangladesh)	Use of Series FACTS devices, through MATLAB as a representation tool.	The paper failed to state that power transfer capability with respect to power demand has a limit(s).
[26]	V. Komoni, A. Lekaj et al	Analysis of the effect of DG injection on the voltage profile	Use of steady state voltage stability index critical in optimal DG placement and 3 bus system via the PSS/E software	IEEE standard of load flow analysis has not been used
[27]	M. H. Mostafa, et al	Analysis of Static Voltage Stability in wind and Solar Photovoltaic DG systems	Use of FVSI on a 15-bus system	Voltage stability analysis had not been carried out at the transmission level.
[39]	S. Oketch et al	Study voltage of Nairobi distribution network.	Modal analysis and VQ sensitivity methods	The research was limited to distribution, and an alternative of the system that was approaching instability was not established.
[52]	R. M. Larik et al	Voltage stability improvement	UVLS scheme using a 3 machine 9 bus system.	Peak demand was not considered to be sufficient, and transmission line construction alternative was not analyzed.
[54	Kumaraswamy et al	Simulation of power flow analysis of a system with and without DG	PSAT software was used	Transmission line analysis was not considered in the research
[57]	T. V. Muni et al	Simulation of parallel A.C and D.C Transmission lines	MATLAB Simulation tool	Simulation of parallel A.C Transmission lines was not done. Cost benefit analysis of the parallel transmission was also not done.
[58]	C. J. Kilonzi	Study was meant to reduce power system losses and improve voltage profile by optimizing DG location.	Hybrid of GA and IPSO	Transmission level analysis for voltage improvement was not conducted.
[59]	A.Singhal and V. Ajjarapu.	Establishment of whether Transmission VSA or Distribution VSA contributes to Voltage Collapse	Simulation using PV curve Superimposition approach	B/C analysis and transmission analysis did not appear in the research paper.

Ref No.	**Author(s)**	**Contribution**	**Method(s) Used**	**Research Gap**
[62]	S. Nascimento and M. M. Gouvea	Enhancement of Voltage Stability	Manipulating variables and automating FACTS devices using Evolutionary Algorithm	Virtual reactive power existent in parallel lines was not considered in the research.
[70]	T. V. Cutsem et al	Optimization of Load shedding scheme, to ensure minimum load is shed	Combinatorial optimization, displaying results on Hydro-Quebec System	The research did not consider importance of meeting peak demand.
[71]	M. S. H. Lipu and T. F. Karim	Voltage Stability Improvement and Power Transfer Capability	FACTS technology and HVDC	Transmission line reinforcement and B/C Analysis were not put into consideration.
[75]	H. F. Khan et al	Rotor Angle and Voltage Stability Analysis with Fault Location Identification on the IEEE 9 Bus System	IEEE 9-bus system designed and simulated using MATLAB Simpower toolbox	The solution of stabilizing the voltage for overloaded systems was not carried out in the research
[77]	I. Kitta et al	Simulation of transmission voltage profile and power losses in South Sulawesi Power System	Load flow Simulation Software	Loading capacity of the transmission line was not considered in the research.
	This Project	Voltage Stability Improvement using parallel transmission lines	Simulation of modified IEEE 39 bus system in DigSilent Powerfactory Software	Simulation of various FACTS devices at the bus with the weakest voltage at peak demand was not pursued.

Some network constraints were identified in the year 2018, including inadequate transmission capacity in Western Kenya, Central Rift and Coast regions. The recommendations made included proposal of either of the following projects to address inadequate transmission capacity in Western Kenya [8]:

i) Olkaria-Lessos-Kisumu 400kV/ 220 kV transmission line to offload Olkaria – Naivasha 132 kV line, Naivasha – Lanet- Lessos and Lessos – Muhoroni – Kisumu lines.

ii) Olkaria – Narok and Narok – Bomet 132 kV line sections to offload Muhoroni – Chemosit and improve voltage in Nyanza sub-region.

WKR's demand of power in 2037 was expected to be 705MW. It was therefore appropriate to construct transmission lines to assist offload the existing 132kV network, whose capacity totals to 146MVA. In determining voltage levels for new power evacuation lines, consideration for all power plants to be developed in any given location were be taken into account to optimize overall transmission cost [8].

An ESIA was carried out by Gibb Africa in 2009 to assist in improving reliability of the region and the country as well. The proposed line was a 220kV line, between Olkaria to Lessos. This proposal has not yet been implemented. Prior to the ESIA conducted, feasibility studies and preliminary EIA on the line was carried out by ETC East Africa Limited in 2003 [33,34]. The study gave 3 alternatives. Alternative 1 proposed execution of the Olkaria – Lessos – Kisumu line. Alternative 2 proposed pursuing a shorter route, which would be nowhere near the existing Transmission lines. The line would pass through Ndabibi and Mau forest. Alternative 3 proposed that the existing network should be left as is. The principal objective of studying the project was meant to provide reliability, by serving the increasing loads in the region. The gap identified in this research was that the previous studies did not capture the aspect of improving voltage in the region [33,34].

2.4. Chapter Conclusion

Several researchers agree that power system voltages have been a menace to the electric power systems and consumers. The studies carried out attempted to improve and/or stabilize the voltage of electric power systems. Some of the initial networks are first analyzed, to justify the need for implementing an alternative method that would contribute towards voltage stability. The major approaches reviewed were placement of DG to improve voltage levels by managing congestion at the distribution level, inclusion of different FACTS devices to improve power transfer capabilities and UVLS which is a biased and traditional method of meeting the peak demand at the transmission level. The method of additional transmission lines in the research improved both the voltage profile of the region, and power transfer capability, to evacuate excessive generated power available to the region. This method created an opportunity to fully utilize the energy generated, without necessarily constructing new generation power plants.

CHAPTER THREE: ANALYSIS AND SIMULATION OF PARALLEL TRANSMISSION LINE INCLUSION FOR VOLTAGE IMPROVEMENT

3.1. Data Analysis and Simulation

The research proposed analysis of additional transmission line infrastructure, which was modelled and simulated on DigSilent power factory software. The proposed parallel transmission lines were established from Naivasha to Lessos substation, at a voltage of 132 kV, and in proximity with the existing double circuit line. Figure 3.1 represents a block diagram which was modelled and simulated on DigSilent Powerfactory software.

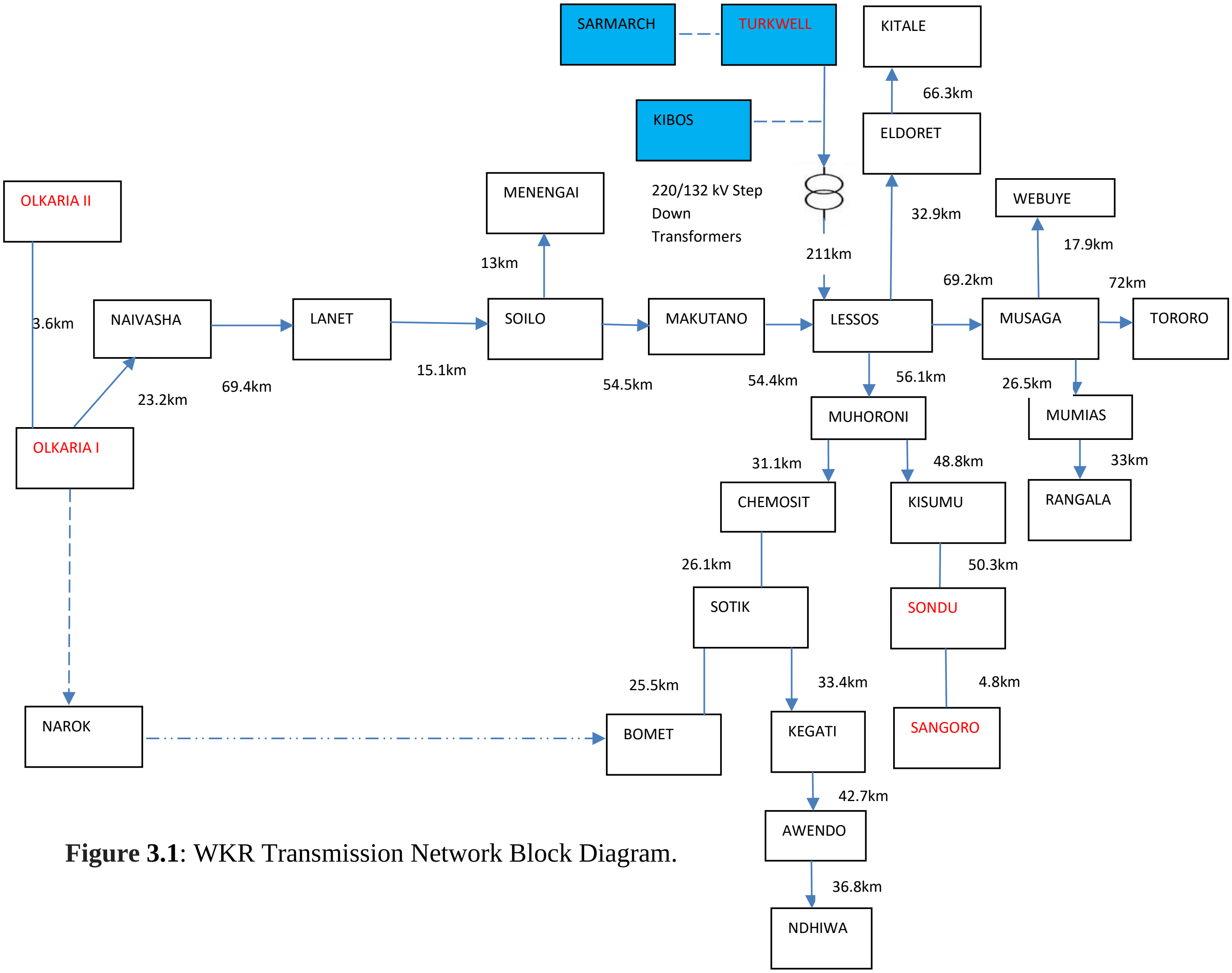


Figure 3.1: WKR Transmission Network Block Diagram.

The IEEE 39-bus 10 generator system whose diagram is given in Appendix F was modelled and simulated on the Digsilent power factory software, as depicted in Appendix H. IEEE 39-bus system was the candidate bus for the research due to the adequate number of buses and generators, sufficient to model Western Kenya Transmission network. DigSilent was chosen due to the flexible capability of designing power equipment, with informative visualization technology.

The parameters collected as data from KPLC were valuable inputs for simulation of the circuit as it currently is, and for the proposal as well. These parameters included transmission line parameters, generator parameters and maximum demand in Western Kenya Region. The collected data for the region are given in Appendix B, Appendix C and Appendix D.

There were existing proposals of additional transmission lines from Olkaria II Substation to Lessos Substation, Turkwell to Sarmach and Lessos to Kibos at voltages of 400kV and 220kV. Technical analysis reports on voltage profile improvement and B/C analysis were not issued to the public. The proposed transmission lines were meant to be stepped down and improve transfer of power to Western Kenya Region. Another transmission line was planned for construction between Narok and Bomet, and another ongoing project established in the research was construction between Olkaria 1 and Narok, each at voltages of 132kV. SCADA being the system used in monitoring and controlling automation systems was used to obtain critical information on Voltage profile of the entire network [8]. The transmission line distances were obtained from the Kenya Power's database system known as the FDB (Facilities DataBase).

The Newton – Raphson method is one of the major power flow method solutions. The other known iterative method is the Gauss Seidel method. Gauss Seidel method is the oldest method used for power flow solutions with low computer memory requirements, whereas Newton – Raphson method has a high convergence rate, suitable for massive systems. Newton – Raphson was therefore the preferable method for analysis and simulation power flow. DigSilent Power Factory simulated the load flow analysis of WKR using the Newton – Raphson approach. Newton – Raphson power flow equations are shown in Appendix E [47].

Table 3.1: Cost of Constructing proposed Transmission lines and Resettlement [34]

Transmission Line	**Length (KMS)**	**Transmission Line Cost per KM (MUSD) - Double Circuit Line**	**Wayleaves Cost per KM (MUSD)**	**Exchange Rate per Dollar**	**Total Cost (Kshs)**
Olkaria - Naivasha	21.9	0.156	0.178	106	775,347,600.00
Naivasha - Lanet	69.4	0.156	0.178	106	2,457,037,600.00
Lanet - Soilo	15.1	0.156	0.178	106	534,600,400.00
Soilo - Makutano	54.5	0.156	0.178	106	1,929,518,000.00
Makutano - Lessos	54.4	0.156	0.178	106	1,925,977,600.00
Lessos - Muhoroni	56.1	0.078	0.178	106	1,522,329,600.00
Resettlement					488,688,639.00
TOTAL					**9,633,499,439.00**

The estimated capital cost for constructing the transmission line was established and tabulated. The cost of construction the single transmission line between Lessos and Muhoroni was assumed to be 0.078 MUSD, because it is half the price of constructing a double circuit transmission line. The resettlement action plan done in 2010 had a budget estimate of 488,688,639 Kenya shillings. Allocation of the funds were divided into three. i.e. land compensation accounting for 77% of the budget, structures compensation, accounting for 22% of the budget and trees compensation accounting for 1% of the budget. The estimated capital cost of Ksh. **9,633,499,439.00** was used to analyze the B/C of implementing the project [34].

3.2. Problem Formulation

The simulation of the entire network of Western Kenya was done using DigSilent Power facory software, adopting Newton – Raphson method, which is an iterative technique for solving non-linear equations. [5]

Newton - Raphson iteration is one of the most common processes used and is known to regularly give preferable convergence properties over fixed point. [35], [64]. One major disadvantage of the Newton – Raphson method is that the J matrix must be updated after every iteration. [47]

The sub objectives required arithmetic approaches to achieve desirable results. The SIL was calculated using equation 3.1 earlier highlighted in chapter two. The Characteristic impedance was calculated after collection of available data from Kenya Power.

$$P_0 = SIL = \frac{{V_{LL}}^2}{Z_0} \qquad \text{(Computation of SIL)} \qquad (3.1)$$

The relationship between voltage and reactive power, a variable controlled to stabilize voltage is very important. The equations reviewed in chapter 2 show expressions valuable for achieving particular voltage profiles. Impedance is also inversely proportional to actual and reactive power. The lower the value of impedance, the higher the values of actual and reactive power respectively.

$$P_2 = E_2 \times I_{P2} = E_2 (\frac{E_1}{Z_{LN}} Sin\delta) \qquad \text{(Active power at the receiving end)} \qquad (3.2)$$

$$Q_2 = E_2 \times I_{Q2} = E_2 \frac{(E_2 - E_1 Cos\delta)}{Z_{LN}} \qquad \text{(Reactive power at the receiving end)} \qquad (3.3)$$

$$V_R = Z_{LD}.I = \frac{Z_{LD}}{\sqrt{F}} \frac{E_S}{Z_{LN}} \qquad \text{(Voltage at the receiving end)} \qquad (3.4)$$

$$Z_T = \left[\sum_{k=1}^{n} \left\{\frac{1}{Z_k}\right\}\right]^{-1} \qquad \text{(Total Impedance of transmission lines in parallel) [51]} \qquad (3.5)$$

The B/C analysis of implementing the project was also done, and the equation used was highlighted previously in equation (2.33).

$$B/C = \frac{benefits - disbenefits}{costs} \qquad \text{(B/C Analysis)} \qquad (3.6)$$

3.3. Source of Data

The sources of data invaluable to the execution of this research were from:

i) Kenya Power's National Control Center.

The information provided from the National Control Center included the transmission line parameters; Generator parameters; maximum demand data; load shedding data in 2018; Kenya's Generation capacity data; KPLC's Merit Order; Data on existing compensation devices; Annual demand data specifying percentage growth and relevant transmission line parameters for Western Kenya Region. This information was vital for modelling the existing network.

ii) KETRACO

The planned and ongoing transmission line projects in Kenya. The information was largely found from KETRACO's website.

iii) The Updated Least Cost Power Development Plan (LCPDP), which is a Kenyan Energy Sector Report, intended to guide the sector on low-cost energy projects.

iv) Research papers, Journals, conference papers, websites, and books.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents the simulation results for all the cases and computations of specific objectives. Data analysis and simulation using the DigSilent Power factory software was successfully done after utilization of data from KPLC. The construction of parallel transmission lines was proposed following analysis of the data presented in Appendix B, Appendix C, Appendix D and Appendix G. The annual demand data was carried out between the year 2003 and 2019, and plotted on the graphs in Appendix A. Every graph is a representation of twelve months from the beginning to the end of respective financial years.

The graphs clearly show the tremendous increase of load requirements of the region. The circuits of the Transmission lines Naivasha-Lanet-Soilo-Makutano-Lessos-Musaga-Tororo have a total rating of 146 MVA. For 0.9 power factor, the True Maximum Power that can be supplied from Olkaria as an external grid will therefore be 131.4 MW. According to Appendix D, the current maximum demand in the region currently stands at 444 MW. Assuming all the generation stations in Western Kenya are operational, then the total power that can be supplied to the load is equivalent to 420.4 MW. This power is still relatively lower than a peak demand of 444 MW.

Currently, there are over 2,000 last mile connectivity projects being executed, targeting over 150,000 customers. This means that the demand will relatively go up every month. To meet the growing demand, it would be prudent to evacuate the excess power available from Naivasha using Transmission lines. The power Generation sources in Appendix L were important sources of information, necessary to inform the decision of proposing transmission lines, instead of generation sources, as solutions for voltage improvement.

According to Appendix C, the total Generation capacity in WKR totals to 188.2MW. This contribution comes from three Hydro-electric power stations (158.2MW), and one Gas Turbine (30MW). When the hydrology is low, the region is bound to depend on 30MW, whereas the region has a capacity of transferring up to 73 MW per circuit from Nairobi region via Olkaria. The total demand for WKR as at 2018/2019 was 416MW. A parallel transmission line(s) with higher capacity therefore improves the voltage profile and availability to all consumers.

4.2. Simulation Results

Analysis was done based on three possible generation schedules and six scenarios for each schedule and tabulated. A power system operates efficiently when the line is loaded below 100%, and voltage levels admissible according to KPLC have a +/- 6% margin error of the nominal voltage. The minimum acceptable voltage should therefore be equivalent to:

$$0.94\ X\ 132kV = 124.08kV\ (0.94\text{ per unit}) \qquad (4.1)$$

Whereas the maximum acceptable voltage should be given by:

$$1.06\ X\ 132kV = 139.92kV\ (1.06\text{ per unit}) \qquad (4.2)$$

One transformer was included in the model, representing both primary and secondary transmission. The parameters were obtained from Appendix G. In each schedule, the first four scenarios were analyzed based on the existing system, while the last two scenarios were based on the proposed construction of transmission lines.

There are several schedules that may be selected when dispatching energy to the consumers via transmission lines, from generating stations. This research intended to only capture three schedules. All the schedules were simulated based on maximum demand periods only.

The additional parallel lines for the two scenarios in every schedule were two additional circuits in the same right of way of the existing transmission lines between Olkaria to Lessos, and one circuit between Lessos – Muhoroni.

Table 4.1: Loading of Transmission Lines for Schedule 1

No	BUSES	Transmission Lines	Compensators Switched off (Current Status)	Compensators Switched on (Current Status)	Capacitors switched on; Inductors switched off (Current Status)	Capacitors switched off; Inductors switched on (Current Status)	Compensators Switched off (Additional parallel lines)	Capacitors Switched on (Additional parallel lines)
1	BUS 32 TO BUS 10	Olkaria 1 - Naivasha	91.2%	83.8%	78.4%	97.6%	34.1%	28.3%
2	BUS 10 TO BUS 13	Naivasha - Lanet	66.0%	60.9%	58.4%	68.9%	36.9%	30.7%
3	BUS 13 TO BUS 14	Lanet - Soilo	45.2%	45.4%	42.4%	48.5%	27.6%	24.1%
4	BUS 14 TO BUS 15	Soilo - Makutano	34.5%	31.9%	28.2%	35.2%	22.0%	18.1%
5	BUS 15 TO BUS 16	Makutano - Lessos	24.3%	24.4%	23.5%	25.9%	17.3%	15.2%
6	BUS 16 TO BUS 21	Lessos - Muhoroni	106.4%	106.6%	104.1%	106.6%	53.4%	51.5%
7	BUS 22 TO BUS 23	Chemosit - Kegati	75.7%	65.7%	65.1%	76.3%	75.2%	64.7%

Table 4.2: Busbar Voltages for Schedule 1 in kV

No	Buses	Transmission Sub Stations	Compensators Switched off (Current Status)	Compensators Switched on (Current Status)	Capacitors switched on; Inductors switched off (Current Status)	Capacitors switched off; Inductors switched on (Current Status)	Compensators Switched off (Additional parallel lines)	Capacitors Switched on (Additional parallel lines)
1	BUS 32	Olkaria 1	132.0	132.0	132.0	132.0	132.0	132.0
2	BUS 10	Naivasha	129.9	130.2	130.4	129..7	132.1	131.4
3	BUS 13	Lanet	129.8	130.1	130.3	129.6	131.1	131.3
4	BUS 14	Soilo	129.7	129.9	130.2	129.4	131.0	131.2
5	BUS 15	Makutano	128.5	128.8	129.3	128.0	130.0	130.5
6	BUS 16	Lessos	128.9	129.1	129.9	128.1	129.7	130.5
7	BUS 21	Muhoroni	128.8	129.0	129.9	128.0	129.7	130.5
8	BUS 23	Kegati	123.0	124.6	125.9	122.2	124.0	126.2

The results in Table 4.1 clearly indicated improved loadability whereas Table 4.2 indicated voltage stability in the region after introducing parallel transmission lines. Additional load could still be accommodated in the network. Bus 23 was also analysed and tabulated, because it revealed that it experienced the lowest voltage in the entire bus system representing Western Kenya Region. The highest loading established prior to additional lines was 106.6% whereas the highest loading for the same section after simulating additional lines became 53.4%. This was a significant improvement in terms of loading.

The lowest voltage before adding transmission lines was 122.2kV (0.926 per unit) whereas the lowest voltage value after introducing transmission lines was 124.0kV (0.939 per unit). Comparing these values to the lowest acceptable per unit voltage level of 0.94, then it was evident that the additional transmission lines improved the voltages to desirable levels, including bus 23 which experienced the lowest voltages in all cases. Appendix I showed simulation of schedule 2, with all compensators switched off, prior to adding proposed parallel lines.

