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MSC. (ENG) ENERGY MANAGEMENT

Analysis of the Network Performance and Development of Electricity Transmission Plan:

A Case Study of Kenya's Coast Region.

RESEARCH PROJECT REPORT

Submitted by:

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F56/87981/2016

In Partial Fulfillment and Requirement of the award of MSc. (Energy Management) at the University of Nairobi

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Declaration

I, **Sungu Harrison Jerry Shiverenje**, **F56/87981/2016,** hereby declare that this research project is my original work and except where acknowledgements and references are made to previous work, the work has not been submitted for examination in any other University.

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I confirm that this study was carried out under my supervision and has been submitted for examination with my approval as University supervisor.

Dr. P. Musau: Signature: .... Date 29/07/2021

Prof. C. Wekesa: Signature: .... Date 28/07/2021

Dedication

Special dedication to my family and friends and especially wife Gentille, your support and prayers are the reasons why I have reached this far. God bless you all.

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I would like to express my heartfelt gratitude to Mr. Amos Nabaala for the relentless support and providing me with updated power system data. To Dr. Peter Musau and Professor Cyrus Wekesa for their invaluable guidance and last but not least to the Late Professor Maurice Mang'oli for his advice, your memory lives on.

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ABSTRACT

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Analysis of Network Performance and Development of Electricity Transmission Plan: A Case Study of Kenya's Coast Region

A coordinated resource requirement planning is vital to ensure growing demand for electric power is adequately and effectively met in an affordable manner. Transmission networks determine how efficiently the generated energy meets the demand. Bottom-up approach; where specific areas/regional requirements are aggregated to form a global or national requirement is preferred to ensure objective investment planning in power systems. In the planning for implementation by the national and county governments, only global system performance is recorded and analysed with little or no focus on the region-specific network needs. As at 2018, the peak power demand for Kenya's Coast Region was 256MW. In 20 years', time, the demand for the region is expected to be 1300MW. The generation as at 2018 was 300MW.This is expected to reach about 2000MW in 2039.The region' electricity network has been modelled in PSS/E. The target year (2039) network model has additionally been prepared with data from the transmission utilities in Kenya. The power system for the region has been analysed. Load flow solution using Newton Raphson methods were employed to analyse the models for both normal (N-0) and during a contingency (N-1) security criterion. The performance of the regional network in terms of efficiency and security has been determined. It is noted that Coast Region's transmission network efficiency is above 95% and the network however does not meet (N-1) security criteria. Additional improvements and reinforcements have been proposed to improve the network. An improved network is developed by modelling the proposed elements into the initial models and analysed again to confirm the impact. Improvement in efficiency (97%) and compliance to (N-1) security criterion is achieved. A transmission plan with schedule and estimated cost has been developed; 300 Million US Dollars being the estimated cost of additional transmission elements required for improvement of efficiency and compliance to (N-1) security requirement. This research project report presents the details of system modelling, simulation and analysis of both the current and planned transmission system of the Kenya's Coast Region. Discussion on the baseline data, analysis methodology, assessment of network performance through analysing of the current and future power system is given. The recommendations for improved system performance is provided in form of scheduled pipeline of transmission projects as the interventions required for realisation of adequate, efficient and reliable transmission system for the Kenya's Coast Region.

Key Words: security, planning, Coast Region.

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List of Abbreviations and Acronyms

A	Ampere
ACS	Aluminium Coated Steel
ACSR	Aluminium Conductor Steel Reinforced
BSP	Bulk Supply Point
CCGT	Combined Cycle Gas Turbine
CIDP	County Integrated Development Plan
COFEK	Consumers Federation of Kenya
EPZ	Export Processing Zone
ERC/EPRA	Energy Regulatory Commission / Energy and Petroleum Regulatory Authority)
ESIA	Environmental and Social Impact Assessment
FiT	Feed In Tariff
HFO	Heavy Fuel Oil
IEC	International Electro technical Commission
JICA	Japan International Corporation Agency
K	Kilo ($x10^3$)
KAM	Kenya Association of Manufacturers
KDP	Kipevu Diesel Plant
KenGen	Kenya Generation Company
KETRACO	Kenya Electricity Transmission Company
KNBS	Kenya National Bureau of Statistics
KNDGC	Kenya National Transmission Grid Code
KNTGC	Kenya National Distribution Grid Code
KPC	Kenya Pipeline Company
KPG&TMP	Kenya Power Generation & transmission Master Plan
KPLC	Kenya Power & Lighting
LCPDP	Least Cost Power Development Plan
LNG	Liquefied Natural Gas
M	Mega ($x10^6$)
m sq.	meters square
MoE	Ministry of Energy
MSD	Medium Speed Diesel
OPGW	Optical Fibre Ground Wire

PB	Parsons Brinkerhoff
PPA	Power Purchase Agreement
PSCAD	Power System Computer Aided Design
PSS/E	Power Simulation Software for Engineers
p.u	per unit
PV	Photo Voltaic
RAP	Resettlement Action Plan
REA/REREC	Rural Electrification Authority/Rural Electrification & Renewable Energy Corporation
SEZ	Special Economic Zone
SGR	Standard Gauge Railway
SLD	Single Line Diagram
TX	Transformer
VA	Volt-amperes
V	Volts
USD	United States Dollars
W	Watts

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CHAPTER 1

1. Introduction

1.1 Background

The key elements in the power systems include generation , transmission and distribution facilities. Transmission system includes a network of subsystems comprising substations, transmission lines, voltage support and reactive power equipment. Power system planning tends to answer key questions required to make sound investment decisions such as when and where an element is required; what, in terms of size and specifications, should the element be in order to satisfactorily meet the particular objective. Power system planning comprises demand forecasting, generation planning, transmission and distribution system planning. These require completely different speciality, tools and efforts. The output of each serve as input of the next in the same order, except for distribution planning whose output can at times be used at input to transmission expansion planning.

According to [2], there exists constraints and uncertainties that notably contribute to complicating the planning process. The constraints broadly include technical, regulatory, legislative, environmental, quality, pricing etc and all these can be addressed through: -

i) Conducting integrated least cost planning studies in both generation and transmission,
ii) Incorporation of constraints and uncertainties into power system planning,
iii) Preforming power market pricing studies,
iv) Preparing feasibility studies, including economic and financial analysis,
v) Recommending rates prices and tariffs after thorough analysis.

Uncertainties in planning for transmission expansion have become more pronounced in market-oriented environment where electricity is traded as a commodity; generated and retailed by more than one player. This has been seemingly adopted by most power industries/utilities over the world and has encouraged independence in choice of sites where the generation sources can be located or sited depending on the economics; the physical aspects of supply and demand playing a prominent role in power markets. These increase the uncertainties in the generation planning that transmission expansion planner will need to find a solution for [3].

In development of concise least cost power development plans reliance to multi-disciplined experienced resource persons from the fields of power system planning, power system operations, power contracts, regulatory, economics, finance drawn from electric utilities, consumers' representatives, academic faculties, consulting firms and government institutions is necessary [4].

Load forecasting is a key step in planning, whose main objective is to predict peak load conditions over a period as determined by factors such as population growth rate, GDP etc.

Generation planning determines the generation requirements to adequately satisfy the load. The type, location, capacities and system security requirements are some of the decisions that are informed by generation planning.

The broader objectives for development of power transmission systems are to improve the system adequacy so as to match the increase in demand, increase system efficiency, improve quality of supply and improve system security to fully satisfy the demand [1]. The transmission investments can be capital intensive; thus, it is imperative that the development/expansion plan be deliberate and objective.

1.2 Basis Terms:

Stability- Is defined as the ability of an interconnected power system to have the power network characteristics such as voltage and frequency remaining constant following a disturbance on the power network.

Security- This is the assurance that the electric power generated to supply power demand connected to the network will be ensured despite changes in the network topology

Planning- power system planning is the action or collection of actions leading to the development of plans required for establishment of power systems and its elements in order to meet agreed objectives and satisfy future needs.

1.3 Problem Statement

At the regional perspective, very little is done to measure and address the transmission network inefficiencies and poor system security. Owing to the significance of the Coast Region, there is need to assess the network performance and recommend a schedule of transmission lines projects development that will ensure efficient and reliable transmission system with improved quality and security of transmission service in the region.

1.4 Justification

System operations data from Kenya Power & Lighting Company Limited (KPLC) and interviews with large power customers in the region suggest that the current transmission network at the Coast Region is not adequate to meet transmission needs for the region. The network in the region is said to be characterised by losses due to overloading on some transmission lines & transformers at peak periods and poor quality due to voltage variations resulting from inadequate voltage support in the region. At peak load, the voltages at some section of the grid are too low and this has negative impact on the supply quality. Similarly, at off peak, some sections of the grid experience extremely high voltages that are detrimental to equipment. System security of transmission system for the region has also been put to question despite the continuous planning and development of new power plants and transmission lines in the region.

Coast Region has a uniqueness of hosting major diesel-powered generators on which the national grid relies on especially during periods of low hydrology. The region in addition, possess as a favourable site for proposed power plants from various sources including LNG, Coal and Nuclear. These are mega power plants that are expected to generate over 2GW of power [7,8]. Several renewable energy based power generation such as Malindi Solar, Bahari Wind, Witu Solar and Rea Vipingo Biomass have also been proposed and are in various stages of development. These notwithstanding and considering the growing interest to invest and develop industries in the coastal areas coupled by the need to increase electricity access to the approximately 2 million households in the region, it is noble to say that the region needs a power transmission plan that will ensure adequate, efficient, reliable and quality power supply to the all in the region [7,8].

1.5 Research Objectives

1.5.1 Main Objectives

The study main objective is to analyse the performance of the power transmission network at the Coast Region and develop a transmission expansion plan for the region.

1.5.2 Specific Objectives

The Specific Objectives are:

i) Develop up to update transmission network models for Coast region.
ii) Investigate the technical losses in the transmission network at the Coast Region.
iii) Establish the degree of system security for the transmission network in Coast Region.
iv) Develop an implementation schedule for future transmission lines projects in the Coast Region.

1.6 Research Questions

i) Which elements comprise the transmission network for the Coast Region?
ii) What are the technical losses in the transmission network at the Coast Region?
iii) At what level system security is for the transmission network in Coast Region?
iv) Which projects will be required to ensure improved efficiency and system security of power transmission in the Coast Region?
v) When should the identified projects be implemented?
vi) What is the cost of implementing these projects?

1.7 Scope

The study focuses on improvement of efficiency and achievement of (N-1) security for the transmission system of Kenya’s Coast Region alongside provision of a 20-year transmission master plan for the Coast Region in Kenya. The target year being 2039. The master plan will contain a schedule of power transmission projects that are determined through power system studies aided by PSS/E a power system simulation software. Power transmission system for the Coast region will be modelled to mirror the existing transmission network and power system. In order to appreciate the current system performance, interviews will be limited to representatives of Kenya Power, KETRACO, EPRA MoE and at least five (5) large power customers in the region. Load data will be collected for all the bulk supply points in the region that include Rabai, Malindi, New Bamburi, Kilifi, Voi, Galu, Kipevu, Garsen and Lamu. In terms of counties coverage, focus will be limited to Mombasa, Kilifi, Kwale, Tana

River Taita Taveta and Lamu. These have shown and demonstrated need for more power in order to power their county developmental projects

1.8 Report Organisation

Chapter 1 includes introduction and provides the background and details the project research objectives and justification. The scope of the research is also given.

Chapter 2 has literature review and elucidates the process and importance of transmission system planning. The previously conducted research exercise in the form of sector planning and system studies reports are given. The research gap is also demonstrated.

Chapter 3 contains methodology, here, the methods used in carrying out the research, data collection techniques, pertinent power system components and topology of the region under study are given. In addition, sources of data for future demand and generation including network performance analysis tools & methods are given.

Chapter 4 includes results with limited interpretation, this chapter gives of the Coast Region's demand forecast data and planned generation as expected from 2019-2039.The simulation results on the future transmission network for years 2020,2022,2025,2030,2035 and 2039 are also given.

Chapter 5 contains the results discussion where the results are discussed in detail, the constraints in network performance are drawn and mitigation measures in terms of network reinforcements are presented.

Chapter 6 finally has conclusion and recommendations. The research is concluded detailing key take homes. The contribution of the research towards filling the gap is given including recommendations further work required to improve on the subject.

CHAPTER 2

2. Literature Review

This Chapter highlights the process and importance of transmission system planning as documented in various reference materials. The previously conducted research exercise in the form of sector planning and system studies reports are also shared then their achievements and gaps on research also highlighted.

2.1 Transmission System Planning and System Studies

Investment in transmission system requires a well thought forward-looking transmission expansion planning process to ensure cost effectiveness [1,3].The investment required to meet objectives in the near short term should, in a large extent, remain relevant and build up to investment required to meet objectives in the long term. Transmission expansion planning can be further broken into substation expansion planning and network expansion planning.

The planning process can be static- where a long period is broken down into shorter periods so as to distinctively fit requirements for particular instance within the considered span of the short period. The planning processes can also be dynamic, where the requirements for the different instances over the longer period are considered all together and implemented or delivered in phases building up to system that is relevant over a longer period. Dynamic planning ensures a gradual but effective expansion process where key performance indicators required of power systems: - security and economy are ensured over longer periods. Security of supply is determined by the quality of equipment, deep knowledge/ understanding of the power system while complying to the set standards/norms that include national codes.

Transmission expansion planning (substation or transmission network expansion) can be further broken down into three steps namely: basic planning, system development planning and project planning. These steps require different tools/expertise and cover different time periods towards realisation of the expanded transmission network. Basic planning is where fundamental concepts are defined, the planning horizon ranging up to 20 years in most cases and can exceed this in some instances [4].

System development planning comprises detailed planning of system topology mostly based on load forecast with alternative concepts analysed via load flow calculations, short circuit analysis, contingency analysis and stability computations [17]. Computer programs have been developed to assist in carrying out these calculations and computations. Main parameter equipment are defined here. This planning ranges 0-10 years [4]. Project planning starts after system development planning, the projects as defined are implemented typically within 1 to 4 years, though this may vary with projects complexity. What is planned ought to have been analysed to ensure that the elements will indeed meet the expected objectives. The depth of the analysis may depend on the cost and complexity of the additional elements.

Just like all other engineering sciences, power systems analysis commences with formulation of appropriate models that are mostly mathematical models defined by a set of equations or relations describing the interactions between various quantities in a time frame that are studied with a desired accuracy of a physical or engineered component or system [4,5].Thus, before any analyses can be performed, the power system needs to be modelled to represent the actual system - system modelling of existing and futuristic/expected systems can be effected through various computer programs. Continuous model validation is additionally required to ensure that the model mirrors the behaviour of installed system over the study period.

System modelling, simulations and analysis aids in understanding and recording of the expected system behaviour and form key aspect of the system studies required in transmission expansion planning. For transmission system planning, this shall at the minimum, include load flows analysis, fault level calculation and contingency analysis.

Load flow calculations/analysis (also power flow calculations) form a fundamental task in planning (during basic and system development planning phases) and operation of power systems. Load flow analysis primarily serves to determine the loading of equipment, calculation of active and reactive power flow through lines and transformers (branches) in the interconnected power system, determine voltage profiles and most importantly calculate system losses.

Power flow Solution/Calculation is well defined [18,2] as network solution problem with the network of transmission line and transformers described by the linear equation below:

$$\boldsymbol{I_n} = \boldsymbol{Y_{nn}} * \boldsymbol{V_n} \tag{2.1}$$

Where I_n is vector of positive-sequence flowing into the network at its nodes(buses), Y_{nn} the network admittance matrix and lastly V_n is the vector of positive-sequence voltages at the network nodes or buses.

Complexity of the power flow is drawn from the fact that neither I_n nor V_n is known, thus requires iterative trial and error process/scheme or algorithm to try out successive values of I_n and V_n that satisfy the linear algebraic equation above hence determine the power flow solution.

A typical iterative scheme/algorithm is given below:

i) Make initial estimate of the voltage at each bus
ii) Build an estimated current inflow vector, In, at each bus from a boundary condition such as:-

$$\boldsymbol{P_k + jQ_k = V_k I_k} \quad (2.2)$$

With P_k+jQ_k as the net load and generation demand at bus k and V_k as the present estimate of voltage at bus k.

iii) Use equation Eq. 2.2 to obtain new estimate of voltage vector, v_n
iv) Return to Step 2 and repeat the cycle till it converges on unchanging estimate of voltage vector, v.

The various iterative schemes employable to carryout Load/Power flow calculation include:-

i) Newton Raphson schemes namely Full, Fixed Slope Decoupled and Decoupled Newton Raphson schemes
ii) Gauss-Seidel methods (Normal and Modified)

The iterative schemes are packaged in computer programs (commercial and non-commercial) that require/rely on micro processing power of computers to carry out the numerous iterations in fractions of a second eventually leading to a converging solution (convergence).

Some non-commercial programs available on open source:

- Matlab based (Matpower and PSAT)
- InterPSS (java based)

Some commercial programs[1] (professional) widely used include:

- PSS/E
- *Powerfactory* by DIgSILENT
- PSCAD
- Eurostag
- Powerworld

Full Newton-Raphson iterative scheme owing to its rapidness in convergence and tight tolerance in mismatches for better network solutions is preferred. Other Newton Raphson iterative schemes available on PSS/E include Fixed Slope Decoupled Newton-Raphson and Decoupled Newton Raphson.

Gauss-Seidel methods are also available as a power solution method but mostly applicable to network data that has errors intolerable in Newton-Raphson methods.

The power flow solution provides results that are used to check the systems behaviour against the following violations:

- Voltage violations (over or under voltages).
- Branch loading violations (over loading of lines and transformers).

The national grid codes among other norms are used as reference for compliance. Transmission expansion criteria is drawn from these. Where the violations exceed the tolerances as stipulated by the grid code, then corrective action that include the following are recommended:

- Voltage regulation by installed equipment (generators, reactive power devices, transformer taps
- Dispatching additional generator units
- Load curtailment
- Additional investments e.g. reactive power devices, new transmission lines,

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[1] The power utilities in Kenya (KPLC and KETRACO) employ PSS/E as the main power system modelling and analysis tool. Other system modelling tools available at KETRACO include Powerfactory by DIgSILENT and PSCAD by Manitoba Hydro International.

Fault level calculations (symmetrical and asymmetrical) are carried out for various system configuration (topology and dispatch) to determine the sequence impendences, fault levels and ensure correct selection of maximum short circuit rating for substation equipment.

Typical short circuit level for various system voltages are given in the Table 2-1 [18]. This is normally region specific and may vary from one power system to another. The same can be revised to meet the prevailing system conditions.

Table 2-1:Maximum Short Circuit Current Levels

S/n	**System Voltage Level (kV)**	**Short Circuit Level (kA)**
1	66	25
2	132	31.5
3	220	31.5 or 40
4	400	40 or 63 (for some countries /systems)

For contingency analysis (based on the stipulated contingency criteria), where one or more branches (transmission circuit or a transformer) is put out of service and the solution for power flow is determined with the aim of checking for any violation during contingency conditions.