Table 4.3: Loading of Transmission Lines for Schedule 2

No	**Buses**	**Transmission Lines**	**Compensators Switched off (Current Status)**	**Compensators Switched on (Current Status)**	**Capacitors switched on; Inductors switched off (Current Status)**	**Capacitors switched off; Inductors switched on (Current Status)**	**Compensators Switched off (Additional parallel lines)**	**Capacitors Switched on (Additional parallel lines)**
1	BUS 32 TO BUS 10	Olkaria 1 - Naivasha	163.9%	163.2%	154.0%	175.5%	55.8%	51.7%
2	BUS 10 TO BUS 13	Naivasha - Lanet	104.7%	103.1%	98.4%	110.6%	59.5%	55.1%
3	BUS 13 TO BUS 14	Lanet - Soilo	82.3%	84.2%	79.0%	88.2%	48.5%	45.6%
4	BUS 14 TO BUS 15	Soilo - Makutano	66.0%	68.0%	62.9%	72.0%	40.5%	37.7%
5	BUS 15 TO BUS 16	Makutano - Lessos	23.9%	25.3%	22.8%	29.0%	19.1%	16.8%
6	BUS 16 TO BUS 21	Lessos - Muhoroni	110.5%	123.2%	113.0%	117.4%	53.4%	53.5%
7	BUS 22 TO BUS 23	Chemosit - Kegati	78.0%	68.7%	67.0%	79.6%	76.5%	65.8%

Table 4.4: Busbar Voltages for Schedule 2 in kV

No	Buses	Transmission Sub Stations	Compensators Switched off (Current Status)	Compensators Switched on (Current Status)	Capacitors switched on; Inductors switched off (Current Status)	Capacitors switched off; Inductors switched on (Current Status)	Compensators Switched off (Additional parallel lines)	Capacitors Switched on (Additional parallel lines)
1	BUS 32	Olkaria 1	132.0	132.0	132.0	132.0	132.0	132.0
2	BUS 10	Naivasha	129.6	129.6	130.2	129.0	131.1	131.3
3	BUS 13	Lanet	129.4	129.5	130.1	128.9	131	131.3
4	BUS 14	Soilo	129.2	129.2	129.9	128.6	130.9	131.1
5	BUS 15	Makutano	126.7	126.5	127.8	125.3	129.0	129.7
6	BUS 16	Lessos	125.5	124.9	127.2	123.2	127.7	128.9
7	BUS 21	Muhoroni	125.4	124.9	127.2	123.2	127.7	128.9
8	BUS 23	Kegati	119.5	120.2	122.7	117.1	121.9	124.4

Loading of the transmission lines was very high in every scenario of Table 4.3, except for the two scenarios whose transmission lines were added. These two scenarios had reduced loading percentages of less than 100%. This therefore meant that additional load could still be accommodated in the network. Only one scenario in Table 4.4 was in adherence to the required voltage levels. This was the scenario where the additional parallel lines with capacitor banks switched on were simulated. Voltage levels got to as low as 117.1kV (0.887 per unit) before including the proposed transmission lines. The lowest value of voltage obtained after adding the transmission lines was 121.9kV (0.923 per unit). Both values were below the required threshold of 0.94 per unit. Appendix J gave the simulation depiction of the parallel lines included in schedule 3, considering all capacitor banks switched on.

Table 4.5: Loading of Transmission Lines for Schedule 3

No	Buses	Transmission Lines	Compensators Switched off (Current Status)	Compensators Switched on (Current Status)	Capacitors switched on; Inductors switched off (Current Status)	Capacitors switched off; Inductors switched on (Current Status)	Compensators Switched off (Additional parallel lines)	Capacitors Switched on (Additional parallel lines)
1	BUS 32 TO BUS 10	Olkaria 1 - Naivasha	163.9%	163.2%	154.0%	175.5%	55.8%	51.7%
2	BUS 10 TO BUS 13	Naivasha - Lanet	104.7%	103.1%	98.4%	110.6%	59.5%	55.1%
3	BUS 13 TO BUS 14	Lanet - Soilo	82.3%	84.2%	79.0%	88.2%	48.5%	45.6%
4	BUS 14 TO BUS 15	Soilo - Makutano	66.0%	68.0%	62.9%	72.0%	40.5%	37.7%
5	BUS 15 TO BUS 16	Makutano - Lessos	23.9%	25.3%	22.8%	29.0%	19.1%	16.8%
6	BUS 16 TO BUS 21	Lessos - Muhoroni	110.5%	123.2%	113.0%	117.4%	53.4%	53.5%
7	BUS 22 TO BUS 23	Chemosit - Kegati	78.0%	68.7%	67.0%	79.6%	76.5%	65.8%

Table 4.6: Busbar Voltages for Schedule 3 in kV

No	BUSES	Transmission Sub Stations	Compensators Switched off (Current Status)	Compensators Switched on (Current Status)	Capacitors switched on; Inductors switched off (Current Status)	Capacitors switched off; Inductors switched on (Current Status)	Compensators Switched off (Additional parallel lines)	Capacitors Switched on (Additional parallel lines)
1	BUS 32	Olkaria 1	132.0	132.0	132.0	132.0	132.0	132.0
2	BUS 10	Naivasha	129.7	130.0	130.2	129.5	131.1	131.3
3	BUS 13	Lanet	129.6	129.9	130.1	129.4	131.0	131.3
4	BUS 14	Soilo	129.4	129.7	130.0	129.2	130.9	131.2
5	BUS 15	Makutano	128.0	128.2	128.8	127.5	129.7	130.2
6	BUS 16	Lessos	128.0	128.2	129.1	127.1	129.1	130.0
7	BUS 21	Muhoroni	127.9	128.2	129.1	127.1	129.1	129.9
8	BUS 23	Kegati	122.1	123.8	124.7	121.2	123.3	125.6

Simulation results in Table 4.5 shows that there was massive improvement in loading of all the transmission lines under consideration when parallel lines were added. Moreover, none of the additions depicted loading of over 80%. The highest transmission loading was 76.5%, which can still transfer additional load. Only two scenarios accomplished desirable voltage levels, with reference to Bus 23 which experienced the lowest voltages at any given schedule. The lowest voltage before adding transmission lines was 121.2kV (0.918 per unit) whereas the lowest voltage value after introducing transmission lines was 123.3kV (0.934 per unit). These values were both below the required threshold of 0.94 per unit. Additional transmission lines relatively improved the voltages of the buses under consideration as shown in Table 4.6. It is worth noting that from the simulations depicted in Appendices I and J, the critical transmission lines are red in color prior to supplementing the parallel lines, thus indicating that they were overloaded. After introduction of the parallel lines, the red color changed to black, implying enhanced loadability. Some voltages after addition of parallel transmission lines indicated were still below the admissible threshold. The results in all the scenarios showed that switching on capacitors at maximum loads raise voltages to be significantly within range.

4.3. Justification of Additional Transmission Lines

From the updated LCPDP, the installed capacity was higher than the maximum demand. From Appendix L, the total effective Capacity available for generation is 2,736MW, whereas the peak demand is 1,893MW. Numerous power plants therefore remain idle in several instances, yet consumers from Western Kenya are subjected to load shedding whenever the power system is threatened by undesirable magnitudes of voltage and/or frequency. As indicated in Appendix Q, West Kenya Region also has the highest average demand growth rate of 6.5% compared to Nairobi Region of 5.6%, Coast Region of 5.2% and Mount Kenya Region of 5.8%. This analysis is subject to Demand data provided between 2003 and 2019. These were therefore reasons enough to ensure the excess energy installed is optimally evacuated to the load centres through transmission lines.

4.4. Surge Impedance Loading

SIL of the existing transmission lines are obtained for lines above 80 kms. There are two main lines whose SIL can be calculated. One is the Turkwell – Lessos single circuit line of 218 kms while the other one is Lessos - Naivasha double circuit line of 193 kms.

Equation 2.37 in Chapter 2 was used to calculate the SIL of these three transmission lines. Substituting the voltage and surge impedance values for Turkwell – Lessos, spanning a total length of 218 kms, we get;

$$P_0 = SIL = \frac{{V_{LL}}^2}{Z_0} = \frac{220^2}{416.15} = 116.30 \text{ MW} \tag{4.1}$$

while substituting the voltage and surge impedance values for Lessos – Nakuru spanning a total length of 193 kms, then;

$$P_0 = SIL = \frac{{V_{LL}}^2}{Z_0} = \frac{132^2}{404.55} = 43.07 \text{ MW} \tag{4.2}$$

According to Figure 2.6, St. Claire loadability values for the transmission lines are 1.7 and 1.8 respectively. The power transfer capability therefore becomes;

Power Transfer Capability for Turkwell – Lessos = $116.3 \times 1.7 = 197.71\ MW$ (4.3)

Power Transfer Capability for Lessos – Nakuru = $43.07 \times 1.8 = 77.53\ MW$ (4.4)

4.5. Benefit/Cost Analysis

The Benefit/Cost ratio is beneficial towards public sector projects through introducing objectivity and justification of pursuing projects. This tool was adopted to evaluate the economic viability of pursuing the proposed transmission projects. The B/C ratio is expressed as:

$$B/C = \frac{benefits - disbenefits}{costs} \tag{4.5}$$

Where

Benefits are the Unshedded energy cost added to Energy cost not paid after decommissioning Muhoroni GT, Disbenefits equivalent to Cost of Energy Losses and Costs are equivalent to Total costs of constructing the transmission lines and resettlement action plan. The simulations did not run Muhoroni GT power plant in any of the schedules. Additional transmission lines proved the possibility of meeting maximum demand of Western Kenya comfortably without excitation from the power plant.

From Appendix K, a total load of 5,482.12 MWh of power in WKR was shed in 2018. The rate of unserved energy in KPLC is 1.5 U. S. Dollars per kWh as indicated in Appendix O. This means that the average energy that could have been saved in 2018 if the proposed project had been implemented was 5,482.12 MWh = 5,482,120 kWh. Total cost of energy saved in U. S. Dollars was $5{,}482{,}120 \times 1.5 = \$12{,}334{,}770$. Assuming this value as average, then the total cost of energy saved for 5 years would be $61,673,850.

The energy losses in appendix N in general did not reduce compared to the initial conditions. The cost of increased losses due to the proposed transmission lines based on KPLC rates was therefore given by: -

$$Cost\ of\ Energy\ Losses = Energy\ loss\ difference\ in\ kW \times LRMC\ in \frac{USD}{kWh} \times LLF \times 24\ hours\ a\ day\ \times 365\ days\ a\ year\ \times 5\ years$$

$$Cost\ of\ Energy\ Losses = 1{,}339.756kW \times \frac{0.2773USD}{kWh} \times 0.553 \times 24\ hours\ a\ day\ \times 365\ days\ a\ year \times 5 = \$8{,}998{,}597.50$$
(4.6)

According to KPLC's financial statements, the total energy purchased for financial years 2016/2017 and 2017/2018 were 108MW and 65.5MW respectively [74]. The energy that was purchased in the calendar year 2018 was 53.776 GWh, which can also be written as 53,776,000kWh. The merit order average cost of energy for Muhoroni GT was 40.314 Kenya shillings per kWh according to the merit order in Appendix M. The total cost of energy was therefore calculated and found to be 2,167,925,664 Kenya shillings, which is equivalent to $106,270,865 at an exchange rate of Ksh. 102 per dollar for 5 years. The B/C analysis over a period of 5 years was therefore found to be

$$B/C = \frac{\$61,673,850.+\$106,270,865-\$8,998,597.50}{\$89,655,007.84+\$4,791,065.09} = 1.68 \qquad (4.7)$$

The B/C analysis was calculated to give a result greater than 1, indicating that implementation of the project would be economically viable. Capacity charges have not been included due to confidentiality of the information. If Muhoroni power plant capacity charges to be paid to KenGen per year in the PPA were included in the calculation, then implementation of the proposed project would be more viable.

4.6. Voltage Profile

The nominal voltage for the area under investigation was 132kV. The voltage profile per bus was therefore plotted for the simulation results as covered in the three schedules. Under every schedule and scenario, the bus that experienced the lowest voltages at all circumstances, and the thoroughfare where the construction of the parallel transmission lines was suggested to be enhanced were analyzed and plotted.

The highest per unit value in all the schedules was 1 pu, whereas the lowest per unit values for schedule 1, schedule 2 and schedule 3 were 0.9258 pu, 0.8871 pu and 0.9182 pu respectively.

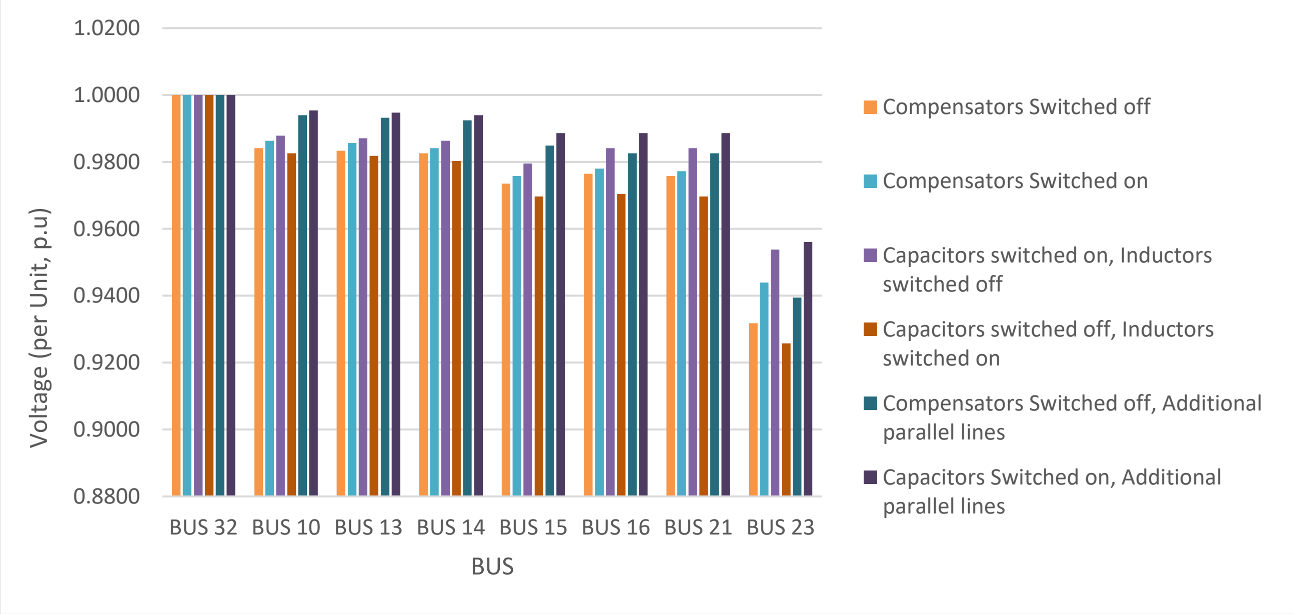


Figure 4.1: Schedule 1 Voltage Profile Bar Graph

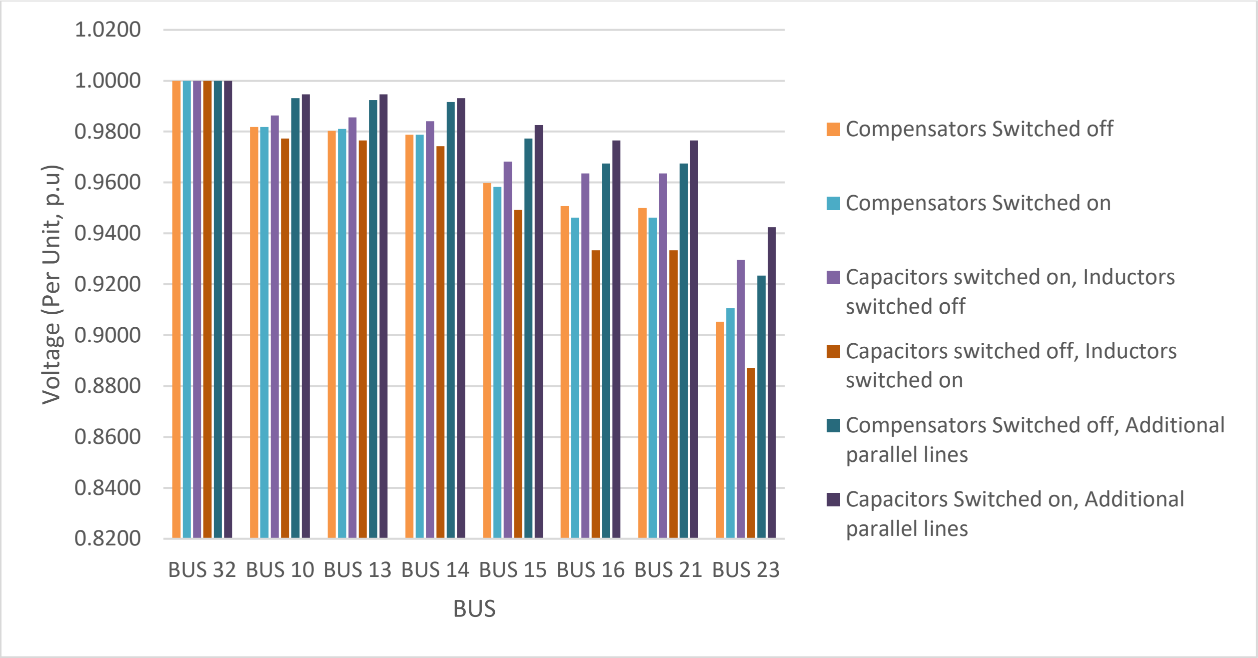


Figure 4.2: Schedule 2 Voltage Profile Bar Graph

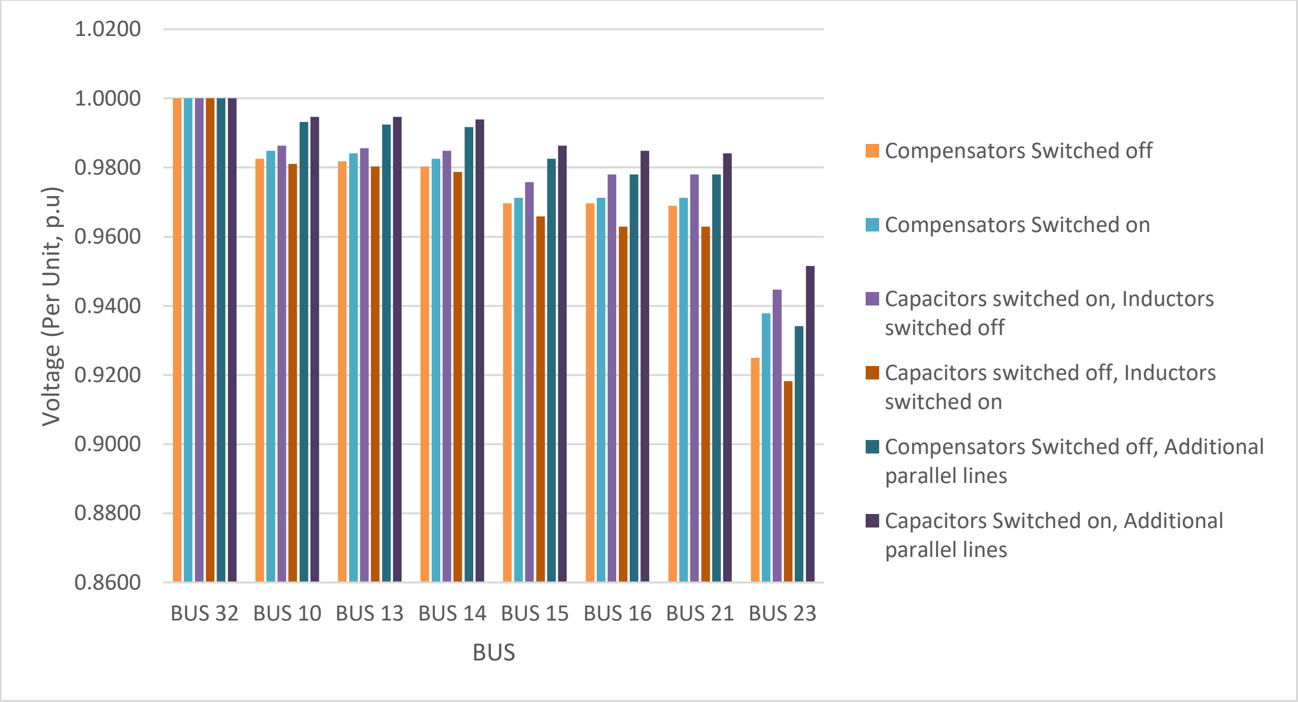


Figure 4.3: Schedule 3 Voltage Profile Bar Graph

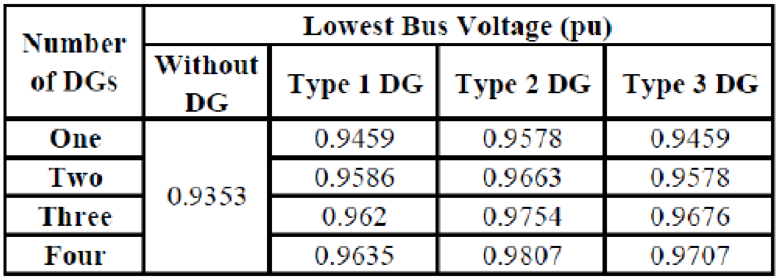
4.7. Validation

The results were a clear indication that stability of voltage and enhanced stability can well be enhanced through constructing parallel transmission lines. According to I. Kitta et al (2019) [77], insertion of 275kV transmission network in one scenario and 150kV in another showed a very slight difference of 0.0046pu in voltage profile improvement between the two. Scenario 2 which inserted 275kV improved to 0.9611pu, whereas scenario 3 which inserted 150kV improved to 0.9565pu. This slight difference justifies the advantage of proposing in this research a 132kV transmission line as opposed to a 400kV or 220kV which costs a lot more. Table 4.7 shows the obtained results for all the scenarios under study. The greatest improvement of voltages at the minimum bus voltage was from 0.9459pu to 0.9611pu giving a difference of 0.0152pu. This value was lower than the value obtained from the lowest bus voltage in this research, where the lowest bus voltage in schedule 2 equivalent to 0.8871 improved to a maximum value of 0.9424, giving a difference of 0.0553pu. this research gave a favorable improvement despite introducing a transmission line at the same voltage with the existing lines.

Table 4.7: Results of Power Flow Analysis for South Sulawesi System [77]

		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Power Gen.	MW	1058.53	1045.08	1048.65	1048.47	1048.55	1048.5
	MVar	541.98	474.09	496.74	472.65	471.06	471.93
Load	MW	1024.66	1024.66	1024.66	1024.66	1024.66	1024.66
	MVar	284.47	284.47	284.47	284.47	284.47	284.47
Losses	MW	32.87	20.42	23.99	23.81	23.89	23.84
	MVar	353.28	288.52	310.09	306.45	305.53	305.94
Bus Volt. Max.	%	100.13	100.22	100.07	100.57	100.30	100.39
Bus Volt. Min.	%	94.59	96.11	95.65	95.89	96.05	95.97

The results shown in Figure 4.4 (2014) [58] display improvement of per unit voltages from the lowest level. The voltage without DG was 0.9353pu, and the highest improved figure after introducing four DGs was 0.9807. The best value therefore improved by 0.0454pu, which is lower than the findings of this research, which had an improved margin of 0.0553pu.



Number of DGs	Lowest Bus Voltage (pu)			
	Without DG	Type 1 DG	Type 2 DG	Type 3 DG
One	0.9353	0.9459	0.9578	0.9459
Two		0.9586	0.9663	0.9578
Three		0.962	0.9754	0.9676
Four		0.9635	0.9807	0.9707

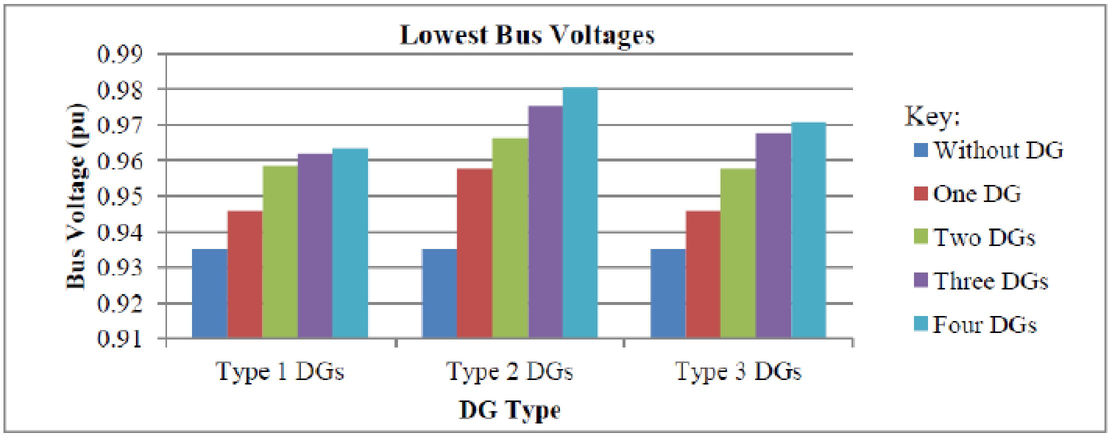


Figure 4.4: Graph of lowest bus voltages for different DG types [58]

A. Singhal and V. Ajjarapu (2017) [59] investigated the VSA of integrated transmission-distribution VSA by use of a PV curve superimposition approach. His results displayed an error of up to 200% in loadability applicable to studies carried out at the transmission level alone. The researchers further claimed Transmission Voltage Stability Assessment to be untrustworthy. This research on the other hand gave reasonable loading values when the transmission lines were analyzed without incorporating distribution systems. The improved values were all below 100%, whereas some sections of the transmission lines before adding the transmission lines displayed loading results of up to 175.5%.

In summary, Table 4.8 depicts a clear comparison of minimum bus voltages and the highest improvements at that level. This project gave the highest percentage of bus voltage improvement. The previous works attained relatively lower improved values.

Table 4.8: Comparison of Results with Previous Works

Ref No.	Author	Initial Minimum Voltage (Per Unit)	Highest Improved Minimum Voltage (Per Unit)	Difference (Per Unit)	Percentage of Voltage Improvement
[77]	I. Kitta et al	0.9459	0.9611	0.0152	1.61%
[58]	C. J. Kilonzi	0.9353	0.9807	0.0454	4.85%
	This Project	0.8871	0.9424	0.0553	6.23%

4.8. Chapter Conclusion

Simulation results sufficiently showed the ability of including the transmission lines to the grid, and importance of switching on capacitor banks. The economic analysis over a five-year period showed that building the transmission lines was economically viable, hence validating the need of implementing the project. Implementation of the project would equally assist in evacuation of bulk energy available in excess to the Western Kenya Region that has been experiencing consistent deficiencies. The high improvement of the bus with the lowest voltage compared with other researchers' was also an indication that this project is viable for implementation. Moreover, improved power transfer capability and voltage profile improvement gives stakeholders confidence to increase customers to the power grid and ensure that all peak loads are served.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. General Conclusions

In conclusion, the research work showed that the introduction of parallel transmission lines improved the voltage profile of the WKR when attempting to meet maximum demand. The improved per unit voltages were improved from values as low as 0.887pu to 0.942pu (6.2%), and values as high as 0.988pu to 0.996pu (0.81%). The simulation results also revealed the bottlenecks experienced in terms of loadability when attempting to meet peak demand. Prior to additional transmission lines, the results showed that some line sections in WKR were loaded above 100%. As shown in Appendix P, the average loading of the transmission lines in scenarios 1, 2, 3 and 4 was 80.83%, whereas average loading of transmission lines after introduction of transmission lines in scenarios 5 and 6 was 44.24%. This significant reduction improved the loadability of the transmission lines by 45.27%.

SIL was formulated, and it was evident that the obtained values of 197.71MW for 220kV Turkwell – Lessos line and 77.53MW for 132kV Lessos – Nakuru line were extremely low to load the transmission lines serving customers' maximum demand of 444MW. Due to this fact, some sections experienced loading above 100%, with a maximum loading of 175.5%. Addition of parallel transmission lines was therefore proof that loading of sections under consideration reduce remarkably while improving voltages of all the buses in the region.

Implementation of the project would be economically viable because the B/C ratio was found to be 1.68. Moreover, execution of the project would be beneficial to every individual desiring to access power, as opposed to the ongoing UVLS. The other upside of recommending implementation of the project is because the excess power available for generation would be evacuated to the load centers that require power, keeping in mind that the maximum demand in Kenya is 1893MW whereas the installed capacity is 2819MW.

5.2. Contribution

The research project demonstrated voltage improvement through construction of parallel transmission lines. The DigSilent Powerfactory software was used by modelling the WKR on an IEEE 39-Bus System, where 24 candidate buses were selected to represent the Western Kenya Region's substation buses. 5 of those buses were modeled as generation substations. The capacitor and inductor banks were also included in 6 buses as currently installed within the region. 3 different schedules of generation and 6 scenarios under each schedule were analyzed in a manner that had not been done by previous researchers. Previous researchers considered inclusion of DG systems, while others considered placement of FACTs devices. One of the works reviewed considered insertion of 275kV, 150kV and capacitor banks for voltage profile improvement and reduction of power losses. The first 4 scenarios of this research project displayed results prior to introducing parallel transmission lines, whereas the last 2 scenarios displayed results after introduction of the parallel transmission lines. Both bus bar voltages and loading of the transmission lines were analyzed and results displayed in section 4.2. This research also carried out SIL and B/C analysis of implementing the project in sections 4.4 and 4.5, respectively.

The simulations gave an accurate picture of the transmission system as currently installed. The simulation results gave a precise framework needed to improve power transfer capability and enhance voltage stability. A combination of voltage stability and enhanced power transfer capability provided a unique set of analysis that informed the impact of both elements towards stability of the power system on both peak and off-peak hours.

5.3. Recommendations for Further Work

i) Inclusion of transmission lines tend to improve power transfer capability and augment voltage levels. The lowest voltage at bus 23 was within range, but not as near as perfect. Placement of specific transmission lines and strategic capacitor banks and/or inductors therefore need to be studied for optimization of the region's voltage profile and loading of the transmission lines. A minimum of 130MVAr may be considered for installation at Bus 23 to ensure voltage is boosted to at least 1.003pu. Further studies on installing the best and economically viable FACTS device ought to be done as well.

ii) Installation of a FACTS device at bus 23 would boost the ever-suppressed voltages as seen in all the three schedules. Further studies ought to be done to ensure that transfer of power is optimized, and voltage at the distribution level is not affected.

iii) The proposed 400kV transmission line by the government between Olkaria to Lessos is expensive due to the high voltage of the network, civil engineering works and transformer installation requirements. According to this research, the simulation envisaged that additional 132kV transmission circuits would serve customers at peak loads sufficiently. The Cost Benefit viability and technical analysis need to be done based on the 220kV and 400kV transmission network proposed by the government.

BIBLIOGRAPHY

[1] A. J. Pansini, "*Transmission Line Reliability and Security*." U.S.A. The Fairmont Press and Marcel Dekker; 2004: p123-9.

[2] I. N. Muisyo, K. K. Kaberere, "*Utilization of FACTS devices in Power Systems*." Proceedings of the Sustainable Research and Innovation Conference, JKUAT Main Campus; Study Period 2nd to 4th May 2018:

[3] L. Blank, A. Tarquin, "*Engineering Economy*". 7th Edition. New York. McGraw Hill. 2012; 7: p228-235.

[4] M. Pitt. Quora. (Internet) 2013. Available from: http://www.quora.com/how-electricity-is-transmitted-from-generation-station-to-the-consumer. [Accessed 21 August 2019].

[5] P. Kundur, "*Power System Stability and Control*." Surrey. McGraw-Hill Professional. 2005: p6-15, 27-32, 200, 228-230, 250-254, 260-267, 581, 627-635, 260-263, 960-967, 1103-1161.

[6] W. C. Turner, S. Doty, "*Energy management Handbook.*" 6th edition. U.S.A. The Fairmont Press and CRC Press. 2006. p279-282.

[7] Arab Academy for Science, Technology and Maritime Transport website(www.aast.edu). Power Factor Correction and VAR Compensation. 2019. [Accessed 03 October 2019].

[8] Lahmeyer. I., "*Updated Least Cost Power Development Plan*." Study Period between 2017-2037. 2018: p106, 159, 163-165, 174-179.

[9] H. Zerriffi, "*Rural Electrification - Strategies for Distributed Generation-Springer Netherlands*." London, New York. Springer Dordrecht Heidelberg. 2011; p7-10, 31-33.

[10] N. Jenkins et al, "*Distributed Generation*." London. The Institution of Engineering and Technology; 2010: p2

[11] J. Vivekananthan1, R. Karthick, "*Voltage Stability Improvement and Reduce Power System Losses by Bacterial Foraging Optimization Based Location of FACTS devices*." International Electrical Engineering Journal (IEEJ). 2013; 4(1) :1034-1040.

[12] A. B. Onyemaechi, O. O. Isaac, "*Minimization of Power Losses in Transmission Lines.*" IOSR Journal of Electrical and Electronic Engineering. 2014; 9(3): 23-26.

[13] A. Elmitwally et al, "*Long-Term Economic Model for Allocation of FACTS Devices in Restructured Power System Integrated Wind Generation.*" Queen's University Belfast; 2016; 10(1): 19-30.

[14] A. D. Patel, "*A review of the Facts Devices for the Improvement of Transient Stability*." Global Journal of Engineering Sciences and Researches. Jabalpur Engineering College Jabalpur. 2015; 2(12) :85-89.

[15] P. Kundur, Paserba. J, Ajjarapu.V et al, "*Definition and Classification of Power System Stability*." IEEE Transactions on Power Systems; 2003.

[16] C. W. Taylor, "*Power System Voltage Stability*." U.S.A. Mcgraw-Hill; 1993:

[17] F. B. Alhasawi, J. V. Milanovic, "*Techno-Economic Contribution of FACTS Devices to the Operation of Power Systems with High Level of Wind Power Integration.*" IEEE Transactions on Power Systems. August 2012. 27(3). 1414-1421.

[18] P. Pavani, "*Placement of DG for reliability improvement and loss minimization with reconfiguration of radial distribution systems*." International Journal on Energy Sector Management; 2014.

[19] S. Shreejith, S.P. Simon, "*Cost benefit analysis on SVC and UPFC in a dynamic economic dispatch problem*." International Journal on Energy Sector Management; 2014; 8(3): 395-428.

[20] H. Kianersi, H. Asadi, "*Voltage Stability Improvement by Using FACTS Elements with Economic Consideration*." Ciência e Natura. 2015. 37(2). 162-167.

[21] A. K. Mohanty, A. K. Barik, "*Power system stability using FACTS devices.*" International Journal of Modern Engineering Research; 2011;1(2) :666-672.

[22] S. Sonwane, P. Ghutke, "*Power Upgrading of Transmission Line by Combining AC-DC Transmission and Analysis of UPFC*." International Journal of Trend in Scientific Research and Development; May-June 2019; 3(4): 387-389.

[23] KETRACO Website, "https://www.ketraco.co.ke/projects/index.html ." [Accessed 15 April 2020].

[24] R. Al-masud, Islam. M et al, "*Capacity Enhancement and Voltage Stability Improvement of Power Transmission Line by Series Compensation*." EAI Endorsed Transactions; March 2019: p1-10.

[25] N. G. Hingoranl, L. Gyigyi, "*Understanding FACTS*." IEEE Press December 1999.

[26] V. S. Komoni et al, “*Impact of Distributed Generation on Voltage Stability and Reduce Losses in Power Systems*.” ResearchGate; November 2014.

[27] M. H. Mostafa, M. A. Elshahed et al, “*Power Flow Study & Voltage Stability Analysis for Radial System with Distributed Generation*.” ResearchGate; January 2016. Volume 138

[28] Manitoba HVDC research Center, “*PSCAD IEEE 39 Bus system*”. Manitoba Hydro International. May 22nd, 2018.

[29] J. D. Glover, M. S. Sarma et al, “*Power System Analysis and Design*”. 4th Edition; U.S.A. Chris Carson, 2008. p213-214, 229.

[30] L. Grigsby, “*Power System Stability and Control*”. CRC Press. Taylor and Francis Group; 2007. p119.

[31] J. Grainger, W. D. Stevenson, “*Power System Analysis*”. Singapore. McGraw Hill; 1994. p195.

[32] Siemens, “*Analytical Methods for Voltage Control and Reactive Power Planning Course*.” Siemens Power Technologies International; April 2013.

[33] Gibb Africa Limited, “*Environmental and Social Impact Assessment of the proposed Kisumu-Lessos-Olkaria Transmission Line Upgrading Project*.” December 2009 p1-1 to 1-9.

[34] Eco Plan Management Limited, “*KPLC Resettlement Action Plan*.” March 2010 p1-6, 118.

[35] M. L. Crow, “*Computational Methods for Electric Power Systems*.” CRC Press, Taylor and Francis Group, 2nd Edition. 2010. p53

[36] Power Systems Relaying Committee of the IEEE Power Engineering Society, “*IEEE Guide for Protective Relay Applications to Transmission Lines*.” 16th September 1999; p28-30.

[37] R. Austria et al, “*Voltage Stability Assessment of the National Grid using modern analytical tools*,” ResearchGate, February 2001. 229-234

[38] F. Milano, “*Advances in Power System Modelling, Control and Stability Analysis*.” The Institution of Engineering Technology; 2016; p175.

[39] S. Oketch, K, Kaberere et al, “*Voltage Stability Analysis of Nairobi Area Power Distribution Network.*” ResearchGate; August 2012.

[40] M. Glavic, D, Novosel, “*Voltage Stability Monitoring, Instability Detection and Control.*” U.S.A. Quanta Technology; May 2011; p6.

[41] (Internet), “*The 10 Worst blackouts of the last 50 years.*” Available Online from: https://www.power-technology.com/features/featurethe-10-worst-blackouts-in-the-last-50-years-4486990/. [Accessed 08 May 2020].

[42] J. M. Filho “*Brazilian Blackout 2009.*” : Blackout Watch Available from: http://www.pacw.org/fileadmin/doc/MarchIssue2010/Brazilian_Blackout_march_2010.pdf. [Accessed 08 May 2020].

[43] Y. Hain, I. Schweitzer, “*Analysis of the Power Blackout on June 8, 1995, in the Israel Electric Corporation.*” IEEE Transactions on Power Systems; 8th June 1995.

[44] C. Vournas et al, “*Postmortem Analysis and Data Validation in the Wake of the 2004 Athens Blackout.*” IEEE Transactions on Power Systems; 2006

[45] T. V. Cutsem, C. Vournas, “*Voltage Stability of Electric Power Systems*.” U.S.A. Springer Science + Business Media, LLC; 1998; p264, 276.

[46] E. F. Kuester, D. C. Chang, “*Theory of Waveguides and Transmission lines*.” U.S.A. Taylor and Francis Inc; 2010; p10.

[47] A. R. Bergen, V. Vittal, “*Power Systems Analysis*.” Second Edition. U.S.A. Prentice Hall; 1999; p341

[48] C. W. Taylor, “*Concepts of Under voltage Load Shedding for Voltage Stability*.” IEEE Transactions on Power Delivery; 1992.

[49] C. Adamson, N. G. Hingorani, “*High Voltage Direct Current Power Transmission*.” Garraway Ltd: England; 1960; p8-9.

[50] H. Wang, *“Comparison and Analysis of Advantages and Disadvantages Based on UHV AC/DC Transmission.”* Academic Journal of Engineering and Technology Science. (No Date); 2(1): 7-12.

[51] D. Rowell, *“Impedance-Based Modelling Methods”.* Massachusetts Institute of Technology – Department of Mechanical Engineering; 2003: p7

[52] R. Larik, M. Mustafa, S. Qazi et al, *“Under Voltage Load Shedding Scheme to Provide Voltage Stability.”* ResearchGate; November 2016: 1-9

[53] D. Kirschen, G. Strbac, *“Fundamentals of Power System Economics.”* John Wiley and Sons; 2004; p111, 113, 175, 227-231.

[54] I. Kumaraswamy. B. VenkataPrasanth et al, *"Role of Distributed Generation in Voltage Stability Enhancement."* International Journal of Current Engineering and Technology; 2014; 4(1): 60-64.

[55] N. Acharya, M. Nadarajah et al, *"Facts about FACTS controllers: Practical installations and Benefits."* ResearchGate; September 2005.

[56] R. Rameshwar, *"Efficient, Reliable and Cost-Effective Transmission of Electrical Energy using FACTS Devices."* National Power Systems Conference, NPSC; 2004. 188-192

[57] T. V. Muni, T. Vinoditha et al, *"Improvement of Power System Stability by Simultaneous AC-DC Power Transmission."* International Journal of Scientific & Engineering Research. April-2011; 2(4): 1-6

[58] C. J. Kilonzi, *"System Loss Reduction and Voltage Profile Improvement by Optimal Placement and Sizing of Distributed Generation using a hybrid of Genetic Algorithm and Improved Particle Swarm Optimization."* University of Nairobi. 2014.

[59] A. Singhal, V. Ajjarapu, *"Long-Term Voltage Stability Assessment of an Integrated Transmission Distribution System."* Department of Electrical and Computing Engineering; Iowa State University. U.S.A; 2017

[60] D. G. Newnan, T. Eschenbach et al, *"Engineering Economic Analysis."* 9th Edition; Oxford University Press. New York; 2004; p490, 496-501.

[61] M. El-shimy, *"Power System Stability."* Researchgate Technical Report; 2018: p1-5.

[62] S. Nascimento, M. M. Gouvêa, "*Voltage stability enhancement in power systems with automatic facts device allocation*." 3rd International Conference on Energy and Environment Research, ICEER, 7-11 September 2016.

[63] D. F. Peelo, *"Current Interruption Transients Calculation."* John Wiley and Sons; 2014; p29, 160.

[64] G. Kusic, *"Computer-Aided Power Systems Analysis."* Second Edition. CRC Press; 2008; p21, 243.

[65] U. S. Department of Energy, *"Maintaining Reliability in the Modern Power System."* December 2016; p28-29

[66] N. G. Hingorani, L. Gyugyi, *"Understanding FACTS - Concepts and Technology of Flexible AC Transmission Systems."* U.S.A. IEEE press and Wiley Interscience; 2000; p1-2.

[67] N. Tleis, *"Power Systems Modelling and Fault Analysis."* Newnes, Elsevier Ltd. 2008; p1-2, 272-273.

[68] M. Lin, R. Rayudu, S. Samarasinghe, *"A review of Voltage/var Control."* Centre for Advanced Computational Solutions - Lincoln University. (No Date).

[69] O. A. Mousavi, R. Cherkaoui, *"Literature Survey on Fundamental Issues of Voltage and Reactive Power Control."* ETH. 2011: p19,27

[70] T. V. Cutsem, C. Moors, D. Lefebvre. *"Design of Load Shedding Schemes against Voltage Instability using Combinatorial Optimization."* Power Engineering Society Winter Meeting, 2002: 848-853.

[71] M. S. H. Lipu, T F Karim, *"Effectiveness of FACTS controllers and HVDC transmissions for improving power system stability and increasing power transmission capability."* International Journal of Energy and Power Engineering, Science Publishing Group. 2013; 2(4) :154-163.

[72] R. J. Lings, *"EPRI AC Transmission line reference book."* Third Edition. USA. EPRI; 2005; p14-5 - 14-7.

[73] M. P. Musau, T. Chepkania, A. Odero, C. Wekesa, *"Effects of Renewable Energy on Frequency Stability: A Proposed Case Study of the Kenyan Grid."* IEEE PES-IAS – Power Africa. 2017. p12-15.

[74] K.P.L.C, "*Annual Report and Financial Statements for the year ended 30th June 2018."* Available from: https://www.kplc.co.ke/AR2018/KPLC%20Annual%20Report%2017_12_2018_Wed.pdf:[Accessed 29 May 2020]. p205

[75] H. F. Khan, A. Hanif, N. Anwar, *"Rotor Angle and Voltage Stability Analysis with Fault Location Identification on the IEEE 9 Bus System."* Engineering, Technology & Applied Science Research. 2020; 10(1): 5259-5264

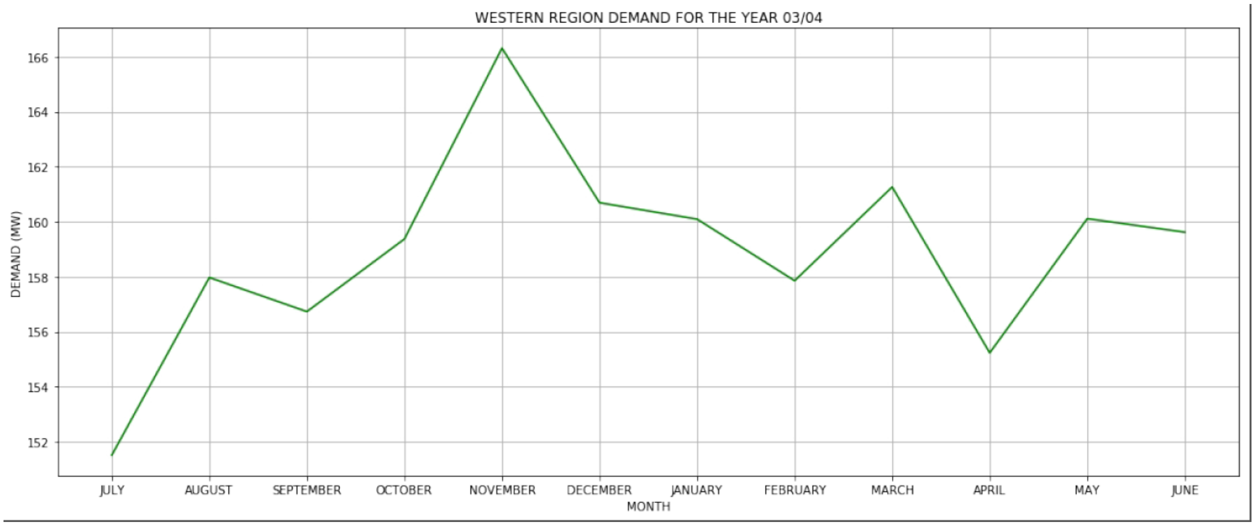
[76] M. Natarajan R. Balamurugan, L. Lakshminarasimman, "*Optimal Placement and Sizing of DGs in the Distribution System for Loss Minimization and Voltage Stability*