Three possible outcomes as detailed below are expected up on each [18]: -

- Converged and maximum bus mismatch within tolerance, where the system may accommodate the event that this particular element is put of service. However, the magnitude of the violations needs to be checked against the requirement of the grid code
- Voltage collapse solution stopped by non-divergent solution, here the has the impression that the system will try to accommodate the contingency event but may have major issues that could cause system collapse. For this, measures such as re-dispatching, load curtailment, changing generator voltage set points and using installed reactive power devices will be required to mitigate against the effects.
- Not converged. This indicates that the power flow solution is not possible owing to the contingency event. This signals for changes in network topology that include additional reinforcement, in addition to the measures highlighted in the previous section.

2.2 Transmission System Expansion in Kenya

The Government of Kenya through the various agencies is in the process of implementing the vision 2030 projects. These projects are expected to impact the socio-economic aspects and thereby improve the livelihoods of its citizens. Once implemented, it is envisioned in that Kenya will be transformed into a newly industrializing, middle-income country providing a high quality of life to all its citizens [7]. It has been noted that energy related projects are basically one of the fundamental enablers with regards to the achievement of the vision. These include development of new power sources and power networks that will provide and improve accessibility to reliable, clean and affordable power supply. Moreover, the vision projects traverse the entire country and it's expected that, with the devolution and formation of counties, the reliance to affordable, reliable and adequate electric power is set to increase.

The Government of Kenya, through the Ministry of Energy, has identified a number of power generation, transmission projects across the country that will ensure that the power requirements as mentioned above will be adequately met. These projects are in various stages of development and are expected to be complete within the vision period [7].

The projects and their respective schedules are periodically reviewed by the electricity sub sector planning committee, i.e., the Least Cost Power Development Plan or the (Kenya Energy Integrated Development Plan) planning committee under the coordination and stewardship of the Energy Regulatory Commission. This is for the purposes of updating the plan by taking into consideration gains made (or setbacks suffered) and the recent prevailing conditions [6].However, the studies and planning report done in the previous planning exercises are not specific to regions. They focus on the global network perspective and fail to highlight the issues on the regional level.

Development of a robust power network is key to ensure that the increasing demand is adequately met. The requirement of the Kenya National Grid Code notwithstanding, [7] system security and efficiency are key performance indicators in provision of electric power transmission service.

As the power system evolves, the bottom up approach (starting from counties to regions to Country) needs to be considered when carrying out power system planning. This ensures that most of the underlying network issues are determined and suitable corrective actions established for improved transmission service that is efficient and reliable.

2.3 Electricity Transmission System in Kenya

The Electricity system in Kenya is divided into four major regions as follows [9]:

i) Mt Kenya
ii) Coast
iii) West Kenya (Central Rift, North Rift and Western)
iv) Nairobi

The regions are mainly characterized in terms of geographical position of the location of the bulks supply points or substations [9,7]. Appendix 5 describes the regions in detail.

The Coast Region has been identified as a major generation source due to the power plants in the area. The region is preferred as the location for diesel powered generators (or other imported fuels) owing to its proximity to the coast line and sea ports. These are expensive sources of power. Although least cost options are imported to cater for the supply in this region, some diesel bases are required to be on line so as to support the voltages and ensure system both system stability and better quality of power. Despite this, it reported that the region has continued to suffer from power supply constraints resulting from inadequate transmission system leading to increasing transmission losses and reduced power quality that negatively impact the system security [7].

2.4 Review of Previous Works

Other research works in the form of master plans, feasibility studies, transmission master plans have been reviewed. This work draws a lot of information and experiences from these works. The following is a summary of the works:

- Kenya Electricity Supply Study (KESS).
- Distribution Master Plans (DMP).
- Least Cost Power Development Plans (LCPDP).
- County Integrated Development Plans (CIDPs).
- Project Feasibility Studies' Reports [20-25].

The KESS reports analysed, in a general way, the power flows within the region with less focus on the specific regional transmission requirements or constraints. The recommendations were made over five (5) years ago and are considerably outdated.

The LCPDP presents the country needs at a broader level and barely focus on the regional and sub-regional issues. Furthermore, the projects as identified and reported are pegged to national/global objectives that may at times neglect the most nerving challenges and issues in regional level.

2.5 Research Gap

Although it has been mentioned in [10] that some of the counties have initiated development of power master plans, none of the counties within the Coast Region has started developing its county power master plan. None of the counties has developed an energy balance statement to provide information of the amount of electric energy, generated within the county, imported from other counties, consumed within the counties and/or exported to other counties

The feasibility reports are specific to the particular project areas and in a many occasion, lack the overall picture or fail to subject the projects impacts to the entire region. The previous works are further described in the Appendix 3. There is therefore need to update the models and carry out analyses that are region specific with the objective of providing optimized network development for the Coat region.

2.6 Chapter Conclusion

The process and importance of transmission system planning has been described, review on previous works in the form of sector planning and system studies reports given and research gap in provision of region-specific network performance analysis and transmission plan for the region is given.

CHAPTER 3

3. Methodology

This chapter presents network data collection process and introduces the case under study (Coast Region's Electricity Transmission network). The data processing techniques and analysis methods are also discussed. In addition, the tools used in the analysis are mentioned.

3.1 Introduction

The investigation and assessment of the electricity transmission network involved:

Data Collection – KPLC, being the system operator, relevant information was sought from the systems operation department in Nairobi and the regional control centre in Rabai.

Interviews were also arranged and conducted with relevant transmission system personnel in the region. The objective was to get the latest information regarding the attributes and status of the regions transmission system.

KETRACO has on other hand been involved with the planning and development of new transmission lines infrastructure and has completed several projects in the region. Additional information was sought from KETRACO regarding the progress of committed projects and the future transmission network outlook for the region. Interviews with large power customers – this provided feedback on the current power quality issues suffered by major customers at the coast region.

3.2 Case Study Coast Region: Current Situation in the Coast Region:

3.2.1 General Information

Counties considered to be within Coast region, include Mombasa, Kwale, Kilifi, Taita Taveta and some sections of Tana River Counties and some parts of Makueni County.Figure 3-1 shows the physical location of this region on the Kenyan map.

Coast Region is one of the major sources of expensive power supply with an installed generation capacity of about 357MW that is mainly produced by Heavy fuel oil (HFO) powered medium speed diesel (MSD) generators.

Currently, the region has an estimated peak demand of about 294MW and hence makes the area a net exporter of power to the National grid. There are 490,290 customers connected on the power grid in this region.

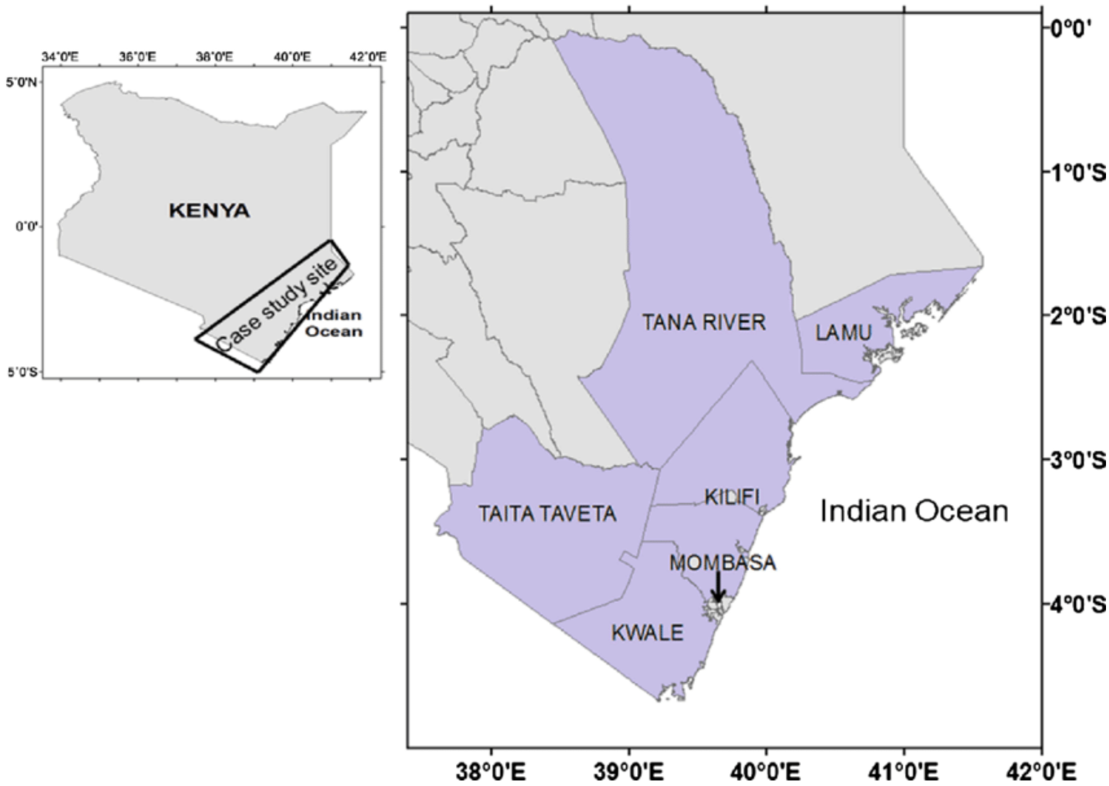

Figure 3-1:Coast Region Physical Location

3.2.2 Coast Region's Load

The load is characterised by domestic, commercial load (heavy industrial load and light industrial load). There are over three cement factories and about four steel processing plants in the area. The region also serves Titanium mining in Kwale. These mainly comprise the major heavy industrial.