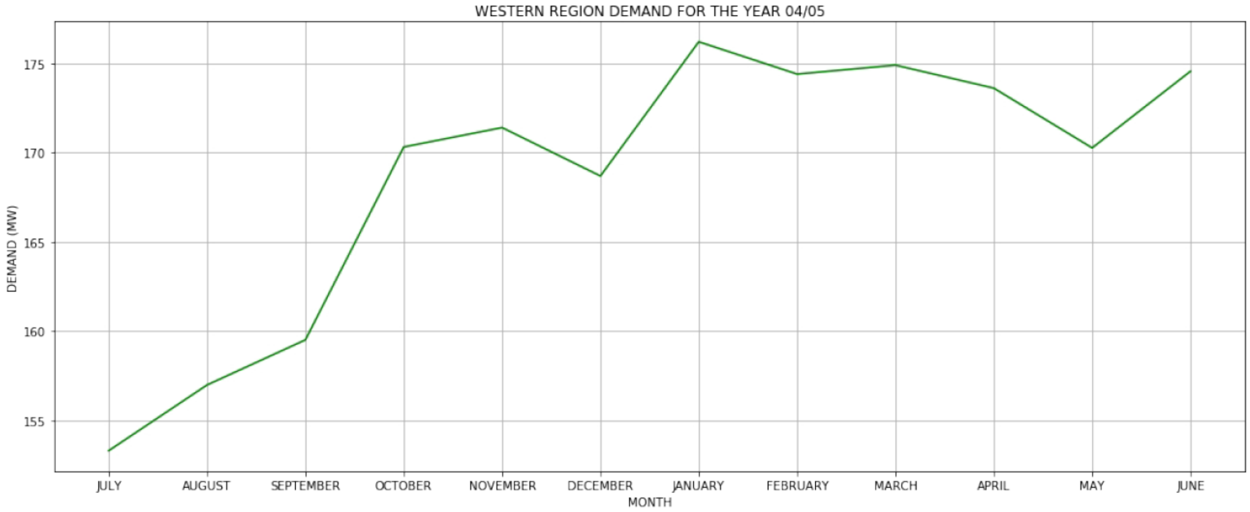
Improvement using CABC." International Journal on Electrical Engineering and Informatics. 2015; 7(4): 679-690

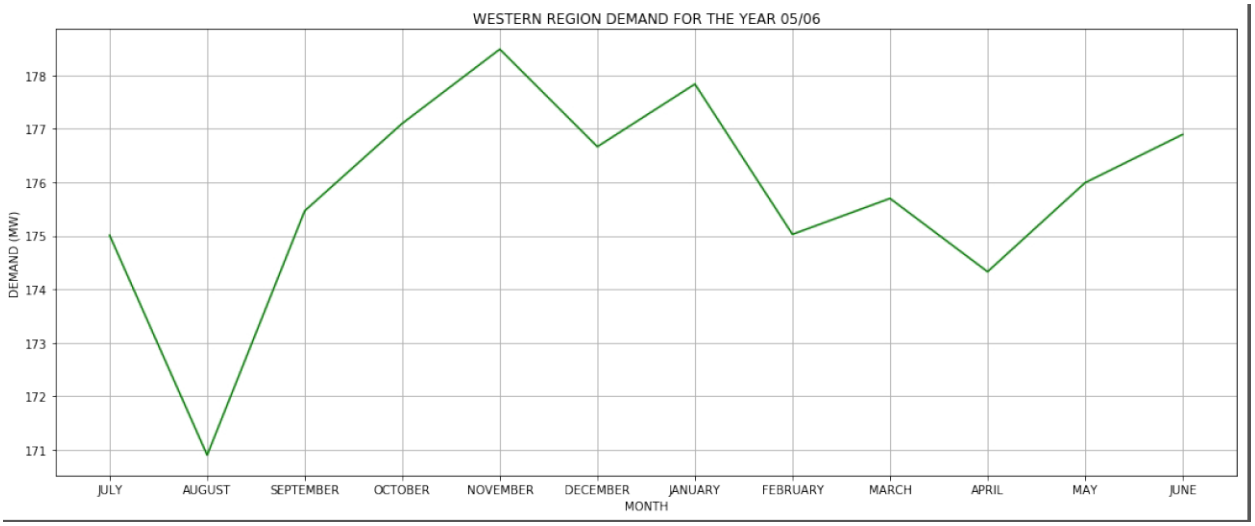
[77] I. Kitta, S. Manjang et al, "*Insertion of 275kV Transmission Line for Improving the Voltage Profile and Efficiency of electrical Power System*." IOP Conference Series: Materials Science & Engineering. 2019; 676(1).

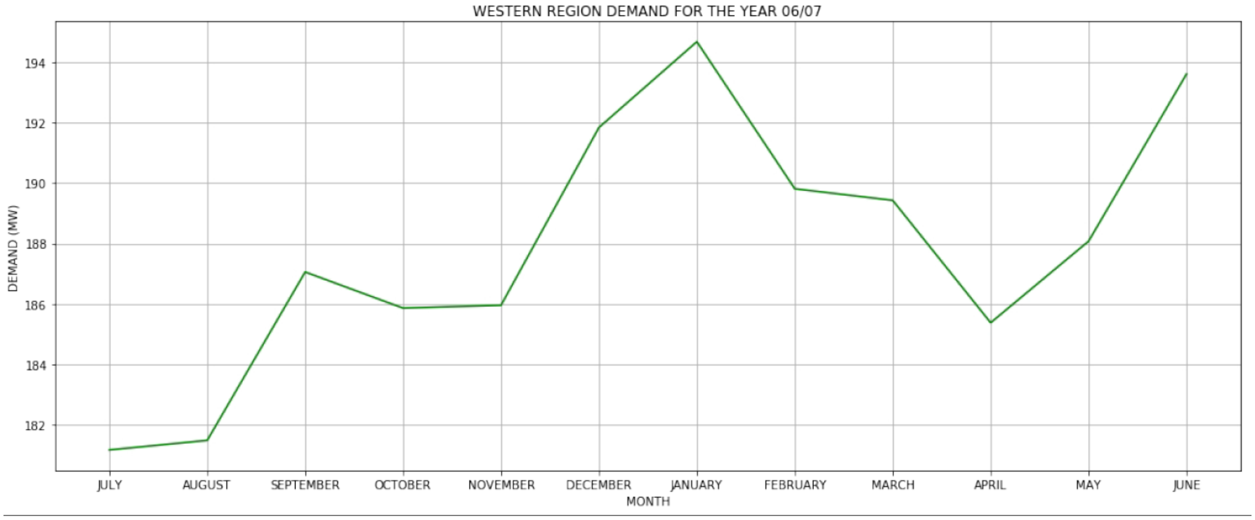
APPENDICES

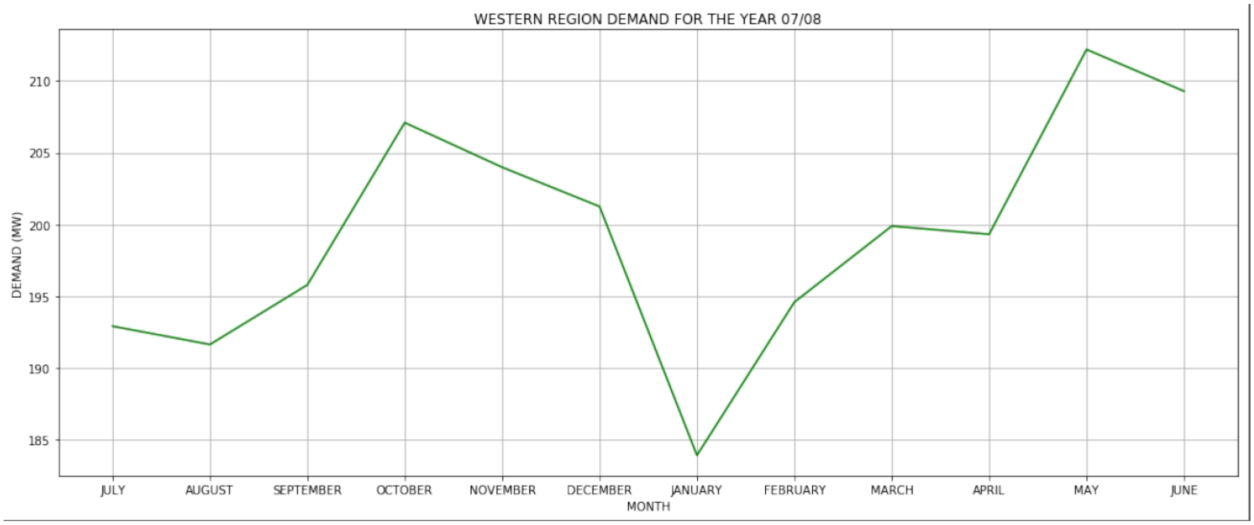
APPENDIX A: Demand Curve Analysis Between 2003 to 2019

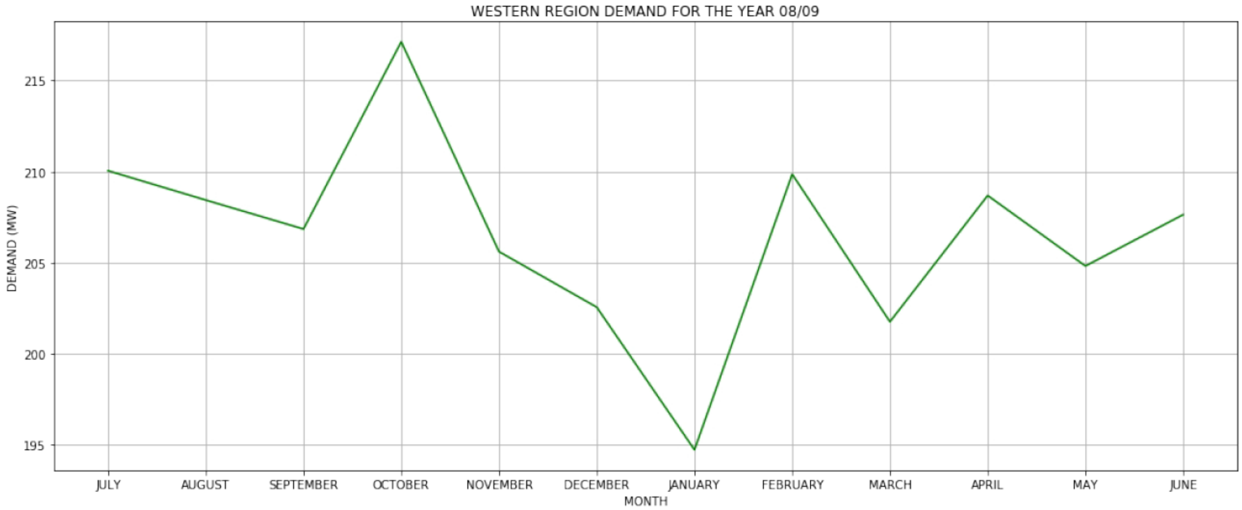

WESTERN REGION DEMAND FOR THE YEAR 03/04

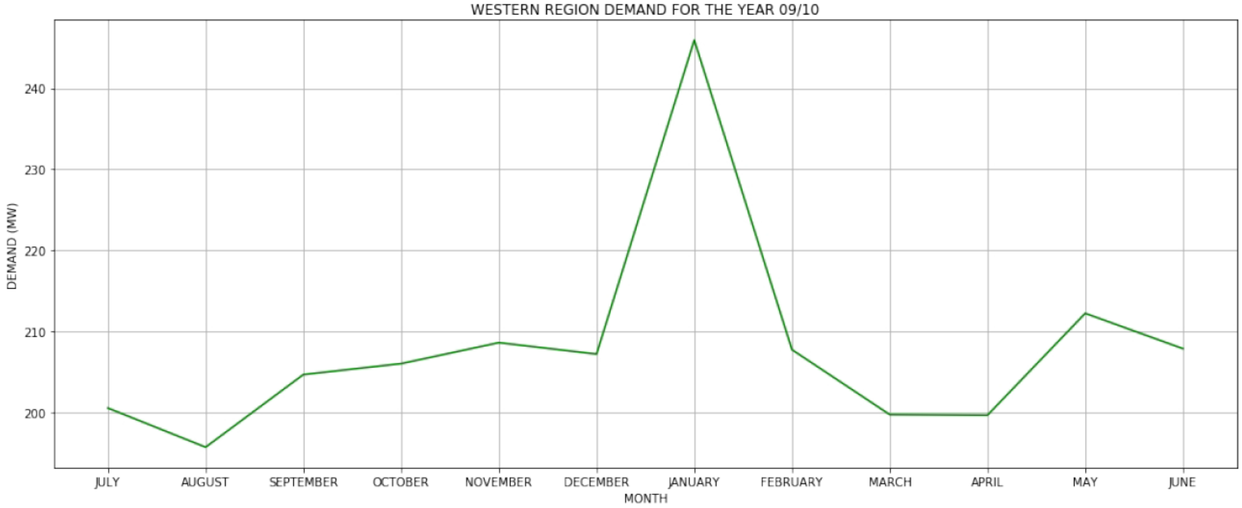

WESTERN REGION DEMAND FOR THE YEAR 04/05

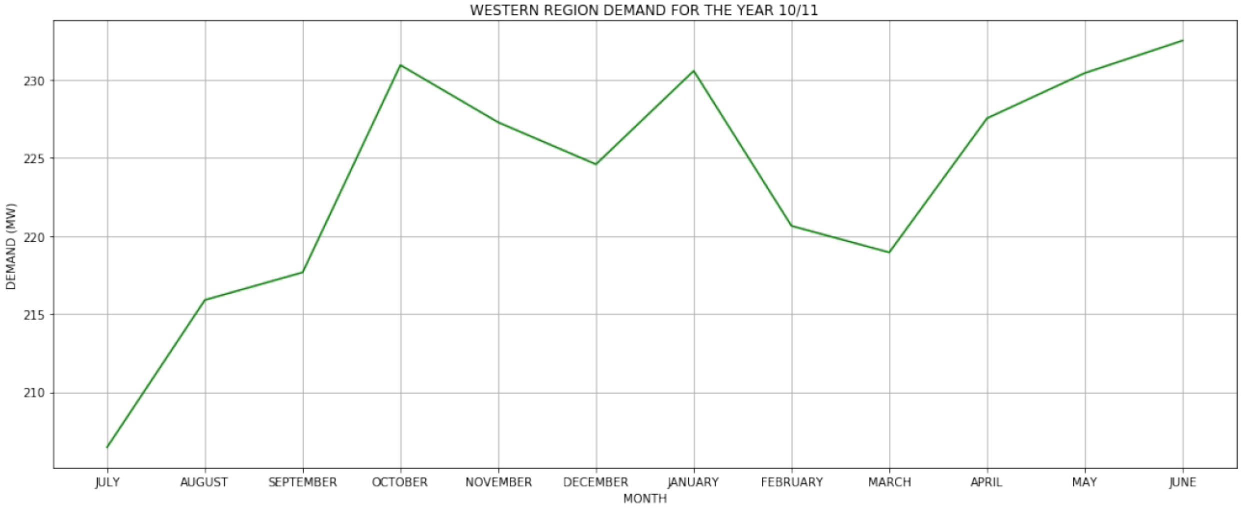

WESTERN REGION DEMAND FOR THE YEAR 05/06
DEMAND (MW)
178
177
176
175
174
173
172
171
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

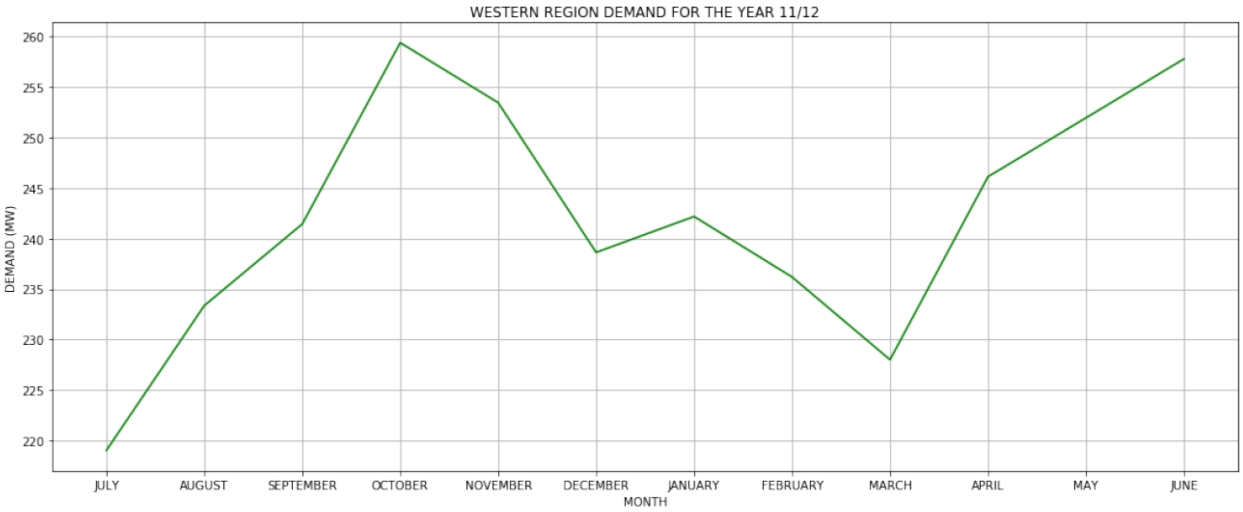

WESTERN REGION DEMAND FOR THE YEAR 06/07
DEMAND (MW)
194
192
190
188
186
184
182
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

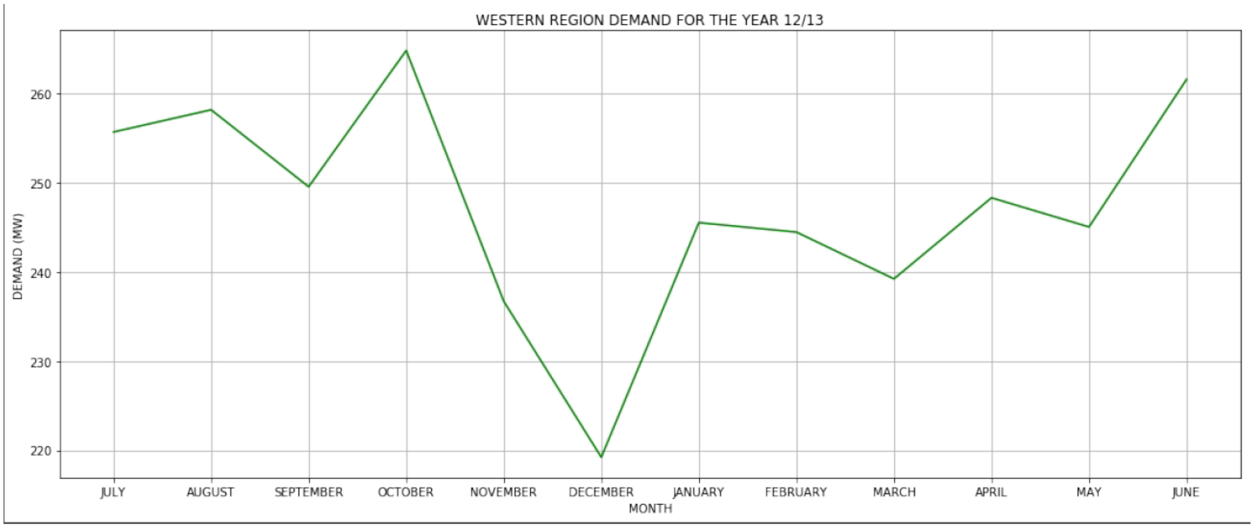

WESTERN REGION DEMAND FOR THE YEAR 07/08
DEMAND (MW)
210
205
200
195
190
185
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

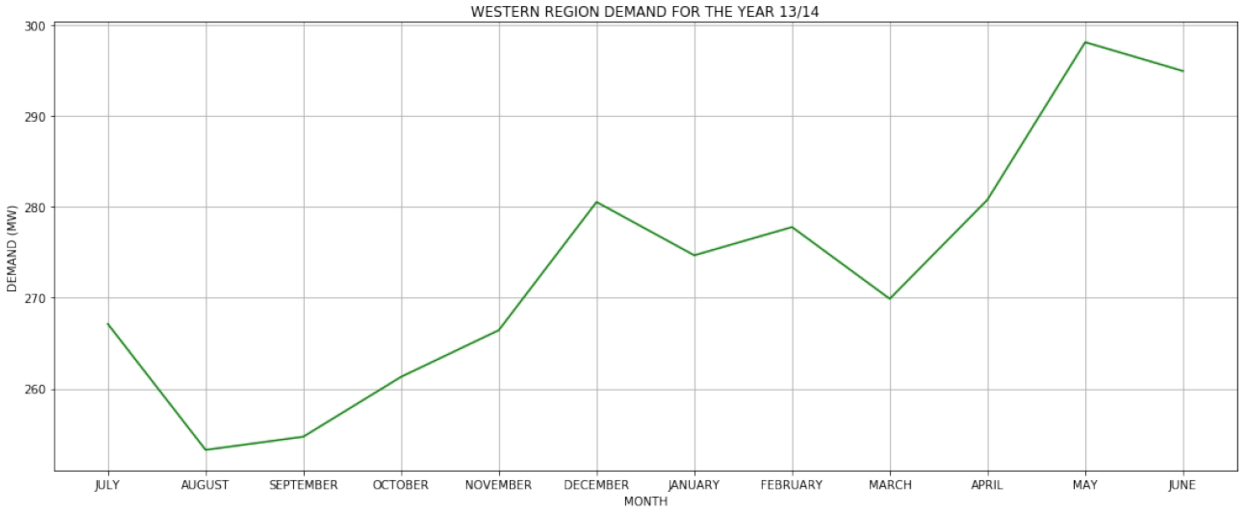

WESTERN REGION DEMAND FOR THE YEAR 08/09
DEMAND (MW)
215
210
205
200
195
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

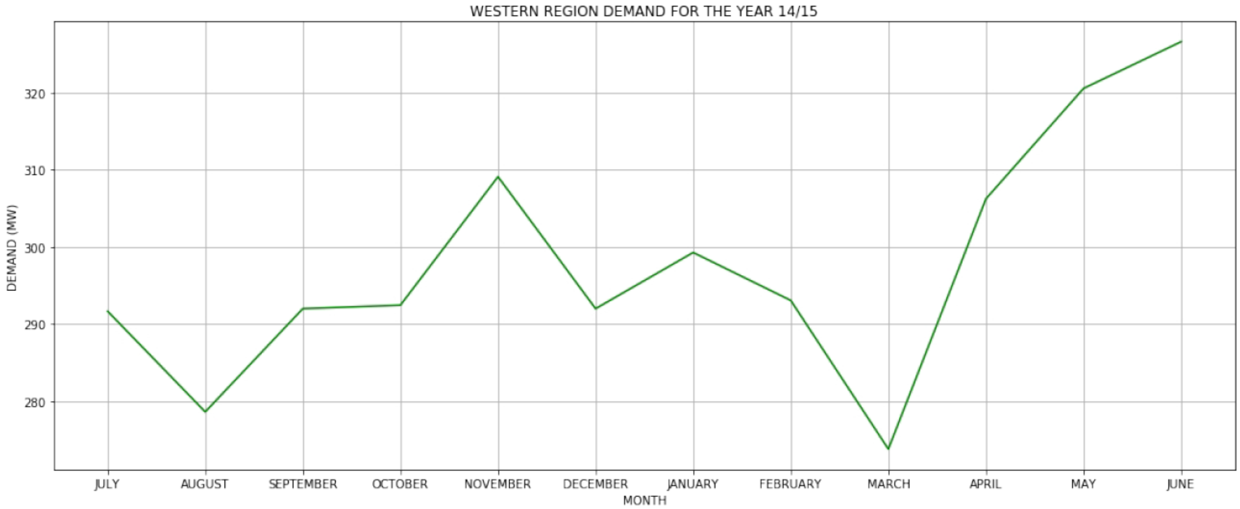

WESTERN REGION DEMAND FOR THE YEAR 09/10
DEMAND (MW)
240
230
220
210
200
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

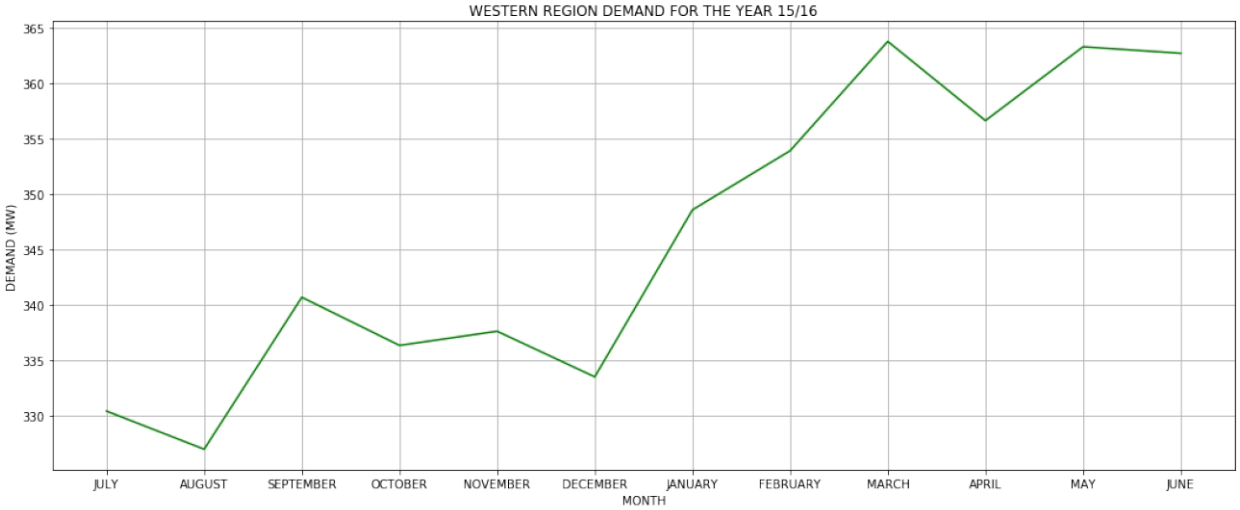

WESTERN REGION DEMAND FOR THE YEAR 10/11
DEMAND (MW)
230
225
220
215
210
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

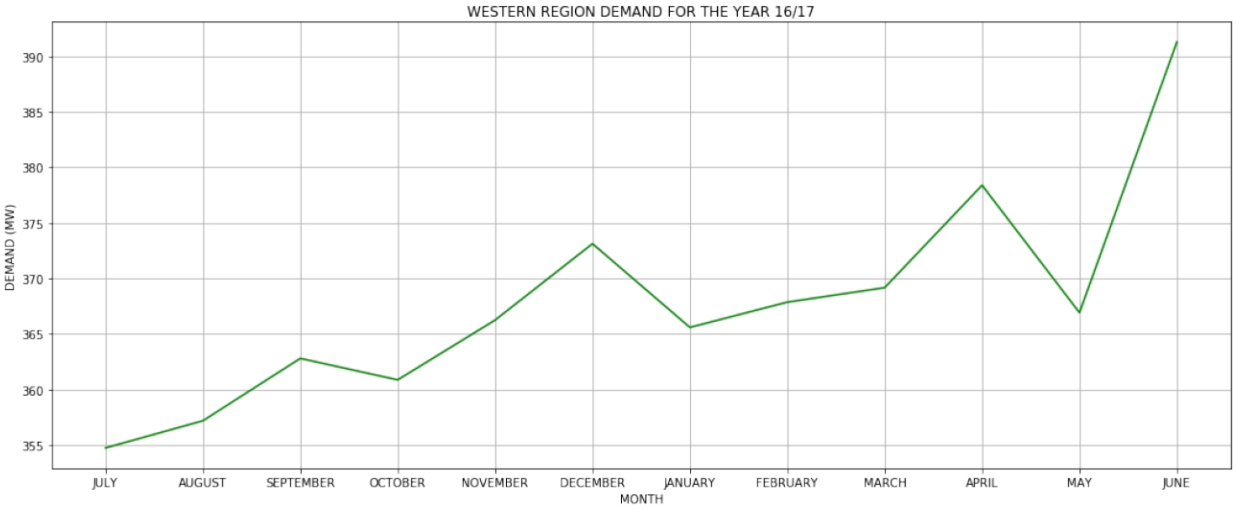

WESTERN REGION DEMAND FOR THE YEAR 11/12
DEMAND (MW)
260
255
250
245
240
235
230
225
220
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

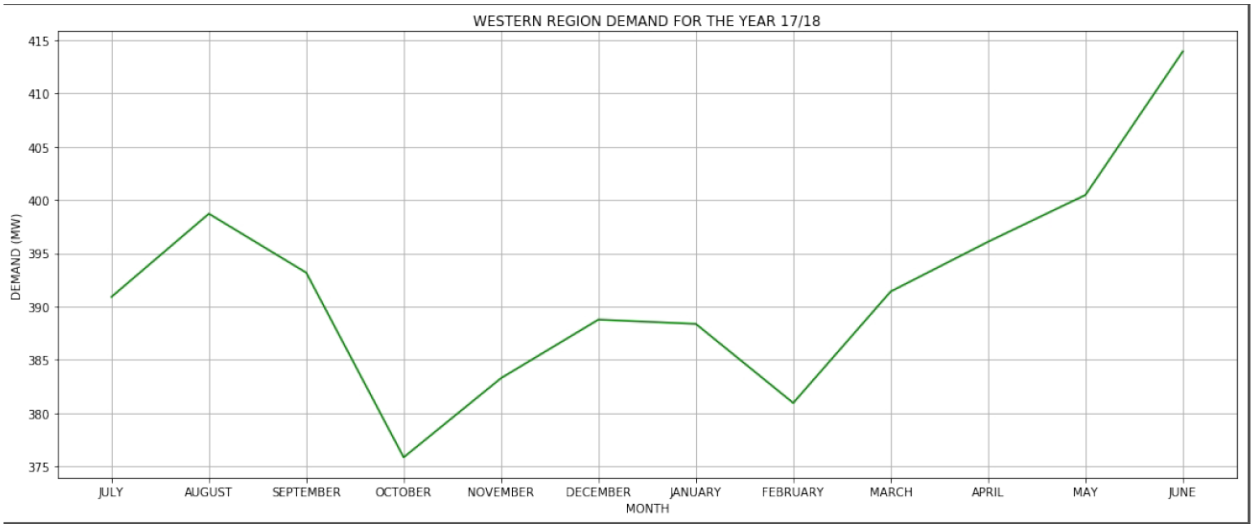

WESTERN REGION DEMAND FOR THE YEAR 12/13
DEMAND (MW)
260
250
240
230
220
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

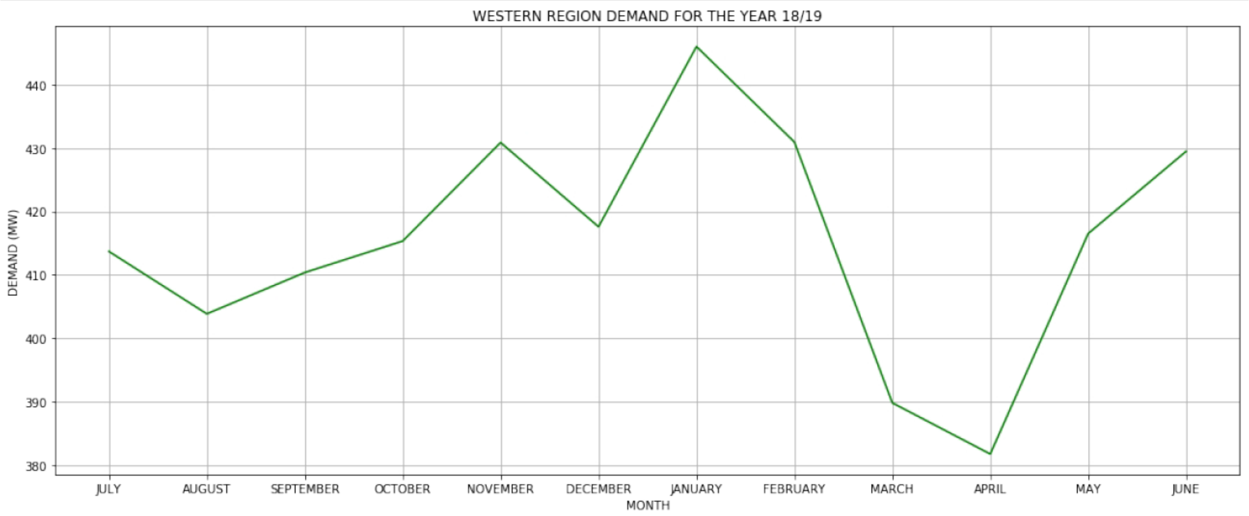

WESTERN REGION DEMAND FOR THE YEAR 13/14
DEMAND (MW)
300
290
280
270
260
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH


WESTERN REGION DEMAND FOR THE YEAR 14/15
DEMAND (MW)
320
310
300
290
280
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH


WESTERN REGION DEMAND FOR THE YEAR 15/16
DEMAND (MW)
365
360
355
350
345
340
335
330
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH


WESTERN REGION DEMAND FOR THE YEAR 16/17
DEMAND (MW)
390
385
380
375
370
365
360
355
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH


WESTERN REGION DEMAND FOR THE YEAR 17/18
DEMAND (MW)
415
410
405
400
395
390
385
380
375
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH


WESTERN REGION DEMAND FOR THE YEAR 18/19
DEMAND (MW)
440
430
420
410
400
390
380
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
MONTH

APPENDIX B: Transmission Line Parameters

From Bus No	From Bus Name	To Bus No	To Bus Name	cct	Line R (pu)	Line X (pu)	Susceptance (p.u.)	In Service	Rate A (I as MVA)	Length (km)
1108	OLKARIA 1 132.00	1109	OLKARIA II 132.00	1	0.0006	0.00357	0.00508	1	150	4
1108	OLKARIA 1 132.00	1142	NAIVASHA 132.00	1	0.0097	0.0559	0.0108	1	150	23.1
1127	ELDORET 132.00	1140	LESSOS 132.00	1	0.0385	0.0779	0.015	1	73	32.1
1128	MUHORONI 132.00	1129	KISUMU 132.00	1	0.0581	0.1177	0.0225	1	73	48.5
1128	MUHORONI 132.00	1130	CHEMOSIT 132.00	1	0.0368	0.0745	0.0143	1	73	30.7
1128	MUHORONI 132.00	1140	LESSOS 132.00	1	0.068	0.1376	0.0266	1	73	56.7
1129	KISUMU 132.00	1160	SONDU 132.00	1	0.041667	0.119722	0.023611	1	150	50
1130	CHEMOSIT 132.00	1167	KISII 132.00	1	0.05	0.143666	0.028333	1	150	60
1131	WEBUYE 132.00	1139	MUSAGA 132.00	1	0.0216	0.0437	0.0084	1	73	18
1138	TORORO 132.00	1139	MUSAGA 132.00	1	0.0845	0.171	0.0329	1	73	70.5
1138	TORORO 132.00	1139	MUSAGA 132.00	2	0.0845	0.171	0.0329	1	73	70.5
1139	MUSAGA 132.00	1140	LESSOS 132.00	1	0.0784	0.1585	0.0308	1	73	66
1139	MUSAGA 132.00	1140	LESSOS 132.00	2	0.0784	0.1585	0.0308	1	73	66
1139	MUSAGA 132.00	1155	MUMIAS 132.00	1	0.0324	0.0648	0.0135	1	81	27
1140	LESSOS 132.00	1183	MAKUTANO 132.00	1	0.0685	0.15215	0.0296	1	73	63
1140	LESSOS 132.00	1183	MAKUTANO 132.00	2	0.0685	0.15215	0.0296	1	73	63
1141	LANET 132.00	1142	NAIVASHA 132.00	1	0.0803	0.1626	0.0315	1	73	67
1141	LANET 132.00	1142	NAIVASHA 132.00	2	0.0803	0.1626	0.0315	1	73	67
1141	LANET 132.00	1149	SOILO 132.00	1	0.010892	0.024192	0.004706	1	73	10.017
1141	LANET 132.00	1149	SOILO 132.00	2	0.010892	0.024192	0.004706	1	73	10.017
1142	NAIVASHA 132.00	1150	RUARAKA TEE 132.00	1	0.0828	0.1725	0.0323	1	73	71.2
1142	NAIVASHA 132.00	1150	RUARAKA TEE 132.00	2	0.0828	0.1725	0.0323	1	73	71.2
1149	SOILO 132.00	1183	MAKUTANO 132.00	1	0.057609	0.127958	0.024894	1	73	52.983
1149	SOILO 132.00	1183	MAKUTANO 132.00	2	0.057609	0.127958	0.024894	1	73	52.983
1155	MUMIAS 132.00	1178	RANGALA 132.00	1	0.014277	0.082277	0.015896	1	150	34
1160	SONDU 132.00	1161	SANGORO 132.00	1	0.005993	0.012134	0.002329	1	73	5
1207	TURKWEL 220.00	1240	LESSOS 220.00	1	0.0458	0.1879	0.2856	1	210	218
1210	OLKARIA II 220.00	1224	NBNORTH220 220.00	3	0.0103	0.0615	0.0875	1	250	69
1210	OLKARIA II 220.00	1224	NBNORTH220 220.00	4	0.0103	0.0615	0.0875	1	250	69
1210	OLKARIA II 220.00	1280	OLKARIA III 220.00	1	0.001045	0.006239	0.00888	1	250	7

APPENDIX C: Generator Parameters

Bus No	Bus Name	Id	Code	Voltage Schedule (p.u)	Pgen (MW)	P_{max} (MW)	M_{base} (MVA)	X Source (pu)
1007	TURKWEL 11.000	1	2	1.05	52.5	52	58	0.18
1007	TURKWEL 11.000	2	2	1.05	52.5	52	58	0.18
1008	OLKARIA 1 11.000	1	-2	1.05	44.0	45	56	0.12
1055	MUMIAS 11.000	1	-2	1.05	14.0	26	42.75	0.16
1059	SONDU 11.000	1	2	1.05	20.0	30	38	0.16
1060	SONDU 11.000	2	2	1.05	20.0	30	38	0.16
1061	SANGORO 11.000	1	2	1.05	6.6	12	14.4	0.192
1061	SANGORO 11.000	2	2	1.05	6.6	12	14.4	0.192
1078	MUHORONI MSD11.000	1	-2	1.05	30.0	30	37.5	0.18
	TOTAL					**289**	**357.05**	

APPENDIX D: Maximum Demand Data from West Kenya Substations

SUBSTATION	**DEMAND (MW)**
Musaga: 23 MVA Tx 1	8.00
Musaga: 23 MVA Tx 2	8.00
Panpaper: 35 MVA (2 Txs)	11.56
Kisumu: 45 MVA Tx 1	25.00
Kisumu: 45 MVA Tx 2	25.00
Muhoroni 23MVA TX	15.00
Chemosit: 23 MVA Tx 1	25.00
Chemosit: 23 MVA Tx 2	20.00
Kegati: 23MVA TX 1	20.00
Kegati : 23MVA TX 2	15.00
Rang'ala: 23 MVA Tx 1	10.00
Rang'ala: 23 MVA Tx 2	15.00
Eldoret: 45 MVA Tx 1	15.00
Eldoret: 45 MVA Tx 2	15.00
Kitale 23MVA Tx	20.00
Sarmach: 45 MVA Tx	2.00
Lessos: 23 MVA Tx 1	8.97
Lessos: 23 MVA Tx 2	15.33
Naivasha: 23 MVA Tx1	5.00
Naivasha: 23 MVA Tx2	15.00
Naivasha: 23 MVA Tx3	10.00
Soilo 23MVA TX 1	18.00
Soilo 23 MVA TX 2	14.00
Lanet: 23 MVA Tx 1	25.00
Lanet: 23 MVA Tx 2	15.00
Lanet: 23 MVA Tx 3	10.00
Makutano: 23 MVA Tx 1	5.00
Makutano: 23 MVA Tx 2	5.00
Bomet: 23 MVA Tx 1	12.00
Webuye: 23 MVA Tx 1	11.00
Awendo: 23 MVA Tx 1	6.00
Awendo: 23 MVA Tx 2	6.00
Ndhiwa: 23 MVA Tx 1	9.00
National Cement: 10 MVA Tx	4.12
	443.98

APPENDIX E: Newton-Raphson Power Flow Equations.

$$\widetilde{S_k} = P_k + jQ_k = \widetilde{V_k}\breve{I}_k^* \tag{A.E.1}$$

$$\widetilde{I_K} = \sum_{m=1}^{n} \widetilde{Y_{km}}\widetilde{V_m} \tag{A.E.2}$$

$$P_k + jQ_k = \tilde{V}_k \sum_{m=1}^{n} (G_{km} - jB_{km})\, V_m^* \tag{A.E.3}$$

$$\tilde{V}_k\tilde{V}_m = \left(V_k e^{j\theta_k}\right)\left(V_m e^{-j\theta_m}\right) = V_k V_m e^{j(\theta_k - \theta_m)} \tag{A.E.4}$$

$$\tilde{V}_k\tilde{V}_m = (\cos\theta_{km} + j\sin\theta_{km}) \qquad \theta_{km} = \theta_k - \theta_m \tag{A.E.5}$$

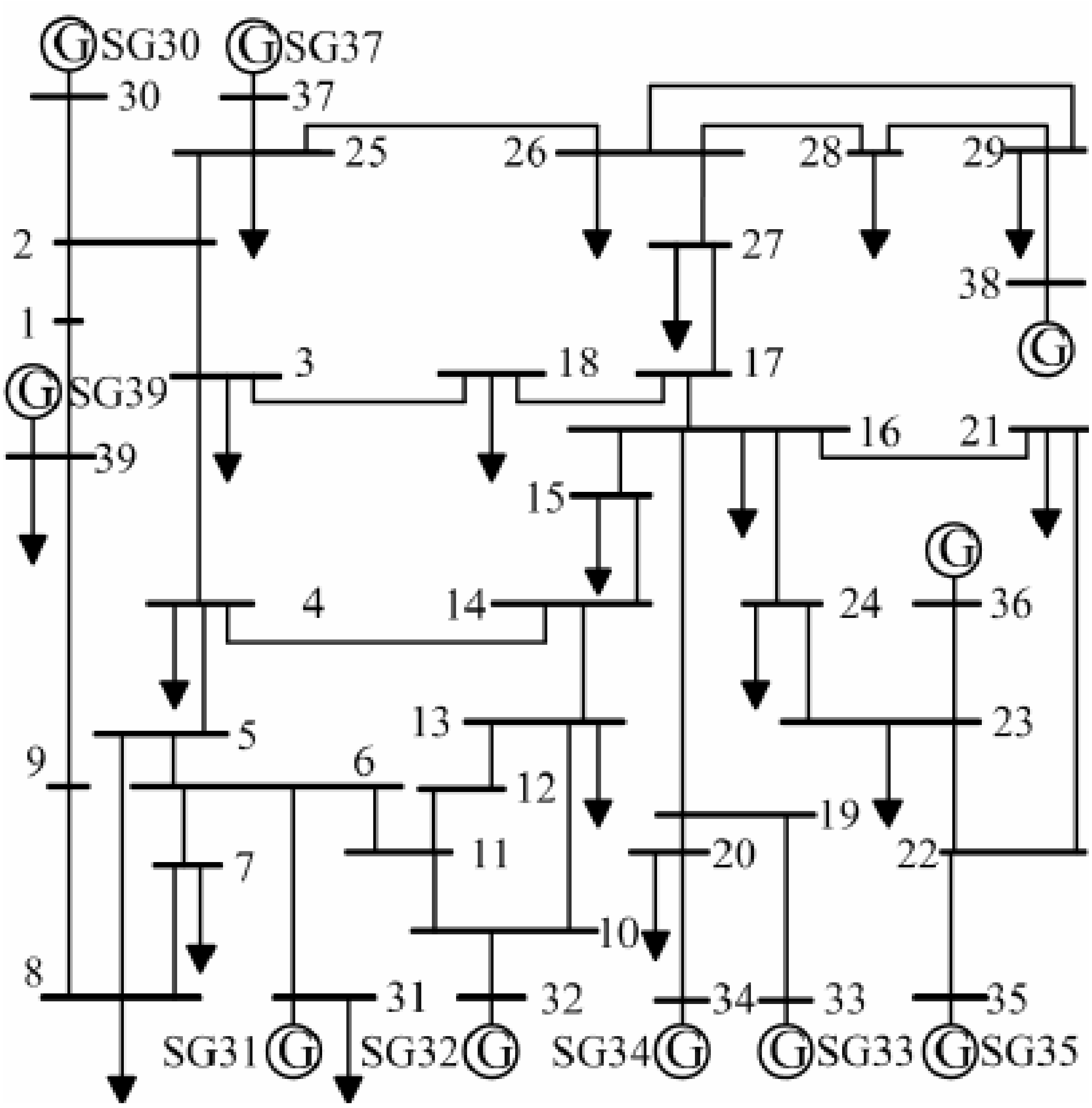
P$_k$ and Q$_k$ therefore become;

$$P_k = V_k \sum_{m=1}^{n} (G_{km} V_m \cos\theta_{km}) + (B_{km} V_m \sin\theta_{km}) \tag{A.E.5}$$

$$Q_k = V_k \sum_{m=1}^{n} (G_{km} V_m \sin\theta_{km}) + (B_{km} V_m \cos\theta_{km}) \tag{A.E.6}$$

Real and reactive power, P and Q at each bus are functions of Voltage Magnitude V and angle θ.