Light industrial loads are mainly from several food processing plants and also service industry such as transport (pipeline, airports and sea ports), tourism - hotels and resorts. In terms of domestic load, the region's population is concentrated in urban and peri-urban centres from where much of the domestic load is recorded. Vast counties of Tana River, Kilifi and Kwale account for less than 40% of the regions demand, Mombasa county on the other hand takes the lion share of the region's demand despite its small size. The current peak demand for the region stood at 265 MW in 2017 as recorded from bulk supply points substations' 33kV outgoing feeders loading data. This later increased to 290MW as recorded on 23rd November 2018. In 2019, the peak demand for the region was 284MW 14th February 2019.

Table 3-1 presents the main bulks supply points of the study area as at 2018. The associated loads are as recorded during a load check exercise done by KPLC in 2017. The complete table including the 33 and 11kV feeders are given in Appendix 2A.

This demand was noted to compare well with what was recorded during the peak in 2017 (of 263MW and 265MW for simultaneous peak and region's non-simultaneous peak respectively.

Table 3-1: Bulk Supply Points (BSPs) for Coast Region.

Sn	**Bulk Supply Point (BSP)**	**County**	**2017 Demand (MW)**
1	Voi	Taita Taveta	2.04
2	Lamu	Lamu	3.02
3	Garsen	Tana River	3.70
4	Galu	Kwale	13.11
5	Maungu	Taita Taveta	17.60
6	Kakuyuni	Kilifi	18.02
7	Jomvu	Mombasa	19.34
8	Kilifi	Kilifi	19.90
9	Rabai	Kwale	25.96
10	Kipevu	Mombasa	66.42
11	Bamburi	Kwale	70.49
Total			259.6

Source: KPLC load checks exercise of 2017

3.2.3 Coast Region's Generation

The region currently contributes about 15% of the national's installed capacity. The mix is dominated by diesel thermal generation. The Table 3-2 gives the breakdown the regions generation capacity.

Table 3-2:Generation and Energy Contributed by Coast Region

S/n	Power Plant	Capacity (MW)		Energy purchased (KWhr)
		Installed	Effective	
1	Kipevu I	73.5	52	211.3
2	Kipevu III	120	115	512.1
3	Tsavo Power	74	74	121
4	Rabai Power	90	90	606
Region's Total		357.5	331	1450.4
System's Total		2333	2259	10205
% Contribution		15.3%	14.7%	14.2%

Source: KPLC Annual Report June 2018

3.2.4 Coast Region's Transmission System.

The region currently boasts of eleven bulk supply points mostly 220/33 and 132/33kV substations with various out-going 33kV feeders. The transmission network comprises radial 132 and 220kV overhead lines with Rabai as the nerve centre for the region's transmission network. Most of the lines are implemented on steel structures while some sections are on either wooden or concrete poles. The 220kV lines are implemented on self-supporting cat head towers with both OPGW and ACS while the 132kV have a mixture of guyed and self-supporting towers both OPGW and ACS on guyed towers and OPGW only on single peak self-supporting towers. For both 132 and 220kV, the phase conductors are of ASCR type. Coast region connects to other regions as given in the Table 4-3.The transmission network topology and inter connection to other regions as of 2018-2020 is given in Appendix 2B, Figure 1.The complete tabulation of transmission lines, substation and outgoing medium and low voltage feeders are given Appendix 2A.

Table 3-3:Regions Connected to Coast Region

S/n	Region	Interconnector Line	Voltage Level (kV)
1	Mt. Kenya	Kiambere-Rabai	220
2	Nairobi	Isinya-Mariakani[2]	220/400
3	Nairobi	Sultan Hamud-Maungu[3]	132

[2] 400kV awaits completion of Mariakani Substation
[3] There are other 132kV substation between Sultan and Maungu, these substations are connected as physical T off from the 132kV line between Maungu and Sultan Hamud.

3.3 Demand Forecasting and Generation Planning Methodology

3.3.1 Demand Forecasting

This included demand forecast review for the Coast region for next 20 years. The demand forecast has been estimated for the region and presented in various reports that include the Kenya Power Generation and Transmission Master Plan (KPG&TMP) of 2015 for MoE, the Least Coast Power Development Plan (LCPDP) among other feasibility studies. All these were reviewed and additional information from the Counties collected and considered. The most recent CIDPs were used as the baseline/reference for additional information regarding the demand. Where CIDPs were not readily available or more information is required, interviews were done with the respective county development and energy secretaries. Information on expected special projects as planned by under various government initiatives such aa Big 4 Agenda and Vision 2030 blue print were equally considered. The demand forecast data is provided in the subsequent sections.

3.3.2 Generation Planning

With the demand data reviewed/collected as detailed above, the demand balance for the region was determined. The recorded load profile in the distribution substations within the counties in the region formed the basis of demand forecast and gave good impression of the region's demand. The installed generation capacities were used to determine the current demand balance. For the years beyond 2020, and leading to 2039, the planned generation capacities as presented in the KPG&TMP and or the most recent LCPDP planning reports were reviewed and adopted. The generation data is provided in the subsequent sections.

3.4 Transmission Expansion

3.4.1 Transmission Systems Planning

The transmission plan adopted was based on the LCPDP and information collected from KETRACO.As noted previously, the target network approach and alternative network approach was used to develop the transmission plan. Table 1-3 in Chapter 1, gives the planned transmission line and substations expected to be developed in the region.

The regional target network model (year 2038 model later updated to 2039) was developed with network data collected from KPLC and KETRACO. This was then subjected to system studies to demonstrate and confirm both system adequacy and compliance to the grid code requirements. The base models for 2035, 2030, 2025, 2022 and 2020 were developed by ridding off the elements as expected in the available plans. The system studies activity involved power system modelling and power system analysis. These are further discussed in section 3.4.3.Where these requirements were not met, network upgrades and reinforcement were proposed and modelled into the existing network model. The improved network was again subjected to system studies and analysis to confirm adequacy and compliance to the Grid Code. Use of alternative network options was also used for the mid-term period (for years 2020 and 2024) to determine additional network improvements that may be required within/between the short to medium term (by year 2025). The committed transmission lines projects as modelled in these years were reviewed and subjected to additional system studies, here, various option of meeting the expected objectives were analysed to determine the most cost effective solution. Where necessary the project schedule was once again revised as per the recommendations of the system studies.

3.4.2 Diagnostics and identification of bottlenecks using power system simulations

The system studies comprised steady state analyses. The Power System Software for Engineers (PSS/E) was used. The power flow solution for network models (once reviewed and developed as detailed above) were determined using Newton Raphson Method. With the network solution determined, the models were analysed for the following: - voltage stability, fault level analysis and contingency analysis for system security.

Guided by the Kenya National Grid Code, where loading and bus voltage among other violations are experienced, mitigation measures in terms of network upgrades, re-configuration and new projects were proposed for consideration. System security depends on the network topology. Topology on the other hand is related to how the system reacts to network vulnerabilities with respect to various attacks and robustness to major network failures [15]. For any additional network development above what is planned/committed, the investments cost was estimated. Once technically justified, the development schedule (sequence) was provided and various sources of project finance mentioned for consideration. This culminates to the electricity transmission master plan for Coast Region for the planning period.

3.4.3 Network Modelling

Modelling of power systems remains a key component during investigation and planning of the power systems. It is from the model that one purposes to mimic the topography and configuration of a power system network in order to aptly carry out studies/analysis whose objective is assess system performances based on a set of criteria. It is worth noting that availability of network data and the modelling process determines the accuracy and hence integrity of the process and resultant assessment.

The current network comprises of lines and transmission lines constructed and implemented by KPLC and KETRACO. The current model was reviewed and updated to include the most recent developments as expected by the end of 2018.The modelling included network data and development of slider diagrams on PSS/E. The peak demand recorded in 2018 and 2019 were used. Information on the progress of ongoing and committed project as envisaged by the KETRACO master plan and Medium Term (2018-2023) Least Cost Power Development Plan (LCPDP) was used to update the 2020 and 2024 models as prepared in the 2015-2035 Long Term Plan of the LCPDP by Lahmeyer International. The transmission planning data from KETRACO and LCPDP reports was used as the basis.

3.4.4 Power System Analysis Approaches

3.4.4.1 Load Flow Analysis

Using PSS/E, steady state network analysis that comprised load flow calculations, fault calculation, contingency analysis was performed for 2019, 2020,2022,2025,2030, 2035 and 2039.By means of activity *SOLV*, in PSS/E, the load flow solution is calculated based on the controls parameters given in Figure 3-2, the results are collected in form of schematics that are analysed for compliance to the grid code. Where violations are seen, the remedial actions are proposed, the model revised accordingly and load flow recalculated.

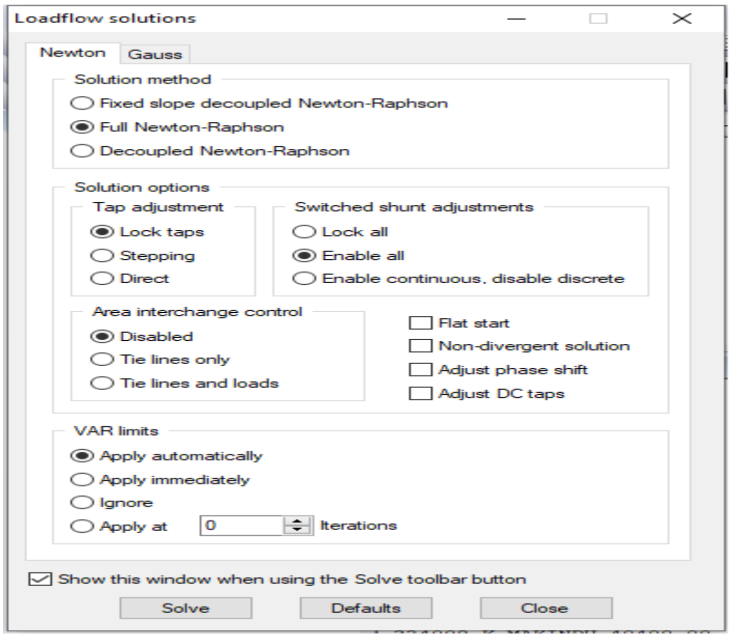

Figure 3-2:Power Flow Solution Settings

The flow chart for full Newton Raphson (NR) iterative solution is given in Figure 3-3.

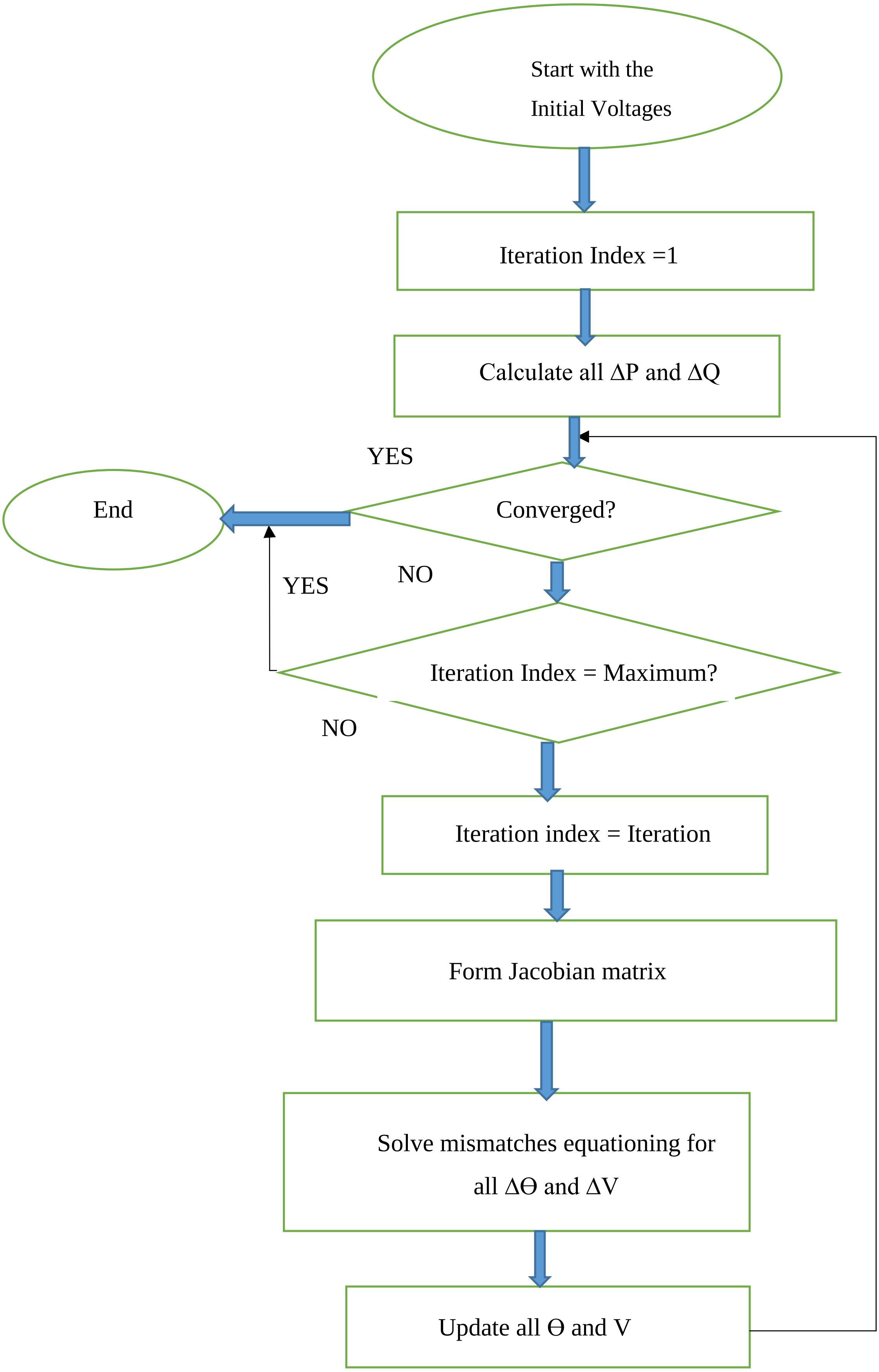

Figure 3-3:Full Newton Raphson (NR) Flow Chart

3.4.4.2 Fault Level Analysis

Fault level calculation are also computed using similar computer program, the analysis is based on symmetrical component system where the positive sequence model (established from power flow model) is directly used with the negative and zero sequence parameters (relevant in single phase faults) introduced in the power flow model on need basis. Using activity IECS in PSS/E and with the controls set as depicted in Figure 3-4. The fault levels for substations are estimated. Activity IECS implements the IEC 60909 standard methods and is based on Thevenin's theorem where an equivalent voltage source is calculated at the short circuit location and the corresponding short circuit current determined [19].

The magnitude of three phase faults is checked against the prevailing maximum short circuit rating of the circuit breakers and substation equipment. Where this is exceeded, the substation is noted and corrective action that may include elevation of the substation short circuit level or lowering the fault currents is used.

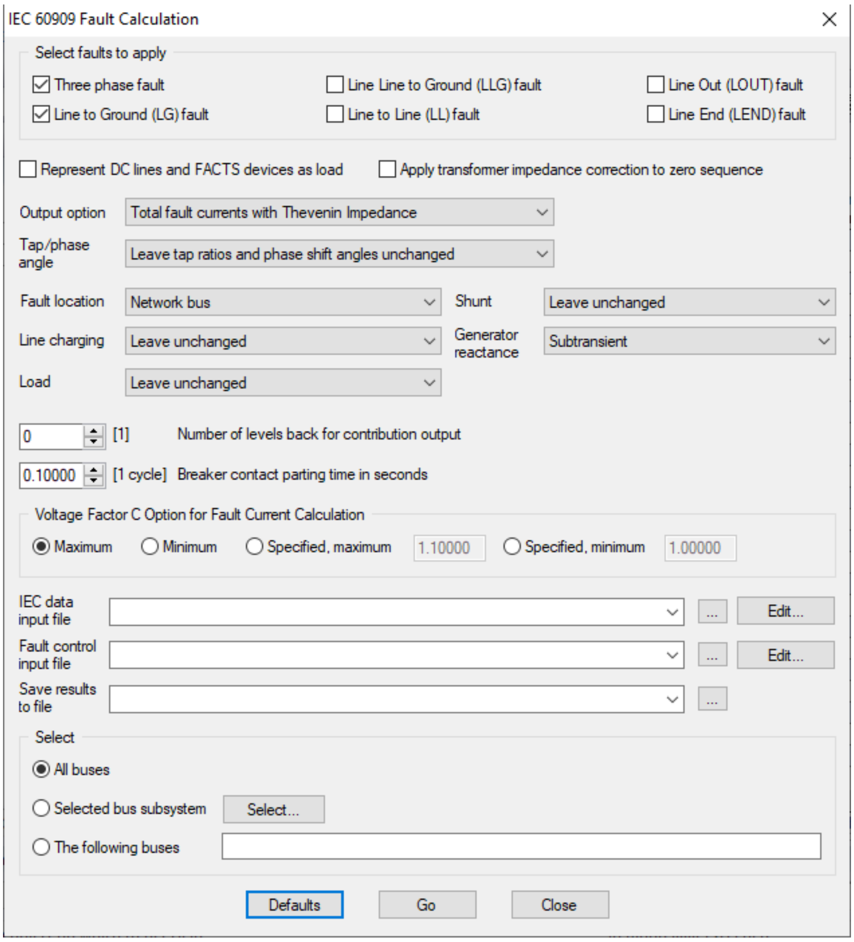

Figure 3-4:Fault Level Calculations Settings

3.4.4.3 Security Analysis (N-1 Contingency Criteria)

According to [26], contingency is the failure of any power system component on a network due to system related issues. This analysis can be involving and tedious in the absence of automatic screening approached Contingency analysis, is analysed in PSS/E using power flow solution activity ACCC for single contingency (one element put out of service). In this analysis, the application takes one branch out of service and recalculates the power flow analysis and once complete it

takes the next branch out of service and recalculates the power flow once again. This is repeated until all the branches in the subsystem taken out of service in turns. The analysis is based on the settings as illustrated by Figures 3-5 and 3-6. On Figure 3-3, the first check box if selected instructs the program to include the description of the contingency in the original file, this option does not over write the previous description. Single contingency if selected, instructs the application to only take one element out of service at a time. Figure 3-4 is the selection panel for the elements to be monitored and the specific ranges beyond which the program will flag as a violation.