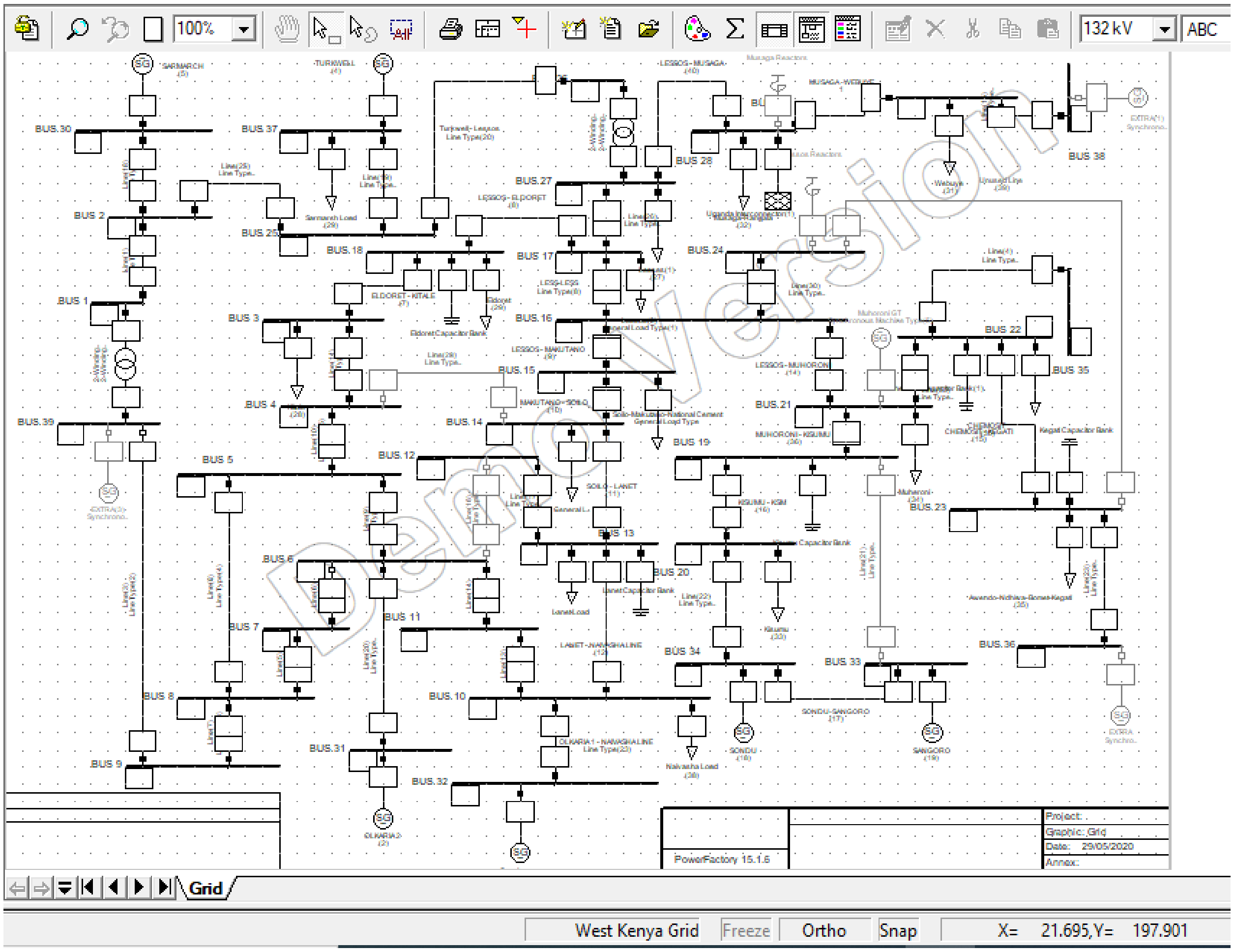
APPENDIX F: IEEE 39 Bus System



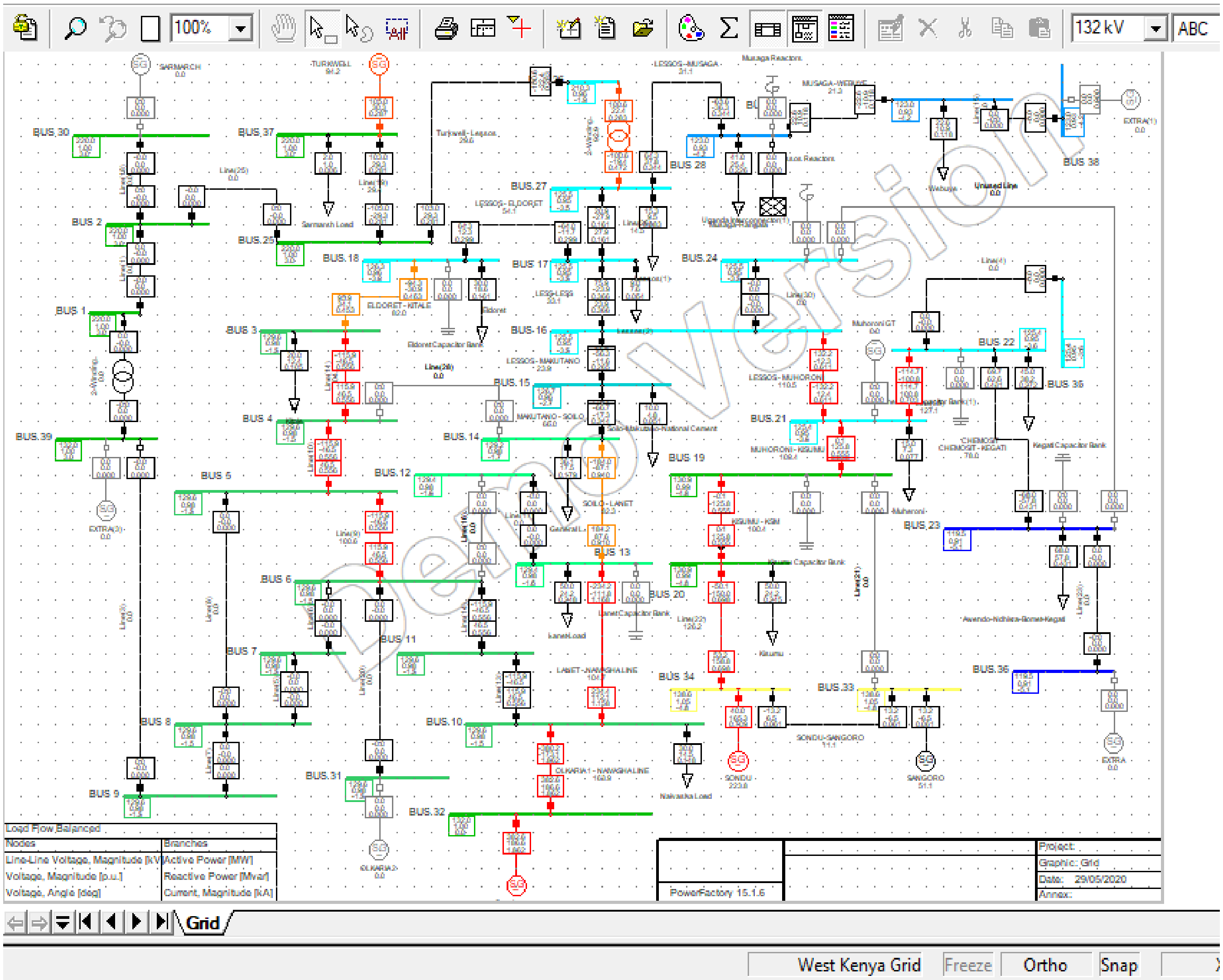
APPENDIX G: Transformer parameters

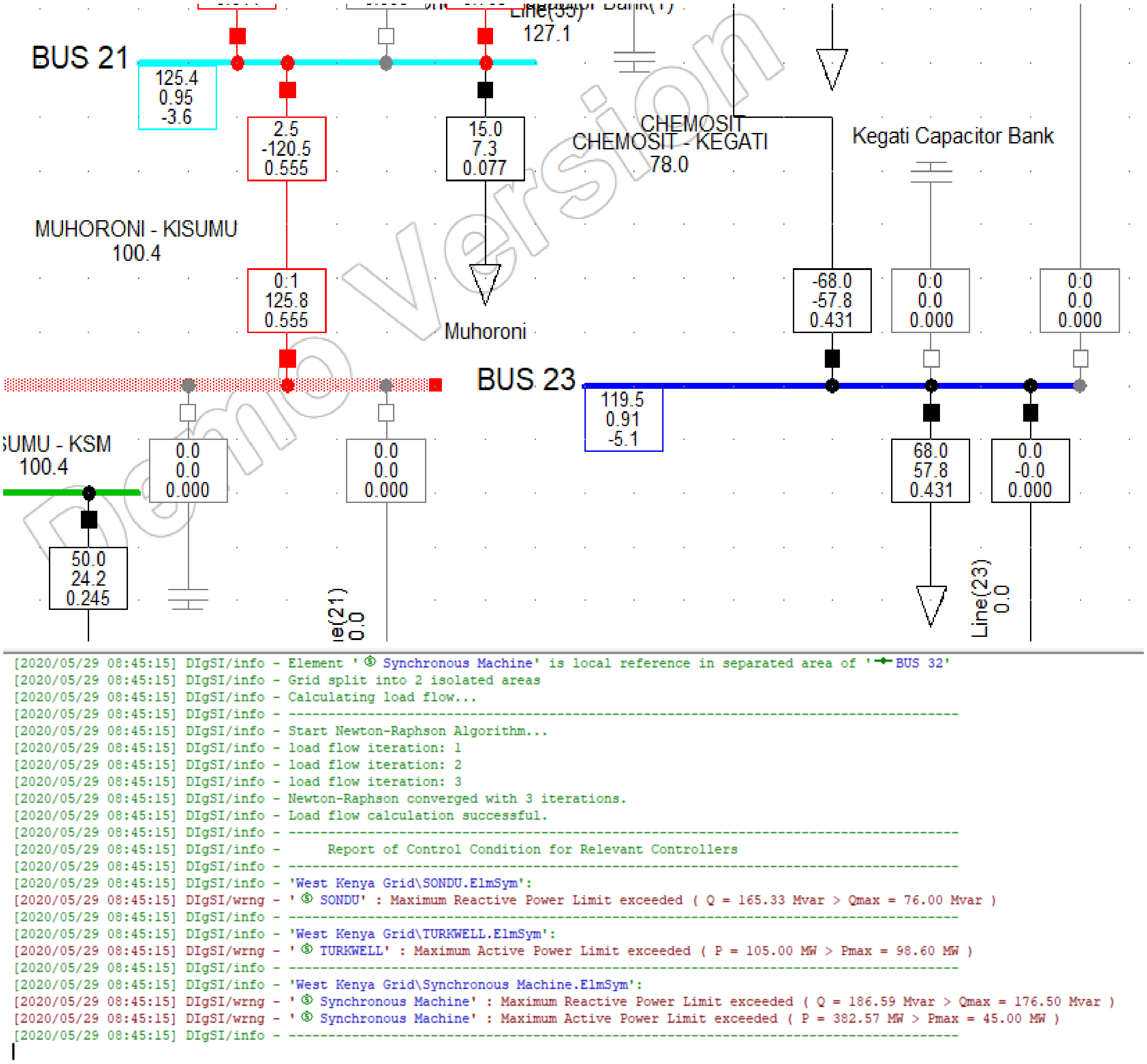
From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	In Service	Specified R (pu or watts)	Specified X (pu)	Rate A (MVA)	Winding 1 Nominal kV	Winding 2 Nominal kV
1109	OLKARIA II 132.00	1210	OLKARIA II 220.00	1	1	0.003376	0.09992	90	220	132
1127	ELDORET 132.00	1327	ELD33 33.000	1	1	0.0138	0.1196	23	132	33
1127	ELDORET 132.00	1328	ELD33 33.000	1	1	0.0138	0.1196	23	132	33
1128	MUHORONI 132.00	1375	MUHORONI 33.000	1	1	0	0.1	23	132	33
1129	KISUMU 132.00	1329	KISU33 33.000	1	1	0.0138	0.13	45	132	33
1129	KISUMU 132.00	1330	KISU33 33.000	1	1	0.0138	0.13	45	132	33
1130	CHEMOSIT 132.00	1350	CHEMO33 33.000	1	1	0.0138	0.1196	23	132	33
1130	CHEMOSIT 132.00	1351	CHEMO33 33.000	1	1	0.0138	0.1196	23	132	33
1139	MUSAGA 132.00	1339	MUSAGA 33.000	1	1	0.015	0.099	15	132	33
1139	MUSAGA 132.00	1339	MUSAGA 33.000	2	1	0.0138	0.097	23	132	33
1140	LESSOS 132.00	1340	LESSO33 33.000	1	1	0.015	0.12	23	132	33
1141	LANET 132.00	1341	LANET33 33.000	1	1	0.0138	0.097	23	132	33
1141	LANET 132.00	1341	LANET33 33.000	2	1	0.0138	0.0978	23	132	33
1141	LANET 132.00	1342	LANET33 33.000	1	1	0.0138	0.0981	23	132	33
1142	NAIVASHA 132.00	1343	NAIVA33 33.000	1	1	0.015	0.12	15	132	33
1142	NAIVASHA 132.00	1344	NAIVA33 33.000	1	1	0.015	0.12	15	132	33
1149	SOILO 132.00	1359	SOILO 33.000	1	1	0.0138	0.097	23	132	33
1167	KISII 132.00	1356	KISII33 33.000	1	1	0.0138	0.1196	23	132	33
1167	KISII 132.00	1356	KISII33 33.000	2	1	0.0138	0.1196	23	132	33
1178	RANGALA 132.00	1376	RANGALA 33.000	1	1	0.0138	0.1196	23	132	33
1183	MAKUTANO 132.00	1316	MAKUTANO 33.000	1	1	0.0138	0.1196	23	132	33
1240	LESSOS 220.00	1740	LESSTRF 132.00	1	1	0.032775	0.09999	75	220	132
1240	LESSOS 220.00	1740	LESSTRF 132.00	2	1	0.032775	0.09999	75	220	132

APPENDIX H: Modelled West Kenya Transmission Line in IEEE 39 Bus System



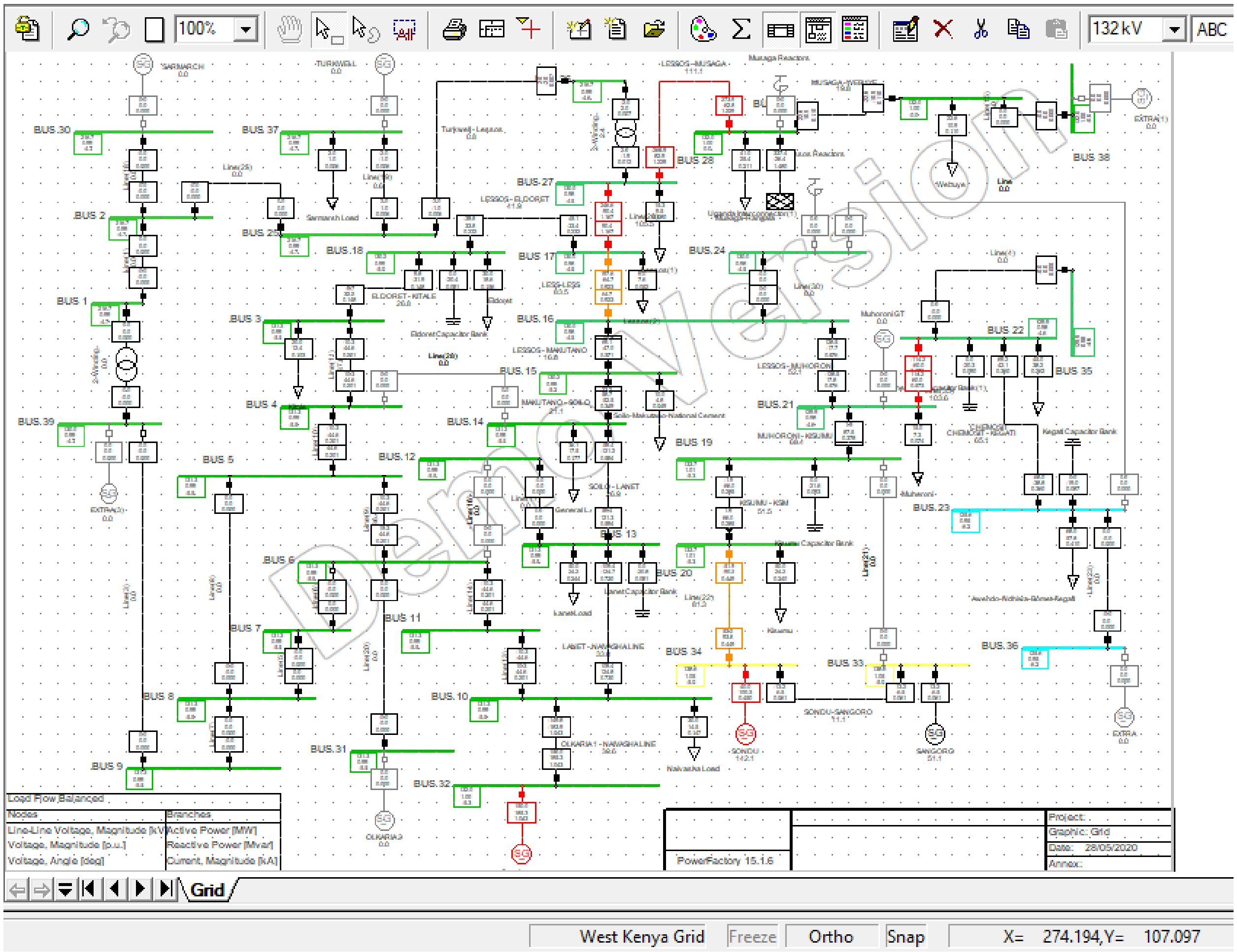
APPENDIX I: Schedule 2 - Compensators Off Without Additional Transmission Lines





```
[2020/05/29 08:45:15] DIgSI/info - Element ' Synchronous Machine' is local reference in separated area of ' BUS 32'
[2020/05/29 08:45:15] DIgSI/info - Grid split into 2 isolated areas
[2020/05/29 08:45:15] DIgSI/info - Calculating load flow...
[2020/05/29 08:45:15] DIgSI/info - ------------------------------------------------------------------------------------
[2020/05/29 08:45:15] DIgSI/info - Start Newton-Raphson Algorithm...
[2020/05/29 08:45:15] DIgSI/info - load flow iteration: 1
[2020/05/29 08:45:15] DIgSI/info - load flow iteration: 2
[2020/05/29 08:45:15] DIgSI/info - load flow iteration: 3
[2020/05/29 08:45:15] DIgSI/info - Newton-Raphson converged with 3 iterations.
[2020/05/29 08:45:15] DIgSI/info - Load flow calculation successful.
[2020/05/29 08:45:15] DIgSI/info - ------------------------------------------------------------------------------------
[2020/05/29 08:45:15] DIgSI/info -      Report of Control Condition for Relevant Controllers
[2020/05/29 08:45:15] DIgSI/info - ------------------------------------------------------------------------------------
[2020/05/29 08:45:15] DIgSI/info - 'West Kenya Grid\SONDU.ElmSym':
[2020/05/29 08:45:15] DIgSI/wrng - ' SONDU' : Maximum Reactive Power Limit exceeded ( Q = 165.33 Mvar > Qmax = 76.00 Mvar )
[2020/05/29 08:45:15] DIgSI/info - ------------------------------------------------------------------------------------
[2020/05/29 08:45:15] DIgSI/info - 'West Kenya Grid\TURKWELL.ElmSym':
[2020/05/29 08:45:15] DIgSI/wrng - ' TURKWELL' : Maximum Active Power Limit exceeded ( P = 105.00 MW > Pmax = 98.60 MW )
[2020/05/29 08:45:15] DIgSI/info - ------------------------------------------------------------------------------------
[2020/05/29 08:45:15] DIgSI/info - 'West Kenya Grid\Synchronous Machine.ElmSym':
[2020/05/29 08:45:15] DIgSI/wrng - ' Synchronous Machine' : Maximum Reactive Power Limit exceeded ( Q = 186.59 Mvar > Qmax = 176.50 Mvar )
[2020/05/29 08:45:15] DIgSI/wrng - ' Synchronous Machine' : Maximum Active Power Limit exceeded ( P = 382.57 MW > Pmax = 45.00 MW )
[2020/05/29 08:45:15] DIgSI/info - ------------------------------------------------------------------------------------
```

APPENDIX J: Schedule 3 – Parallel Transmission Lines Added and Capacitor Banks Switched On



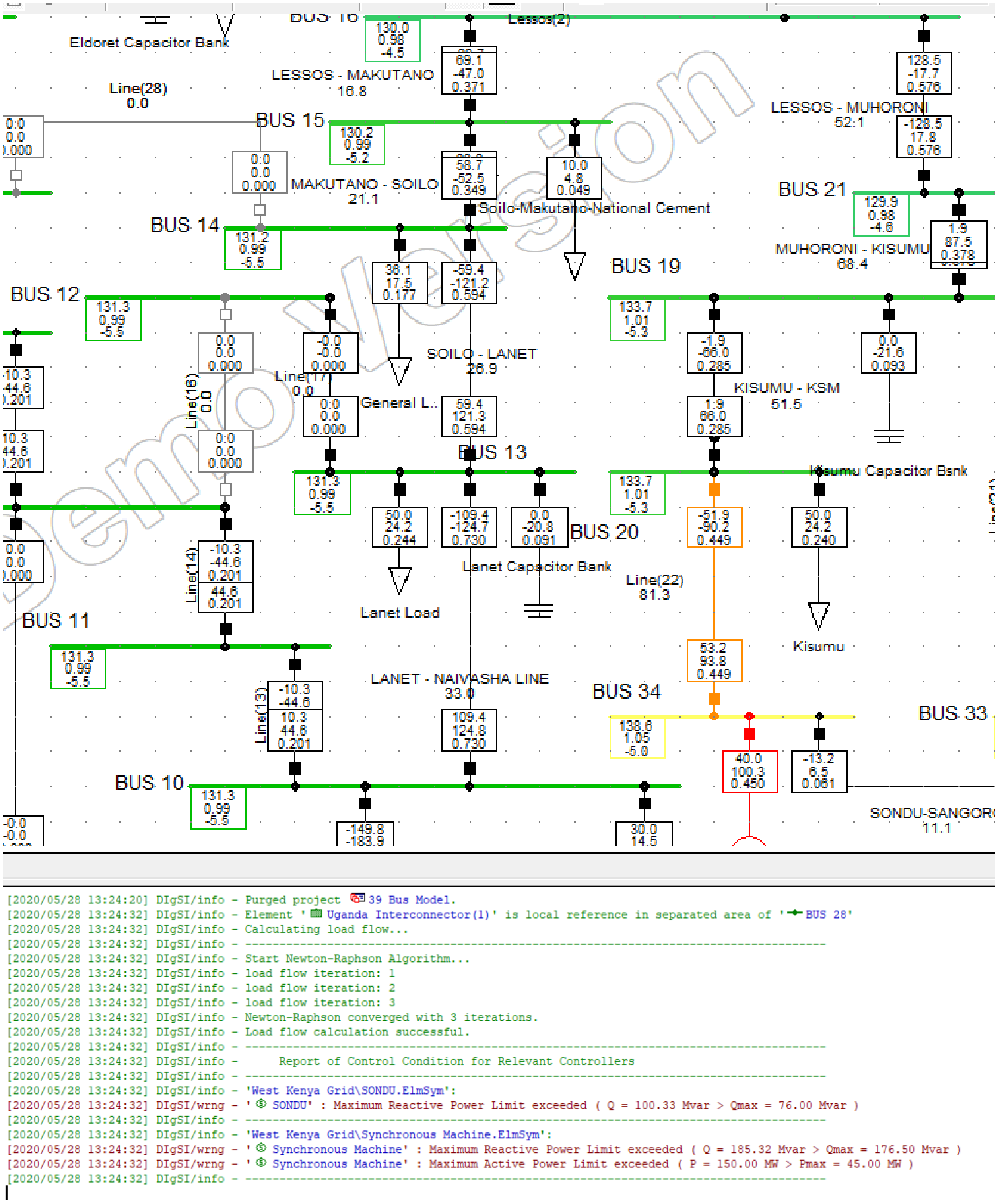
Load Flow Balanced

Nodes	Branches
Line-Line Voltage, Magnitude [kV]	Active Power [MW]
Voltage, Magnitude [p.u.]	Reactive Power [Mvar]
Voltage, Angle [deg]	Current, Magnitude [kA]

PowerFactory 15.1.6

Project:
Graphic: Grid
Date: 28/05/2020
Annex:

West Kenya Grid Freeze Ortho Snap X= 274.194,Y= 107.097



```
[2020/05/28 13:24:20] DIgSI/info - Purged project 39 Bus Model.
[2020/05/28 13:24:32] DIgSI/info - Element ' Uganda Interconnector(1)' is local reference in separated area of ' BUS 28'
[2020/05/28 13:24:32] DIgSI/info - Calculating load flow...
[2020/05/28 13:24:32] DIgSI/info - --------------------------------------------------------------------------------
[2020/05/28 13:24:32] DIgSI/info - Start Newton-Raphson Algorithm...
[2020/05/28 13:24:32] DIgSI/info - load flow iteration: 1
[2020/05/28 13:24:32] DIgSI/info - load flow iteration: 2
[2020/05/28 13:24:32] DIgSI/info - load flow iteration: 3
[2020/05/28 13:24:32] DIgSI/info - Newton-Raphson converged with 3 iterations.
[2020/05/28 13:24:32] DIgSI/info - Load flow calculation successful.
[2020/05/28 13:24:32] DIgSI/info - --------------------------------------------------------------------------------
[2020/05/28 13:24:32] DIgSI/info -      Report of Control Condition for Relevant Controllers
[2020/05/28 13:24:32] DIgSI/info - --------------------------------------------------------------------------------
[2020/05/28 13:24:32] DIgSI/info - 'West Kenya Grid\SONDU.ElmSym':
[2020/05/28 13:24:32] DIgSI/wrng - ' SONDU' : Maximum Reactive Power Limit exceeded ( Q = 100.33 Mvar > Qmax = 76.00 Mvar )
[2020/05/28 13:24:32] DIgSI/info - --------------------------------------------------------------------------------
[2020/05/28 13:24:32] DIgSI/info - 'West Kenya Grid\Synchronous Machine.ElmSym':
[2020/05/28 13:24:32] DIgSI/wrng - ' Synchronous Machine' : Maximum Reactive Power Limit exceeded ( Q = 185.32 Mvar > Qmax = 176.50 Mvar )
[2020/05/28 13:24:32] DIgSI/wrng - ' Synchronous Machine' : Maximum Active Power Limit exceeded ( P = 150.00 MW > Pmax = 45.00 MW )
[2020/05/28 13:24:32] DIgSI/info - --------------------------------------------------------------------------------
```

APPENDIX K: Load Shedding Done in Western Kenya for the Year 2018

M-Y	Dates	MW	MWh	Time of the day	Reasons for Load shedding
Jan-18	05-Jan-18	16.00	36.03	Evening	Done in West Kenya and South Nyanza Regions due to poor system voltages.
	08-Jan-18	28.62	24.69	Evening	Done in C. Rift, West Kenya & S. Nyanza due to poor system voltages & lines overload.
	10-Jan-18	28.37	32.83	Evening	Done in C. Rift, West Kenya & S. Nyanza due to poor system voltages & lines overload.
	11-Jan-18	30.90	43.98	Evening	Done in C. Rift, West Kenya & S. Nyanza due to poor system voltages & lines overload.
	12-Jan-18	36.80	39.84	Evening	Done in C. Rift,N. Rift,West Kenya & S. Nyanza due to poor system voltages & lines overload.
	15-Jan-18	54.00	88.63	Evening	Done in C. Rift,N. Rift,West Kenya & S. Nyanza due to poor system voltages & lines overload.
	16-Jan-18	87.50	106.99	Evening	Done in C. Rift,N. Rift,West Kenya & S. Nyanza due to poor system voltages & lines overload.
	17-Jan-18	92.20	182.50	Evening	Done in C. Rift,N. Rift,West Kenya & S. Nyanza due to poor system voltages & lines overload.
	18-Jan-18	14.40	18.09	Evening	Done in C. Rift & West Kenya due to poor system voltages & lines overload.
	21-Jan-18	105.43	413.92	Morning/Evening	Done in C. Rift,N. Rift,West Kenya & S. Nyanza due to poor system voltages and planned outage at Naivasha substation during the day.
	22-Jan-18	25.00	26.11	Evening	Done in C. Rift,N. Rift & West Kenya due to poor system voltages.
	23-Jan-18	11.80	14.16	Evening	Done in C. Rift, West Kenya & S. Nyanza due to poor system voltages.
	24-Jan-18	12.00	8.00	Evening	Done in C. Rift & S. Nyanza due to poor system voltages.
	25-Jan-18	22.00	1.33	Afternoon	Done in C. Rift,N. Rift,West Kenya & S. Nyanza due to loss of Naivasha-Lanet 132kV Line 1.
	27-Jan-18	11.50	3.96	Evening	Done in S. Nyanza due to poor system voltages.
	29-Jan-18	26.20	20.36	Evening	Done in C. Rift,N. Rift & West Kenya due to poor system voltages.
	30-Jan-18	21.60	25.69	Evening	Done in C. Rift,N. Rift,West Kenya & S. Nyanza due to poor system voltages.
	31-Jan-18	20.00	16.97	Evening	Done in W. Kenya & S. Nyanza due to poor system voltages.
Feb-18	01-Feb-18	49.00	36.77	Evening	Done in West Kenya, South Nyanza, Central Rift and North Rift due to poor system voltages.
	02-Feb-18	7.00	3.38	Evening	Done in S. Nyanza due to poor system voltages.
	06-Feb-18	21.50	36.69	Evening	Done in West Kenya, South Nyanza, Central Rift and North Rift due to poor system voltages.
	07-Feb-18	20.90	7.90	Evening	Done in West Kenya, South Nyanza, Central Rift and North Rift due to poor system voltages.
	08-Feb-18	10.15	15.74	Evening	Done in West Kenya & Central Rift due to poor system voltages and overload on Naivasha Lanet lines.
	09-Feb-18	25.00	112.22	Afternoon	Done in West Kenya,Central Rift & South Nyanza due to overload on Lessos Muhoroni lines and unavailability of GT Muhoroni.
	09-Feb-18	31.00	83.90	Evening	Done in West Kenya, due to poor system voltages.
	10-Feb-18	9.00	15.90	Evening	Done in W. Kenya & S. Nyanza due to poor system voltages.
	12-Feb-18	10.00	2.83	Evening	Done in C. Rift & S. Nyanza due to poor system voltages.
	13-Feb-18	10.70	7.13	Evening	Done in S. Nyanza due to poor system voltages.
	14-Feb-18	80.00	130.30	Evening	Done in West Kenya, South Nyanza, Central Rift and North Rift due to poor system voltages.
	Total C/F to NEXT Page	**918.57**	**1556.84**		

M-Y	Dates	MW	MWh	Time of the day	Reasons for Load shedding
	Total B/F from PREVIOUS Page	**918.57**	**1556.84**		
	15-Feb-18	8.38	1.75	Morning	Done in South Nyanza and C. Rift due to poor system voltages following GT sudden reduction of output to 15MW and Sondu being off due to poor hydrology.
	15-Feb-18	14.40	24.26	Afternoon	Done in West Kenya, South Nyanza and North Rift due to poor system voltages following GT sudden reduction of output to 15MW and Sondu being off due to poor hydrology.
	15-Feb-18	53.19	157.83	Evening	Done in West Kenya, South Nyanza, Central Rift and North Rift due to poor system voltages.
	16-Feb-18	79.80	80.80	Evening	Done in West Kenya, South Nyanza, Central Rift and North Rift due to poor system voltages.
	17-Feb-18	31.81	26.00	Evening	Done in West Kenya, South Nyanza and Central Rift due to poor system voltages.
	20-Feb-18	15.00	50.05	Evening	Done in South Nyanza, Central Rift and North Rift due to poor system voltages.
	21-Feb-18	17.00	33.53	Evening	Done in West Kenya, South Nyanza and North Rift due to poor system voltages.
	22-Feb-18	19.41	22.44	Evening	Done in West Kenya, South Nyanza, Central Rift and North Rift due to poor system voltages.
	23-Feb-18	42.55	23.68	Evening	Done in Nairobi due to loss of generation (Gulf & Triumph) and in C. Rift, N. Rift & S. Nyanza regions due to poor system voltages.
	25-Feb-18	54.10	54.12	Evening	Done in South Nyanza, Nairobi, Central Rift & West Kenya regions due to overloading of Juja -Naivasha Lines. Olkaria - Naivasha 132kV line outage delayed.
	27-Feb-18	29.75	29.82	Evening	Done in West Kenya, South Nyanza and Central Rift due to poor system voltages.
	Total C/F to NEXT Page	**1283.96**	**2061.11**		

M-Y	Dates	MW	MWh	Time of the day	Reasons for Load shedding
	Total B/F from PREVIOUS Page	**1283.96**	**2061.11**		
Mar-18	06-Mar-18	11.50	12.51	Evening	Done in C. Rift, W. Kenya, N. Rift & S. Nyanza regions due to poor system voltages.
	12-Mar-18	20.00	16.05	Evening	Done in South Nyanza, W. Kenya & Central Rift regions due to poor voltages, overloads on Lessos-muhoroni line and Olkaria 1AU TX after trip of GT at 2041Hrs
	13-Mar-18	37.10	63.98	Evening	Done in South Nyanza, Central Rift & North Rift regions due to poor voltages. Done in Nairobi after CB 5W5 failed to close at Ruaraka to de-load TX 1.
	14-Mar-18	34.56	15.20	Evening	Done in West Kenya, South Nyanza, Central Rift and North Rift due to poor system voltages.
	15-Mar-18	13.11	18.86	Evening	Done in North Rift and West Kenya regions due to poor system voltages.
	16-Mar-18	17.10	6.33	Evening	Done in West Kenya, South Nyanza and North Rift due to poor system voltages.
	18-Mar-18	10.50	26.24	Morning/Evening	Done in Central Rift due to planned outage at Lanet substation.
	19-Mar-18	39.58	95.63	Evening	Done in Nairobi & Central Rift Regions due to poor system voltages & B/Down on Juja-Naivasha line 2 (Deloading Ruaraka TX1) .
	29-Mar-18	19.04	17.96	Evening	Load shedding done in South Nyanza, Central and West Kenya Regions due to poor voltages & de-load Naivasha-Lanet lines.
	30-Mar-18	21.00	14.43	Evening	Load shedding done in North Rift, South Nyanza, Central and West Kenya Regions due to poor voltages & de-load Naivasha-Lanet lines.
Apr-18	09-Apr-18	10.00	6.45	Evening	Load shedding done in Central Rift and South Nyanza due to Poor voltage. Kisumu-Muhoroni 132kV was out on breakdown. Most of Kisumu load was out on breakdown
	09-Apr-18	7.00	1.40	Night	Load shedding done in Central Rift due to Poor voltage. Kisumu-Muhoroni 132kV had tripped at 2022Hrs.
	Total C/F to NEXT Page	**1524.45**	**2356.15**		

M-Y	Dates	MW	MWh	Time of the day	Reasons for Load shedding
	Total B/F from PREVIOUS Page	**1524.45**	**2356.15**		
May-18	02-May-18	50.00	47.42	Evening	Done in South Nyanza, West Kenya and Central Rift due to poor voltages (Sondu and Sang'oro units s/d to facilitate CTs terminal block repairs at Sondu substation)
	09-May-18	18.00	36.52	Evening	Done in South Nyanza &West Kenya due to poor voltages-Turkwel G2 failed to come on load due to broken stator pin.
	15-May-18	10.00	6.00	Evening	Done in Central Rift due to poor voltages caused by trip of Sang'oro G1.
	16-May-18	19.71	16.32	Evening	Done in South Nyanza &West Kenya due to poor voltages-Turkwel G1 was un-available.
	18-May-18	17.39	8.42	Evening	Done in Central Rift & West Kenya due to poor voltages caused by trip of GT Muhoroni.
	19-May-18	25.80	10.63	Evening	Done in South Nyanza & Central Rift due to poor voltages-Turkwel G2 was un-available.
	20-May-18	24.08	17.29	Evening	Done in Nairobi, N. Rift, S. Nyanza and W. Kenya due to poor voltages & generation shortfall.
	22-May-18	21.00	16.33	Evening	Done in South Nyanza & Central Rift due to poor voltages.
	25-May-18	22.00	33.00	Evening	Done in South Nyanza and Central Rift region due to poor voltages and de-load Naivasha – Lanet lines. Turkwel G2 was un-available.
Jun-18	05-Jun-18	20.30	6.75	Evening	Done in C. Rift, N. Rift, South Nyanza & West Kenya regions due to poor voltages.
	10-Jun-18	33.00	24.50	Evening	Done in South Nyanza, West Kenya and Central Rift regions due to Trip of 75MVA TX 2 at Lessos limiting evacuation of Turkwel generation.
	14-Jun-18	24.10	12.38	Afternoon	Done in North Rift, Western and Central Rift region due to Trip of 75MVA TX 1 at Lessos and Turkwel-Lessos 220kV line.
Jul-18	03-Jul-18	14.30	18.55	Evening	Done in South Nyanza and Central Rift regions due to poor voltages as a result of unavailability of GT Muhoroni.
	10-Jul-18	21.00	25.62	Evening	Done in South Nyanza and Central Rift regions due to poor voltages as a result of unavailability of GT Muhoroni.
	12-Jul-18	9.00	11.52	Evening	Done in South Nyanza and Central Rift regions due to poor voltages as a result of unavailability of Kegati capacitors.
	18-Jul-18	12.35	9.05	Evening	Done in South Nyanza region due to poor voltages.
	23-Jul-18	20.00	17.27	Evening	Done in North Rift,West Kenya and Central Rift regions due to poor voltages.
	24-Jul-18	22.80	34.08	Evening	Done in North Rift,West Kenya , S. Nyanza and Central Rift regions due to poor voltages.
	25-Jul-18	18.05	27.36	Evening	Done in North Rift,West Kenya , S. Nyanza and Central Rift regions due to poor voltages.
	26-Jul-18	59.96	51.14	Evening	Done in North Rift,West Kenya , S. Nyanza and Central Rift regions due to poor voltages.
	27-Jul-18	21.00	17.39	Evening	Done in North Rift,West Kenya , S. Nyanza and Central Rift regions due to poor voltages.
	28-Jul-18	7.34	9.49	Evening	Done in West Kenya region due to poor voltages.
	30-Jul-18	11.46	24.64	Evening	Done in Central Rift region due to poor voltages.
	31-Jul-18	27.59	30.62	Evening	Done in North Rift,West Kenya , S. Nyanza and Central Rift regions to de-load Naivasha-Lanet lines. Turkwel unit 2 un-available.
	Total C/F to NEXT Page	**2054.68**	**2868.43**		

M-Y	Dates	MW	MWh	Time of the day	Reasons for Load shedding
	Total B/F from PREVIOUS Page	**2054.68**	**2868.43**		
Aug-18	07-Aug-18	21.00	43.86	Evening	Done in South Nyanza, West Kenya & Central Rift regions due to poor voltages and de-load Naivasha-Lanet lines. Turkwel G1 ooc.
	08-Aug-18	29.60	35.76	Evening	Done in South Nyanza, West Kenya, North Rift & Central Rift regions due to poor voltages and de-load Naivasha-Lanet lines. Turkwel G1 ooc.
	10-Aug-18	17.58	22.75	Evening	Done in Western Kenya due to poor voltages. Turkwel G1 ooc.
	13-Aug-18	14.40	14.16	Evening	Done in Western Kenya s due to poor voltages. Turkwel G1 ooc.
	15-Aug-18	70.60	76.53	Evening	Done in Western Kenya due to poor voltages. Turkwel G1 and Olkaria 4 G2
	16-Aug-18	44.60	48.81	Evening	Done in South Nyanza, West Kenya, Central Rift & North Rift regions due to poor voltages. Turkwel G1 and Olkaria 4 G2 ooc.
	17-Aug-18	17.50	17.31	Evening	Done in Western Kenya due to poor voltages. Turkwel G1 and Olkaria 4 G2
	18-Aug-18	21.70	18.10	Evening	Done in West Kenya and South Nyanza due to poor voltage profile. Turkwel G1
	20-Aug-18	9.58	4.15	Evening	Done in Central Rift region due to poor voltages.
	22-Aug-18	17.00	20.40	Evening	Done in South Nyanza & Central Rift regions due to poor voltages.
	23-Aug-18	18.00	6.71	Evening	Done in South Nyanza & Central Rift regions due to poor voltages.
	28-Aug-18	16.15	13.24	Evening	Done in Western Kenya s due to poor voltages.
	29-Aug-18	15.35	18.90	Evening	Done in South Nyanza & West Kenya regions due to poor voltages.
	31-Aug-18	30.00	12.54	Evening	Done in South Nyanza, West Kenya & North Rift regions due to poor voltages.
Sep-18	04-Sep-18	6.02	6.83	Evening	Done in Central Rift & West Kenya regions due to poor voltages.
	09-Sep-18	21.38	6.64	Evening	Done in South Nyanza & West Kenya regions due to poor voltages.
	11-Sep-18	30.00	25.03	Evening	Done in South Nyanza, West Kenya, Central Rift & North Rift regions due to poor voltages.
	12-Sep-18	26.24	30.34	Evening	Done in South Nyanza & Central regions due to poor voltages.
	13-Sep-18	49.99	68.26	Evening	Done in Western Kenya due to poor voltages. GT Muhoroni unavailable and UETCL could not export.
	14-Sep-18	36.97	71.00	Evening	Done in Western Kenya due to poor voltages. GT Muhoroni unavailable and UETCL export fluctuating.
	15-Sep-18	13.00	24.92	Evening	Done in South Nyanza & West Kenya regions due to poor voltages. GT Muhoroni unavailable.
	17-Sep-18	18.80	14.20	Evening	Done in Central Rift & North Rift regions due to poor voltages.
	18-Sep-18	30.70	51.23	Evening	Done in Western Kenya due to poor voltages.
	19-Sep-18	28.82	44.86	Evening	Done in South Nyanza, Central Rift & North Rift regions due to poor voltages.
	20-Sep-18	50.00	85.50	Evening	Done in South Nyanza, West Kenya, Central Rift & North Rift regions due to poor voltages.
	21-Sep-18	51.00	116.32	Evening	Done in South Nyanza, West Kenya,Central Rift & North Rift regions due to poor voltages caused by trip of GT and Sangoro machines.
	22-Sep-18	27.00	47.18	Evening	Done in Western Kenya due to poor voltages caused by lack of GT and Sangoro machines.
	24-Sep-18	23.85	40.88	Evening	Done in Western Kenya due to poor voltages caused by lack of GT Muhoroni.
	25-Sep-18	17.51	28.26	Evening	Done in Western Kenya due to poor voltages caused by absence of GT Muhoroni.
	26-Sep-18	30.34	47.12	Evening	Done in Western Kenya due to poor voltages.
	27-Sep-18	23.00	28.93	Evening	Done in Western Kenya due to poor voltages & deloading Naivasha - Lanet lines.
	28-Sep-18	21.00	24.37	Evening	Done in Western Kenya due to poor voltages.
	29-Sep-18	19.00	14.87	Evening	Done in Western Kenya due to poor voltages.
	Total C/F to NEXT Page	**2922.37**	**3998.37**		

M-Y	Dates	MW	MWh	Time of the day	Reasons for Load shedding
	Total B/F from PREVIOUS Page	**2922.37**	**3998.37**		
Oct-18	01-Oct-18	20.00	24.67	Evening	Done in South Nyanza, Central Rift & North Rift regions due to poor voltages.
	02-Oct-18	18.00	19.37	Evening	Done in South Nyanza, Central Rift & North Rift regions due to poor voltages.
	03-Oct-18	33.93	55.34	Evening	Done in South Nyanza, Central Rift & West Kenya regions due to poor voltages.
	04-Oct-18	25.10	20.47	Evening	Done in West Kenya, Central Rift & North Rift regions due to poor voltages.
	05-Oct-18	22.82	19.14	Evening	Done in West Kenya,South Nyanza & North Rift regions due to poor voltages.
	09-Oct-18	17.20	20.23	Evening	Done in Central & North Rift regions due to poor voltages.
	10-Oct-18	28.20	28.43	Evening	Done in Central & North Rift regions due to poor voltages.
	11-Oct-18	31.00	54.98	Evening	Done in West Kenya,South Nyanza,Central Rift & North Rift regions due to poor voltages.
	12-Oct-18	18.79	17.89	Evening	Done in West Kenya & South Nyanza regions due to poor voltages.
	13-Oct-18	17.00	19.59	Evening	Done in West Kenya,South Nyanza & North Rift regions due to poor voltages.
	14-Oct-18	17.80	22.60	Evening	Done in South Nyanza & Central Rift regions due to poor voltages.
	16-Oct-18	24.40	42.04	Evening	Done in South Nyanza, Central Rift, West Kenya & North Rift regions due to poor voltages.
	17-Oct-18	22.50	40.98	Evening	Done in Central Rift & South Nyanza regions due to poor voltages.
	18-Oct-18	24.13	36.19	Evening	Done in Central Rift & South Nyanza regions due to poor voltages.
	19-Oct-18	23.64	34.54	Evening	Done in North Rift & South Nyanza regions due to poor voltages.
	20-Oct-18	32.00	27.93	Evening	Done in North Rift & South Nyanza regions due to poor voltages.
	21-Oct-18	50.00	48.90	Evening	Done in South Nyanza, Central Rift, West Kenya & North Rift regions due to poor voltages.
	22-Oct-18	32.02	52.31	Evening	Done in South Nyanza, Central Rift, West Kenya & North Rift regions due to poor voltages.
	23-Oct-18	27.70	48.79	Evening	Done in South Nyanza, West Kenya & North Rift regions due to poor voltages and to de-load Naivasha-Lanet lines.
	24-Oct-18	30.61	65.17	Evening	Done in South Nyanza, Central Rift & North Rift regions due to poor voltages and to deload Naivasha-Lanet lines.
	25-Oct-18	17.50	23.47	Evening	Done in South Nyanza & Central Rift regions due to poor voltages and to deload Naivasha-Lanet lines.
	29-Oct-18	16.00	11.92	Evening	Done in South Nyanza, Central Rift & North Rift regions due to poor voltages and to deload Naivasha-Lanet lines.
	30-Oct-18	24.10	47.39	Evening	Done in South Nyanza & Central Rift regions due to poor voltages and to deload Naivasha-Lanet lines.
	31-Oct-18	66.00	59.12	Evening	Done in all Western Kenya Regions due to poor system voltages.
	Total C/F to NEXT Page	**3562.81**	**4839.81**		

M-Y	Dates	MW	MWh	Time of the day	Reasons for Load shedding
	Total B/F from PREVIOUS Page	**3562.81**	**4839.81**		
Nov-18	01-Nov-18	34.77	33.90	Evening	Done in South Nyanza,Western, Central Rift & North Rift regions due to poor voltages
	07-Nov-18	18.00	7.80	Evening	Done in South Nyanza & Central Rift regions due to poor voltages
	08-Nov-18	10.00	6.82	Evening	Done in South Nyanza & West Kenya regions due to poor voltages
	10-Nov-18	10.30	10.82	Evening	Done in South Nyanza & Central Rift regions due to poor voltages
	13-Nov-18	11.00	15.03	Evening	Done in North Rift regions due to poor voltages
	14-Nov-18	13.10	31.88	Evening	Done in South Nyanza region due to poor voltages
	20-Nov-18	16.92	24.26	Evening	Done in South Nyanza & Central Rift regions due to poor voltages
	21-Nov-18	13.20	20.20	Evening	Done in Western & North Rift regions due to poor voltages
	28-Nov-18	46.00	151.48	Evening	Done in South Nyanza, Western, Central Rift & North Rift regions due to poor voltages
	29-Nov-18	41.08	72.91	Evening	Done in Western, Central Rift & North Rift regions due to poor voltages
	30-Nov-18	28.70	46.51	Evening	Done in South Nyanza, Western & North Rift regions due to poor voltages
Dec-18	01-Dec-18	15.10	2.30	Evening	Done in South Nyanza and Western regions due to poor voltages.
	05-Dec-18	39.34	35.79	Evening	Done in South Nyanza, Western & Central Rift regions due to poor voltages.
	06-Dec-18	10.00	15.16	Evening	Done in South Nyanza & Central Rift regions due to poor voltages.
	14-Dec-18	17.11	16.98	Evening	Done in South Nyanza & Central Rift regions to deload Muhoroni - Chemosit 132kV line.
	17-Dec-18	25.00	62.50	Evening	Done in South Nyanza, Western, Central Rift & North Rift regions due to poor voltages.
	19-Dec-18	26.95	30.51	Evening	Done in South Nyanza, Western & Central Rift regions due to trip of Turkwel unit 2.
	21-Dec-18	23.43	54.61	Evening	Done in South Nyanza, Western & North Rift regions due to poor voltages and to de-load Naivasha-Lanet 132kV lines.
	30-Dec-18	16.50	2.86	Evening	Done in South Nyanza and Western regions due to poor voltages and to de-load Naivasha-Lanet 132kV lines.
TOTAL		**3979.31**	**5482.12**		