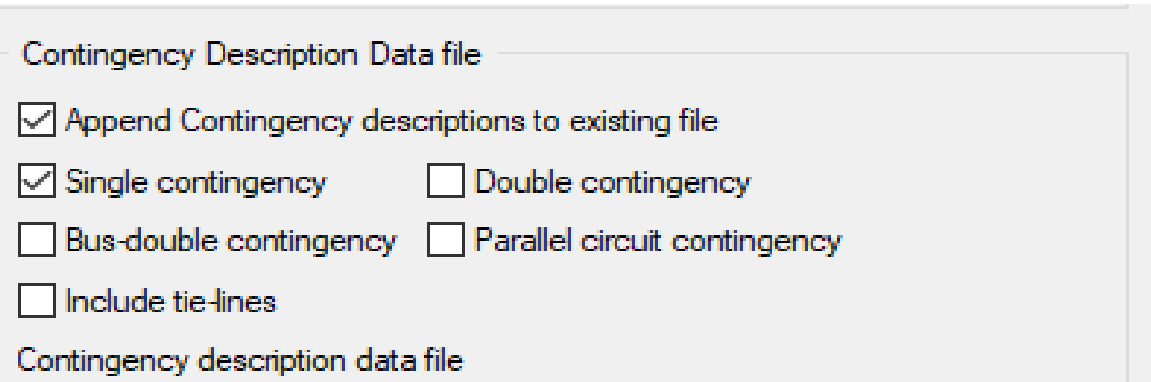

Figure 3-5:Settings for N-1 (Single Contingency) Analysis

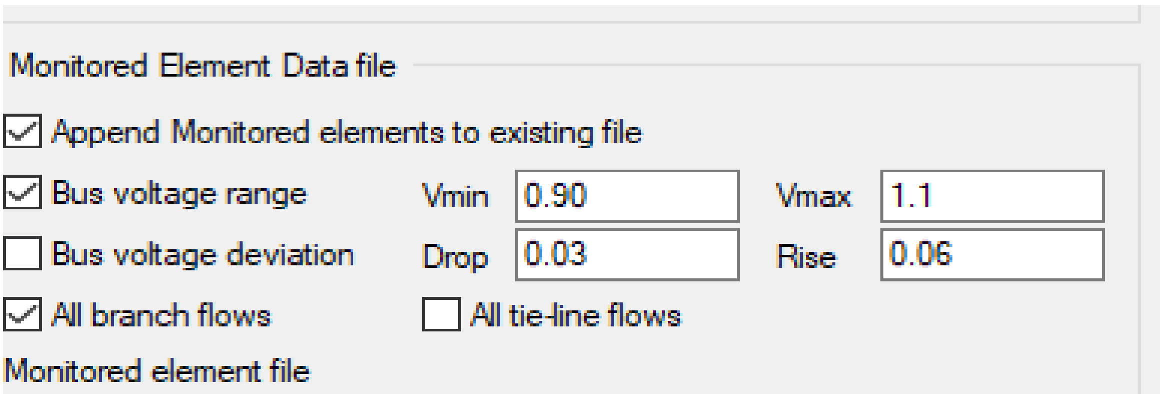

Figure 3-6:Settings for Voltage Violation and Branch Loading Thresholds

3.5 Chapter Conclusion

The demand for the region as at 2019 was about 284MW and comprised of domestic, and industrial (heavy and light) loads. Generation from diesel (HFO) contributes about 14% of the national installed capacity. Demand forecast and generation data was sourced from sector planning reports. Transmission planning was based on power system analysis approaches such as power flow, fault level and contingency analysis.

CHAPTER 4

4. Results with Limited Interpretation

This chapter presents the findings of the transmission expansion studies for Coast Region's power transmission system, details of the generation planning and demand forecast data that was used in the modelling of the power systems for the Coast Region are given. A brief presentation of the current situation and planned scenarios as collected during the data collection exercise is additionally given. The results of the power systems simulation study carried out as detailed in the previous section are also given alongside their respective analysis.

4.1 Electricity Demand & Generation Projections

4.1.1 Introduction

The demand forecast was based on the generation and transmission master plan that was jointly prepared by Lahmeyer International (part of Tractable GmbH as at 2019) and electric energy subsector planners within the Ministry of Energy. It is also from this master plan exercise that all future planning reports based the methodology on. This global demand forecast was adopted for the region as well.

4.1.2 Demand Forecast Data

In order to align the regional load growth with the national growth the MTP 2018-2023 was used for the medium term. Beyond 2023, the demand projections given in the LCPDP 2017-2037 was adopted. In both cases above, the projects envisioned in the government's development blue print (Vision 2030) and projects proposed within the counties were included. The Government has focused on the projects identified and categorised under the Big 4 Agenda. It is expected that these projects will greatly contribute to the growth of GDP. The projects encompass manufacturing, food security and agriculture, health care and housing. Three demand forecast scenario are presented in the above sector report namely High, Reference and Low. For the case of this study, the reference scenario was considered. The highest recorded peak demand of 290MW (as recorded on 23rd November 2018), was used as the base on which the growth rates as presented in the reports above were applied to determine the demand for the next 20 years.

For 2017 and 2018 the actual demand as recorded at the national control centre was used and a demand increase of 25MW was realised, this translated to a growth rate of about 9.4%.Table 4-1 was used for apportioning incremental demand in the respective bulk supply point for the successive years. The bulk supply points demand incorporate exports from the HV/MV transformers that are representative of the cumulative demands for the feeder connected to the substation. From this table, the demand recorded for Kipevu and New Bamburi and Rabai is an indication that these are the most critical substations in the Coast Region going by the magnitude of demand.

Table 4-1: Coast Regional Demand per BSP

S/n	**Bulk Supply Point**	**Demand in MW**		
		2017	**2017 (Corrected)**	**2018**
1	Voi	2.04	2.09	2.28
2	Lamu	3.02	3.08	3.37
3	Garsen	3.70	3.78	4.13
4	Galu	13.11	13.38	14.64
5	Maungu	17.6	17.97	19.66
6	Kakuyuni	18.0	18.40	20.13
7	Jomvu	19.3	19.74	21.60
8	Kilifi	19.9	20.32	22.23
9	Rabai	26.0	26.50	29.00
10	Kipevu	66.4	67.80	74.19
11	New Bamburi	70.5	71.95	78.74
Total		**259.60**	**265.00**	**290.00**

Table 1 in Appendix 4 depicts the growth in demand for the region, having adopted an average growth rate of 6.34%. The average growth rate for high scenario is 8.08% while that of low scenario is about 5%.

The projected demand for the region is expected to increase from 290MW to over 1300MW in the year 2039 for the reference scenario. The Big 4 Agenda and the vision 2030 projects considered for the region and estimated commissioning dates are given in the Table 4-2.

These projects are spread over the region and are in preliminary stages apart from Top Steel and Feast Foods and Neptune in Kwale that have been in operation while Devki Steel is in construction phase. These projects have the private investors as the main proponents.

Table 4-2: Big 4 Agenda and Vision 2030 Projects in Coast Region

Projects Description	**County**	**CoD**
Electrified SGR (Mombasa-Voi traction stations)	Mombasa and T.Taveta	2021
Resort Cities (Lamu)	Lamu	2022
Oil pipeline terminal and Lamu Port	Lamu	2022
Dongo Kundu SEZ	Kwale	2021
Top Steel (Samburu)	Kwale	2016
EPZ Kwale (Samburu)	Kwale	2022
Devki Steel (Samburu)	Kwale	2022
KPC (Maungu)	Taita Taveta	2021
Bamburi Cement (Kwale)	Kwale	2023
Food Processing Plants (Feast Foods and Neptune)	Kwale	2019
Fish processing (Kibuyuni)	Kwale	2026
Shimoni Port	Kwale	2025
Ukunda Air Strip Upgrade	Kwale	2021
Food security (Galana)	Tana River	2024

It is assumed that the demand considered and included some of the Big 4 Agenda and the vision 2030 projects whose demand data was not available. Additionally, the complete demand data considered forecast data given in table 4-3. Tiomin has been in operation since 2015, the peak demand is as recorded in 2019. There are no indication of additional demand required in future. Shimoni and Kibuyuni are set to host a modern port and a ship making factory respectively. A total demand of 90MW is expected according to the proposal received by KETRACO and KPLC.A total 254MW is expected from the vision 2030 Projects.

The demand with the regional apportioned to all bulk supply points including the point load above are given in Table 1 Appendix 4 Part A. Figure 4-1 presents the peak regional demand growth for the three scenarios.

Table 4-3: Big 4 Agenda and the Vision 2030 Projects Demand Forecast Data

Year	Point Load/Demand (MW) Assumptions					
	Tiomin	Shimoni	Galana	Samburu	Dongo Kundu	Total
2019	17	0	0	0	0	17
2022	17	0	0	10	15	42
2025	17	50	7	20	20	114
2030	17	90	12	38	60	217
2035	17	90	12	45	70	234
2039	17	90	12	45	90	254

The projection is steady and uniform throughout the period except for 2022, 2025 and 2030. This is attributed to the commissioning and operationalisation of the Big 4 Agenda for periods leading to 2022 projects and vision 2030 projects for periods leading to 2030.