APPENDIX L: Kenya’s Power Generation Capacities as of 2019

	Installed	Effective*/Contracted	% (effective)
Hydro	826.23	805.00	29.4%
Geothermal	828.44	816.04	29.8%
Thermal (MSD)	689.25	659.96	24.1%
Thermal (GT)	60.00	56.00	2.0%
Wind	336.05	325.50	11.9%
Biomass	28.00	23.50	0.9%
Solar	50.97	50.45	1.8%
Total Capacity MW	2818.93	2736.44	100.0%
Peak Demand MW	1893.00	1893.00	

APPENDIX M: KPLC Merit Order Running for January 2019 Based on Costs for December 2018

STATION	VARIABLE ENERGY COST (A) (KSH/KWH)	FUEL COST (B) (KSH/KWH)	CAPACITY / DEEMED COST CONVERTED TO ENERGY AT CONTR. LOAD FACTOR (C) (KSH/KWH)	FOREX ADJUSTMENT CHARGES (D) (KSH/KWH)	TOTAL GEN. COST (A+B+C+D) (KSH/KWH)	TOTAL VARIABLE COST (A+B) (KSH/KWH)	MERIT ORDER BASED ON VARIABLE COST (A+B)
	1	**2**	**3**	**4**	**5**	**6**	**7**
LTWP 1	0.000	0.000	9.938	0.000	0.000	0.000	**1**
Major Hydros	0.083	0.000	2.664	0.193	2.940	0.083	**2**
Olkaria II	0.107	0.000	4.211	0.029	4.347	0.107	**3**
Olkaria I	2.373	0.000	0.000	0.000	2.373	2.373	**4**
Orpower4-Plant III	2.979	0.000	6.811	0.000	9.790	2.979	**5**
Orpower4-Plant II	2.979	0.000	6.811	0.000	9.790	2.979	**5**
Orpower4-Plant IV	2.979	0.000	6.811	0.000	9.790	2.979	**5**
Orpower4-Plant I	2.979	0.000	6.829	0.000	9.809	2.979	**5**
Olkaria I - AU	3.091	0.000	3.064	0.106	6.261	3.091	**6**
Olkaria IV	3.091	0.000	3.360	0.127	6.578	3.091	**6**
LTWP 3	4.969	0.000	0.000	0.000	4.969	4.969	**7**
Garissa Solar (REA)	5.616	0.000	0.000	0.000	5.616	5.616	**8**
Imenti Tea Factory	6.138	0.000	0.000	0.000	6.138	6.138	**9**
Sang'oro Hydro	6.732	0.000	0.000	0.000	6.732	6.732	**10**
Small Hydros	8.144	0.000	0.000	0.000	8.144	8.144	**11**
Gura - KTDA	8.183	0.000	0.000	0.000	8.183	8.183	**12**
Wind (Ngong)	8.285	0.000	0.000	0.000	8.285	8.285	**13**
WellHead (OW37 & 43)	8.695	0.000	0.000	0.000	8.695	8.695	**14**
Eburru Hill	8.695	0.000	0.000	0.000	8.695	8.695	**14**
Regen Terem	9.715	0.000	0.000	0.000	9.715	9.715	**15**
LTWP 2	9.938	0.000	0.000	0.000	9.938	9.938	**17**
Gikira Hydro Power	10.229	0.000	0.000	0.000	10.229	10.229	**18**
Biojoule (Biogas)	10.323	0.000	0.000	0.000	10.323	10.323	**19**
Chania - KTDA	10.645	0.000	0.000	0.000	10.645	10.645	**20**
Strathmore	12.339	0.000	0.000	0.000	12.339	12.339	**21**
Kipevu Diesel I	0.322	12.350	1.672	0.044	14.388	12.671	**22**
Kipevu III Diesel	0.868	11.909	2.559	0.491	15.827	12.778	**23**
Thika Power2	1.466	11.922	3.044	0.000	16.432	13.388	**24**
Tsavo Power	1.124	12.513	3.770	0.000	17.406	13.637	**25**
STATION	**VARIABLE**	**FUEL**	**CAPACITY / DEEMED COST**	**FOREX**	**TOTAL**	**TOTAL**	**MERIT ORDER**

	ENERGY COST (A) (KSH/KWH)	**COST (B) (KSH/KWH)**	**CONVERTED TO ENERGY AT CONTR. LOAD FACTOR (C) (KSH/KWH)**	**ADJUSTMENT CHARGES (D) (KSH/KWH)**	**GEN. COST (A+B+C+D) (KSH/KWH)**	**VARIABLE COST (A+B) (KSH/KWH)**	**BASED ON VARIABLE COST (A+B)**
Gulf Power	0.844	16.446	3.140	0.000	20.431	17.291	**30**
Triumph Power2	5.408	12.342	4.028	0.000	21.778	17.749	**31**
Iberafrica-Existing	1.234	16.753	3.332	0.000	21.319	17.987	**32**
Triumph Power1	5.408	12.894	4.028	0.000	22.330	18.302	**33**
UETCL (Tie Line)	6.882	14.509	0.000	0.000	21.391	21.391	**34**
UETCL (Requested)	6.882	18.240	0.000	0.000	25.122	25.122	**35**
Muhoroni GT (Active)	0.540	38.939	0.836	0.000	40.314	39.478	**36**

APPENDIX N: Energy Losses under schedule 1 with all Compensators switched off.

No	*BUSES*	*Loading of the Transmission Lines (In percentage)*	*Length (km)*	*Resistance p.u length*	*Initial current conditions prior to additional lines (kA)*	*Initial Energy Losses (W)*	*Current after addition of parallel lines (kA)*	*Energy Losses After proposed simulation (W)*
1	BUS 32 TO BUS 10	Olkaria 1 - Naivasha	23.2	0.0097	1.041	243,872	1.172	309,111
2	BUS 10 TO BUS 13	Naivasha - Lanet	69.4	0.0803	0.732	2,986,051	0.821	3,756,309
3	BUS 13 TO BUS 14	Lanet - Soilo	15.1	0.0109	0.502	41,477	0.617	62,658
4	BUS 14 TO BUS 15	Soilo - Makutano	54.5	0.0576	0.351	386,753	0.492	759,887
5	BUS 15 TO BUS 16	Makutano - Lessos	54.4	0.0685	0.270	271,655	0.387	558,099
6	BUS 17 TO BUS 18	Lessos - Eldoret	32.9	0.0385	0.244	75,411	0.205	53,231
7	BUS 18 TO BUS 3	Eldoret - Kitale	66.3	0.0385	0.199	101,084	0.190	92,147
8	BUS 27 TO BUS 28	Lessos - Musaga	56.1	0.0784	0.734	2,369,578	0.732	2,356,683
9	BUS 28 TO BUS 29	Musaga - Webuye	18	0.0216	0.110	4,704	0.110	4,704
10	BUS 16 TO BUS 21	Lessos - Muhoroni	56.1	0.068	0.599	1,368,754	0.601	1,377,910
11	BUS 21 TO BUS 22	Muhoroni - Chemosit	30.7	0.0368	0.701	555,165	0.695	545,702
12	BUS 22 TO BUS 23	Chemosit - Kegati	59.5	0.05	0.430	550,078	0.426	539,891
13	BUS 21 TO BUS 19	Muhoroni - Kisumu	48.5	0.0581	0.390	428,595	0.346	337,342
14	BUS 20 TO BUS 34	Kisumu - Sondu	50	0.014667	0.544	217,025	0.504	186,283
15	BUS 34 TO BUS 33	Sondu - Sangoro	5	0.005993	0.061	111	0.061	111
	TOTAL					**9,600,312**		**10,940,069**
							`	

APPENDIX O: KPLC Rates for Economic Analysis of Transmission Lines

Item	**Rate**	**Unit**
Capital Cost	x	Dollars
Load Factor	0.7	
LLF	0.553	
LRMC	0.2773	USD/kWh
COUE	1.5	USD/kWh
Exchange Rate	100	USD/KSHS
O & M	2.5% of x	Dollars
Project Lifetime	40	Years
Discount Rate	12%	
Growth rate	7%	
Losses Before	y	MW
Losses After	z	MW
Loss Savings	$y - z$	MW
Loss Savings	$(y - z)$*LLF*1000*8760	kWh
Avoided Loadshedding		kWh
LRMC of Generation	0.1893	USD/kWh
LRMC of Distribution	0.0854	USD/kWh

APPENDIX P: Average loading of the Schedule 1, 2 and 3

BUSES	Transmission Lines	Compensators Switched off	Compensators Switched on	Capacitors switched on; Reactors switched off	Capacitors switched off; Reactors switched on	Compensators Switched off, Additional parallel lines	Capacitors Switched on, Additional parallel lines
BUS 32 TO BUS 10	Olkaria 1 - Naivasha	91.20%	83.80%	78.40%	97.60%	34.10%	28.30%
BUS 10 TO BUS 13	Naivasha - Lanet	66.00%	60.90%	58.40%	68.90%	36.90%	30.70%
BUS 13 TO BUS 14	Lanet - Soilo	45.20%	45.40%	42.40%	48.50%	27.60%	24.10%
BUS 14 TO BUS 15	Soilo - Makutano	34.50%	31.90%	28.20%	35.20%	22.00%	18.10%
BUS 14 TO BUS 16	Makutano - Lessos	24.30%	24.40%	23.50%	25.90%	17.30%	15.20%
BUS 16 TO BUS 21	Lessos - Muhoroni	106.40%	106.60%	104.10%	106.60%	53.40%	51.50%
BUS 22 TO BUS 23	Chemosit - Kegati	75.70%	65.70%	65.10%	76.30%	75.20%	64.70%
BUS 32 TO BUS 10	Olkaria 1 - Naivasha	163.90%	163.20%	154.00%	175.50%	55.80%	51.70%
BUS 10 TO BUS 13	Naivasha - Lanet	104.70%	103.10%	98.40%	110.60%	59.50%	55.10%
BUS 13 TO BUS 14	Lanet - Soilo	82.30%	84.20%	79.00%	88.20%	48.50%	45.60%
BUS 14 TO BUS 15	Soilo - Makutano	66.00%	68.00%	62.90%	72.00%	40.50%	37.70%
BUS 15 TO BUS 16	Makutano - Lessos	23.90%	25.30%	22.80%	29.00%	19.10%	16.80%
BUS 16 TO BUS 21	Lessos - Muhoroni	110.50%	123.20%	113.00%	117.40%	53.40%	53.50%
BUS 22 TO BUS 23	Chemosit - Kegati	78.00%	68.70%	67.00%	79.60%	76.50%	65.80%
BUS 32 TO BUS 10	Olkaria 1 - Naivasha	163.90%	163.20%	154.00%	175.50%	55.80%	51.70%
BUS 10 TO BUS 13	Naivasha - Lanet	104.70%	103.10%	98.40%	110.60%	59.50%	55.10%
BUS 13 TO BUS 14	Lanet - Soilo	82.30%	84.20%	79.00%	88.20%	48.50%	45.60%
BUS 14 TO BUS 15	Soilo - Makutano	66.00%	68.00%	62.90%	72.00%	40.50%	37.70%
BUS 14 TO BUS 16	Makutano - Lessos	23.90%	25.30%	22.80%	29.00%	19.10%	16.80%
BUS 16 TO BUS 21	Lessos - Muhoroni	110.50%	123.20%	113.00%	117.40%	53.40%	53.50%
BUS 22 TO BUS 23	Chemosit - Kegati	78.00%	68.70%	67.00%	79.60%	76.50%	65.80%
Average		81.04%	80.48%	75.92%	85.89%	46.34%	42.14%
		80.83%				**44.24%**	

APPENDIX Q: Annual Growth Rate in the Four Regions of Kenya

NAIROBI REGION																
YEAR	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19
MONTH																
JULY	406	429	467	486	539	562	565	589	617	638	718	754	776	829	818	857
AUGUST	401	431	466	489	536	557	568	597	610	659	721	772	761	831	808	882
SEPTEMBER	408	435	468	496	532	539	573	596	600	672	722	762	823	817	835	872
OCTOBER	416	436	460	501	541	542	581	606	610	681	736	765	842	818	824	871
NOVEMBER	418	446	466	504	537	567	582	614	629	669	736	811	796	830	829	882
DECEMBER	413	446	471	503	540	562	588	602	641	670	735	761	771	802	843	868
JANUARY	408	439	465	500	530	568	578	603	645	682	748	767	826	798	841	871
FEBRUARY	410	436	458	501	531	561	570	607	644	703	768	767	796	789	829	879
MARCH	408	453	464	512	544	555	566	606	647	670	738	752	785	799	821	913
APRIL	420	443	466	517	547	547	567	610	642	676	757	767	803	804	838	903
MAY	419	450	475	520	545	556	569	623	647	716	756	758	830	808	881	898
JUNE	427	448	481	522	548	566	585	611	662	713	756	775	827	800	857	905
AVERAGE	413	441	467	504	539	557	574	605	633	679	741	768	803	811	835	883
Annual Growth Rate	5.4%	6.8%	6.0%	7.9%	6.9%	3.3%	3.1%	5.4%	4.6%	7.3%	9.1%	3.6%	4.6%	0.9%	3.1%	5.7%
Average Annual Growth	**5.2%**															

COAST REGION																
YEAR	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19
MONTH																
JULY	130	134	142	146	171	165	173	182	202	221	227	228	245	250	318	308
AUGUST	131	140	145	156	173	166	176	182	206	214	234	243	261	282	275	300
SEPTEMBER	129	141	145	153	166	166	182	206	203	218	252	249	259	268	299	305
OCTOBER	130	137	147	151	162	205	188	200	208	237	248	244	257	271	284	307
NOVEMBER	131	140	152	167	166	175	188	203	216	226	254	249	254	274	299	320
DECEMBER	137	143	153	164	164	199	188	200	210	224	251	257	262	290	289	344
JANUARY	138	147	157	166	155	183	195	205	252	261	251	247	276	276	298	322
FEBRUARY	138	150	164	164	170	176	188	208	247	218	243	270	279	312	317	318
MARCH	141	152	160	179	170	183	187	220	232	256	267	262	269	323	290	340
APRIL	135	149	153	165	174	196	192	213	271	227	246	247	262	292	292	337
MAY	129	143	145	174	180	169	181	217	221	224	233	237	251	279	294	319
JUNE	126	145	140	164	159	168	178	197	201	212	235	237	315	290	296	329
AVERAGE	133	143	150	162	168	179	185	203	222	228	245	248	266	284	296	321
Annual Growth Rate	-1.4%	7.9%	4.8%	8.0%	3.2%	7.1%	2.9%	9.7%	9.8%	2.6%	7.4%	1.0%	7.3%	6.9%	4.2%	8.4%
Average Annual Growth	**5.6%**															

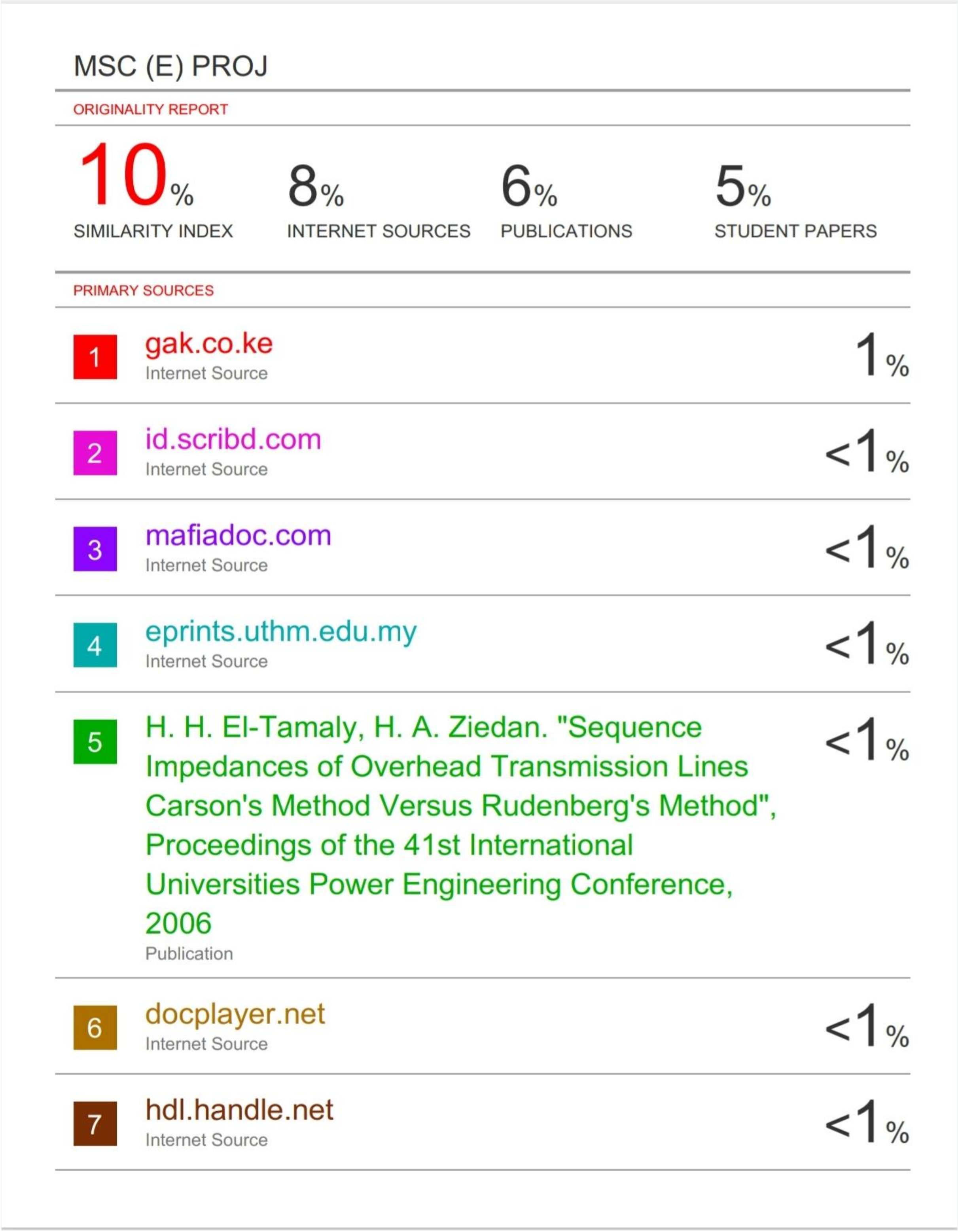
WESTERN REGION

YEAR	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19
MONTH																
JULY	152	153	175	181	193	210	201	206	219	256	267	292	330	355	391	414
AUGUST	158	157	171	181	192	208	196	216	233	258	253	279	327	357	399	404
SEPTEMBER	157	160	175	187	196	207	205	218	241	250	255	292	341	363	393	410
OCTOBER	159	170	177	186	207	217	206	231	259	265	261	292	336	361	376	415
NOVEMBER	166	171	178	186	204	206	209	227	253	237	266	309	338	366	383	431
DECEMBER	161	169	177	192	201	203	207	225	239	219	281	292	334	373	389	418
JANUARY	160	176	178	195	184	195	246	231	242	245	275	299	349	366	388	446
FEBRUARY	158	174	175	190	195	210	208	221	236	244	278	293	354	368	381	431
MARCH	161	175	176	189	200	202	200	219	228	239	270	274	364	369	391	390
APRIL	155	174	174	185	199	209	200	228	246	248	281	306	357	378	396	382
MAY	160	170	176	188	212	205	212	230	252	245	298	321	363	367	400	417
JUNE	160	175	177	194	209	208	208	233	258	262	295	327	363	391	414	429
AVERAGE	159	169	176	188	199	207	208	224	242	247	273	298	346	368	392	416
Annual Growth Rate	4.2%	6.2%	4.2%	6.9%	6.1%	3.6%	0.7%	7.5%	8.3%	2.1%	10.5%	9.0%	16.2%	6.2%	6.5%	6.0%
Average Annual Growth	**6.5%**															

MT. KENYA REGION

YEAR	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19
MONTH																
JULY	73	75	80	84	96	118	109	113	107	124	142	148	140	160	154	168
AUGUST	72	79	90	85	100	110	109	112	110	114	136	150	139	142	161	186
SEPTEMBER	79	81	90	90	104	111	108	114	116	125	149	151	177	149	167	168
OCTOBER	78	79	87	100	104	103	104	111	123	122	147	158	141	148	163	167
NOVEMBER	76	80	85	87	102	102	110	98	124	103	149	149	151	151	157	179
DECEMBER	72	79	86	89	112	105	113	104	122	108	147	154	155	159	160	182
JANUARY	78	83	83	90	109	106	111	97	119	103	152	151	153	153	167	181
FEBRUARY	79	81	82	99	103	105	108	98	129	117	143	148	150	154	155	177
MARCH	77	83	80	100	105	104	110	96	111	119	143	140	151	153	142	178
APRIL	75	73	80	96	101	100	110	105	113	111	144	139	159	152	160	177
MAY	81	83	81	92	110	103	110	116	136	122	159	141	152	171	159	185
JUNE	80	86	88	99	113	105	113	114	125	120	158	138	156	157	160	178
AVERAGE	77	80	84	93	105	106	110	107	120	116	147	147	152	154	158	177
Annual Growth Rate	3.5%	4.5%	5.1%	9.9%	13.3%	1.1%	3.3%	-2.8%	12.2%	-3.2%	27.4%	-0.2%	3.4%	1.4%	2.8%	11.7%
Average Annual Growth	**5.8%**															

SIMILARITY REPORT



MSC (E) PROJ

ORIGINALITY REPORT

10%	8%	6%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	gak.co.ke Internet Source	1%
2	id.scribd.com Internet Source	<1%
3	mafiadoc.com Internet Source	<1%
4	eprints.uthm.edu.my Internet Source	<1%
5	H. H. El-Tamaly, H. A. Ziedan. "Sequence Impedances of Overhead Transmission Lines Carson's Method Versus Rudenberg's Method", Proceedings of the 41st International Universities Power Engineering Conference, 2006 Publication	<1%
6	docplayer.net Internet Source	<1%
7	hdl.handle.net Internet Source	<1%