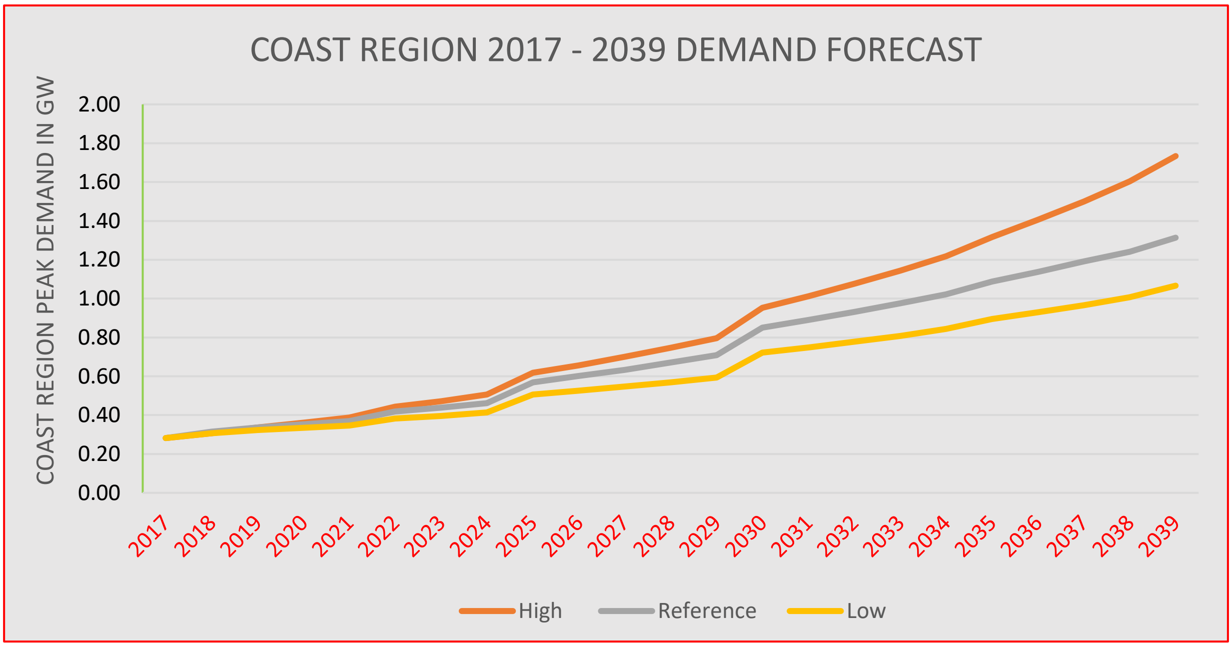

Figure 4-1: Regional Peak Demand Projections for Coast Region

4.1.3 Generation Expansion Data:

The Medium-Term Plan 2018-2023 having included the projects with signed PPA and the 2017-2037 Least Cost Power Development Plan updated to include the FiT projects whose PPAs are under negotiations formed the basis of the generation projection over the period 2019 to 2039.The generation plan is given in Table 2 Appendix 4 Part B.

Within this period, we note that quite a number of generations that will be decommissioned in the region. The decommissioned capacity will equally be replaced with new generation and the net effect will be increase in generation capacity in the region.

4.2 System Studies' Simulation Results

Table 4-4 gives the results summary of the performance of the Coast region network for the years 2019, 2020,2022,2025,2030, 2035 and 2039.

Table 4-4:Simulation Summary

Year	**Normal System Operation Conditions**			**Contingency Operation Conditions (N-1)- Security analysis**				**New Projects Proposed**
	No of Voltage Violations	**No. of Branches Overloaded**	**% Transmission Losses**	**No. of Voltage Violations (No. of Contingency events)**	**No. of Branches Overloaded (No. of Contingency events)**	**Load Shedding (No. of Contingency events)**	**No. of Contingencies without Converging network solutions**	
2019	-	-	7.7	4 (2)	-	14 (6)	40	-
2020	3	-	4.7	24 (7)	13 (8)	29 (21)	7	-
2022	-	1	2.9	26 (5)	7 (7)	10 (16)	-	-
2025	3	2	3.7	5 (1)	8 (5)	11 (5)	-	220kV Kwale-Mariakani double circuit line and new 220/132kV substation at Shimoni
2030	-	2	3.8	11 (4)	10 (13)	6 (7)	-	Voltage Support devices at Kilifi and Rabai 132kV buses
2035	-	-	3.7	8 (4)	26 (13)	12 (12)	-	220kV Mariakani-Bamburi and 220kV Kilifi-Bamburi and new 220/132kV at Bamburi
2039	-	-	3.8	21 (4)	71 (49)	7 (8)	-	-

In 2019, there are no overloads nor voltage violations during normal system operation. The transmission losses as a percentage of the maximum demand is 7.7%. There are 4 voltage violation recorded from 2 contingency events. 6 contingency events lead to shedding of 14 loads and 40 contingency events failed to get power flow solution. 220kV Kwale-Mariakani double circuit line and new 220/132kV substation at Shimoni is proposed in 2025.This is primarily to serve the new port and ship making factory in Shimoni and Kibuyuni area.

Performance during normal and (N-1) contingency operation are considered and this is pegged on the number of voltage and loading violations. The number of loads shed as a result of an outage on a network element are also indicate the performance of the transmission networks in terms of security. All these are used as a measure of the system performance for the periods and inform on the necessary actions that are required to be undertaken in order to improve the systems adequacy and security. The findings for each year are detailed in the next sub sections; more details including the respective load flow single line diagrams and tabulated results are given in Appendix 4 Part C.

4.2.1 Simulation Results for Year 2019

Under normal system operations, there are no overloaded branches and the bus voltages were within the operation thresholds. Certain buses however recorded bus voltages that were in the vicinity of the lower band. The fault levels for high voltage buses are within the maximum equipment ratings. Transmission losses amounting to 27.8MW (7.7% of region's demand) is recorded in 2019.

Under contingency (N-1) conditions, there are no branch overloads were recorded, however, voltage violations are noted at four buses during instances of two (2) contingency events; these are however within the N-1 Voltage thresholds of $0.9 \leq V \geq 1.1$ p.u. Up to fourteen loads are load shed as a result of six different/isolated contingency events.

In terms of converging power flow solution, calculation for forty contingency events failed to converge.

4.2.2 Simulation Results for Year 2020

Under normal system operations, there are no overloaded branches, bus voltages violations were noted at three buses namely Mariakani (1.053), Kilifi (0.94p.u.) and Mombasa Cement

(0.947p.u.). The fault levels for high voltage buses are within the maximum equipment ratings. Transmission losses amounting to 17.2MW (4.7% of region's demand) is recorded. Under contingency (N-1) conditions, overloading is noted in thirteen branches during eight contingency events, while twenty-nine loads are shed as a result of twenty-one contingency events. Up to twenty-three 132kV and one 220kV buses are have voltage outside the N-1 Voltage thresholds of $0.9 \leq V \geq 1.1$ p.u.

With respect to convergence of power flow solutions, calculation for seven contingency events failed to converge.

4.2.3 Simulation Results for Year 2022

Under normal system operations, overloading was noted on the 15MVA 132/33kV transformer at Maungu that was 194.7% loaded. There were no voltage violations on the transmission buses and the fault levels for all substations are within the maximum equipment ratings. Power losses amounting to 11.6MW (2.9% of regions demand) was recorded. Under contingency (N-1) conditions, overloading is noted in seven branches during seven contingency events, while ten loads are shed as a result of sixteen contingency events. Up to twenty-six buses have voltage outside the N-1 Voltage thresholds of $0.9 \leq V \geq 1.1$ p.u. Calculation for two contingency events failed to converge and no solution was possible.

4.2.4 Simulation Results for Year 2025

In order to cater for the new load expected at Shimoni by the year 2025, three options (scenarios) were checked. The scenarios as are as follow:

i) Option 1: No New line to Shimoni
ii) Option 2: Introduction of 220/132kV at Kwale and with a 132kV double circuit line to Lunga Lunga.
iii) Option 3: Similar to Option 2 but with a 220kV double circuit line to Shimoni instead of 132kV line to Lunga Lunga.

The results summary is given in Table 4-5. Option 1 resulted to 10 voltage violations, 4 branch loading violations and recorded 29 MW in transmission system losses. These compared with Option 3, where 3 voltage violations, 2 branch loading violations and transmission losses of 19.57MW was recorded. Scenario 3 provided the best results and was considered for further analysis.

Table 4-5:2025 Case Scenarios Power Flow Results Comparison

Scenario	Number of Bus Voltage Violations	Number of Overloading Violations	Transmission Losses (MW) Coast Subsystem
Opt 1	10 (all are 132kV with the worst violation recorded at Shimoni 132kV = 0.81pu)	4: 2 132kV lines (Rabai-Likoni & Likoni –Galu) and 2 No 132/33kV Transformers at new Bamburi	29.09
Opt 2	8 (all are 132kV with the worst violation recorded at New Bamburi 132kV = 0.9281pu)	2: 2 No 132/33kV Transformers at new Bamburi	21.85
Opt 3	3 (all are 132kV with the worst violation recorded at New Bamburi 132kV = 0.931pu)	2: 2 No 132/33kV Transformers at new Bamburi	19.57

Under normal system operation conditions, the two 132/33kV transformers at New Bamburi are 116.6% loaded. Bus voltage violation were noted in three (3) 132kV buses. The fault levels for the substations are within the maximum equipment ratings and the transmission losses amounting to 19.57MW (3.4% of regions demand) is recorded.

Under N-1 Contingency, voltage violations outside the N-1 Voltage thresholds of 0.9≤ V ≥1.1 p.u are noted in six (6) buses during an outage on the 132kV Rabai-New Bamburi line. Overloading is noted in Eight (8) branches during five (5) contingency events. Upto eleven loads are shed as a result of eleven contingency events and there were no contingency events that failed to get converging solution.

4.2.5 Simulation Results for Year 2030

Building from the recommended model of 2025, (with 220kV link to Shimoni) and in order to mitigate against the voltage violations as noted on the Rabai-Kilifi system, two options (scenarios) were checked. The scenarios as are as follow: -

i) Option 1: No voltage support devices at Rabai and Kilifi

ii) Option 2: With Voltage support devices (grid grade capacitors) installed at Rabai and Kilifi

The results summary is given in Table 4-6. The two options more or similar performance in terms of voltage and branch loading violations. Option 1 recorded 36.55MW in transmission losses while Option 2 recorded 35.67MW. Therefore, Option 2 provided the better results

(2% improvement in efficiency compared with Option 1 achieved) and was considered for further analysis.

Table 4-6:2030 Case Scenarios Power Flow Results Comparison

Scenario	Number of Bus Voltage Violations	Number of Overloading Violations	Transmission Losses (MW) Coast Subsystem
Opt 1	No voltage violations were noted	2: 2 No 132/33kV Transformers at new Maungu	36.55
Opt 2	No voltage violations were noted, the buses have a better voltage.	2: 2 No 132/33kV Transformers at new Bamburi	35.97

Under normal system operating conditions, no voltage violations are noted, however, the two (2) 132/33kV transformers at New Bamburi are 156 % loaded. The fault levels for the substations are within the maximum equipment ratings and the transmission losses amounting to 35.97MW (3.4% of regions demand) is recorded.

Under N-1 Contingency operations, voltage violations outside the N-1 voltage thresholds of $0.9 \leq V \geq 1.1$ p.u. are noted in eleven buses during an outage on five 132kV lines. Overloading is noted in ten branches during thirteen contingency events and up to six loads are shed as a result of seven contingency events. There were no contingency events that failed to get converging solution.

4.2.6 Simulation Results for Year 2035

In order to reinforce and increase transmission capacity for the Rabai-Kilifi system as a result of increased demand at Bamburi and Bomani and Mombasa Cement supply points, two options (scenarios) were considered and analysed/ checked. The scenarios as are as follow:

i) Option 1: No new 220kV line to Bamburi
ii) Option 2: Introduction of 220/132kV at Bamburi with a 220kV double circuit line to Mariakani and Kilifi.

The results summary is given in table 4-7. There were no voltage violations recorded for both options, 1 branch was overloaded in Option 1, while no branch overloads were recorded for Option 2. In terms of loss performance (efficiency), Option 1 recorded 49MW while Option 2 returned 42 MW. Therefore, Option 2 provided the better results (14% improvement in efficiency compared with Option 1 achieved) and was considered for further analysis.

Under normal system operating conditions, there were no voltage violations and the faults levels for the substations are within the maximum equipment ratings. The transmission losses amounting to 42.8MW (3.4% of regions demand) is recorded.

Table 4-7:2035 Case Scenarios Power Flow Results Comparison

Scenario/ Option	Number of Bus Voltage Violations	Number of Overloading Violations	Transmission Losses (MW) Coast Subsystem
Option 1	No voltage violations were recorded	1: 1No - 132kV line (Rabai-New Bamburi)	49.76
Option 2	No voltage violations were recorded	No overloading was recorded	42.8

During N-1 contingency operation, voltage violations outside the N-1 voltage thresholds of 0.9≤ V ≥1.1 p.u are noted in eleven buses during an outage on five lines. Overloading is noted in twenty-six branches during twenty-three contingency events and upto twelve loads are shed as a result of twelve contingency events. There were no contingency events that failed to get converging solution.

4.2.7 Simulation Results for Year 2039

During normal system operating conditions, the simulation results did not show any violations in branch loading. There were also no voltage violations during normal system operations. The fault levels for the substations are within the maximum equipment ratings. Transmission losses amounting to 47.07MW (3.4% of regions demand) is recorded.

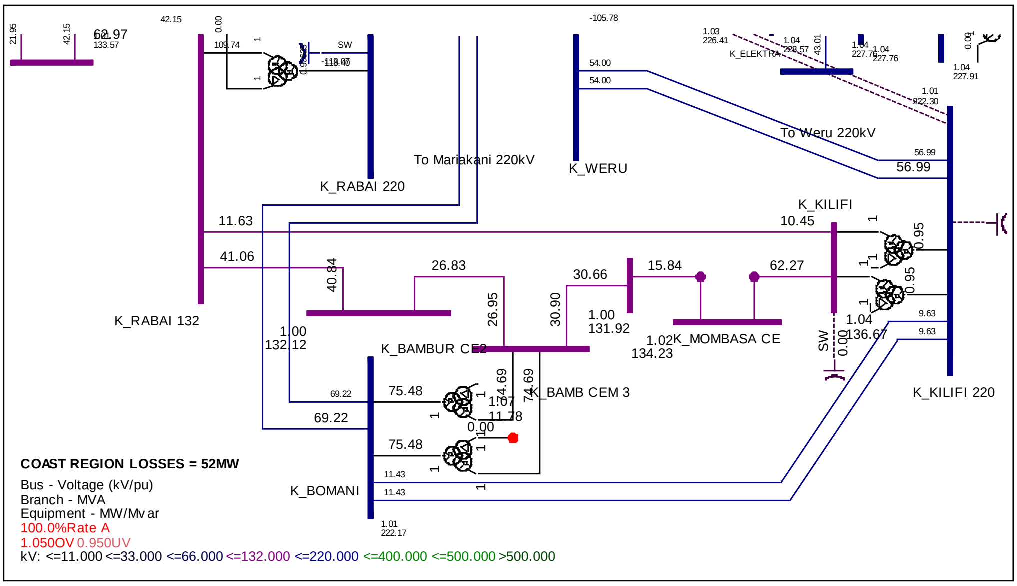

Figure 4-1: Load Flow Results for Section of 2039 Coast Region Transmission Grid

During N-1 contingency operation, voltage violations outside the N-1 voltage thresholds of $0.9 \leq V \geq 1.1$ p.u are noted in twenty-one buses during an outage on four 132kV lines. Overloading was noted in seventy-one branches during forty-nine contingency events while up to eight loads are shed as a result of eight contingency events. There were no contingency events that failed to get converging solution.

4.3 Chapter Conclusion

The demand forecast data and generation planning data have been presented and have been used in transmission planning. The assessment of transmission system performance has been carried out through simulations. The simulation results for planned and recommended transmission system for 2019,2020,2022,2022,2025,2030,2035 and 2039 have been recorded.

CHAPTER 5

5. Results Discussion

5.1 Preliminary Analysis

The Coast Region subsystem transmission system as planned over the years continues to improve, this is seen on the reduction of system losses (technical-transmission), system adequacy and security. However, it is noted that 132/33kV transformers are overloaded at New Maungu from 2022 and the 132/33 kV transformers at New Bamburi are overloaded as from 2025.This is attributed mostly by natural demand growth in these areas. In addition, the over voltages as noted at 220kV Mariakani can be attributed to the operationalization of the 400kV Nairobi-Mombasa transmission line that is currently operated at 220kV.
Further, under voltages as noted at 132kV Mombasa Cement and 132kV Kilifi in 2020 can be attributed to the increased voltage drop resulting from increased demand on the 132kV system. The under voltages are notably remedied once the 132kV Rabai-Bomani-Kilifi and Rabai-Kilifi project is complete.

Increase in demand in the region continue to put pressure on the 132kV Rabai-Kilifi system. By 2035 this 132kV subsystem is noted to be overloaded during normal system operations. The 132kV subsystem is notably loaded in 2025 during contingency on either of the links to Kilifi from Rabai. In 2035, introduction of establishment of 220kV system to reinforce the 132kV Rabai-Kilifi system. Although this project is to be implemented earlier, the project impacts to system adequacy and system security are felt in 2035.

Over the years, the Coast Region does not fully comply to the (N-1) contingency criteria. The situation worsens as the load increases over the years especially beyond 2035. Security of supply becomes critical as load increases. The 132kV Rabai-Kilifi, Rabai-Voi and Rabai-Galu systems suffer overloads and under voltage during the contingency of a section as the lines are radial and depend on the 220kV system at Rabai for voltage support in the event of low generation at the Coast Region. The situation improves up on introduction of 220kV systems at Kilifi, Kwale and Shimoni for Rabai-Galu system for the periods between 2025 and 2034.

5.2 Projects for System adequacy during normal system operations

The following projects are recommended to ensure that future electricity transmission system for the Coast region is adequate to efficiently and reliably meet the transmission needs for the region.

i) Installation of new transmission lines as follows will decongest line segments that would be otherwise overloaded and reduce the efficiency of the transmission network in the region.
   - Development of 220kV Mariakani/Dongo Kundu-Shimoni in 2023 tied to the development of Shimoni Special Economic Zone and Ship Making Factory in Kibuyuni.
   - 220kV Mariakani-Samburu (2022 tied to development of Samburu Special Economic Zone)
   - 220kV line Mariakani-Bomani-Kilifi (2035)

ii) Moreover, addition of transformers units and upgrade of transformers in the following substations will ensure that capacity increase to adequately accommodate the growing demand over the years.
   - Addition of second 132/33kV transformer at New Maungu. The Maungu transformers are overloaded as from 2022 and is recommended that the new transformer be in place before 2022.
   - Replacing all the 15MVA 132/33kV transformer at New Maungu with 45MVA transformers in 2030.
   - Replacing all the 45MVA 132/33kV transformer at New Bamburi with 75MVA transformers by the year 2025.

iii) Lastly installation of dynamic reactive power devices as follows will provide voltage support and improve the quality of supply for the region.
   - Two reactive power devices with 100MVAR capacitive and 50MVAR inductive reactive power capacity at Rabai load bus from 2025.
   - Two reactive power devices with 75MVAR capacitive and 50MVAR inductive reactive power capacity at Rabai load bus from 2025.

5.3 Projects for System Security and Compliance to N-1 Contingency Criteria.

In order to alleviate overloading of system when one element (transformer or transmission line) is put out of service, the following are recommended for implementation. These will improve the security of supply for the region's electricity transmission system.

i) Increasing transformer capacity and/or installation of third transformers at Malindi.

ii) Increasing transformer capacity and/or installation of third transformers at Galu.

iii) Increasing transformer capacity and/or installation of third transformers at Mbaraki.

iv) Increasing transformer capacity and/or installation of third transformers at Bomani.
v) Replacing all the 45MVA 132/33kV transformer at Rabai with 75MVA.
vi) Replacing the 23MVA 132/33kV transformer at Kilifi with 60MVA and installation of third transformer at Kilifi.
vii) Installation of second transformers at Garsen, Lamu and Kokotoni.
viii) Installing second circuit to Taveta (132kV Voi -Taveta second circuit or new 132kV Loitoktok-Taveta or both).
ix) Installing second circuit to Galu (132kV Rabai-Likoni-Galu second circuit or intruding 220/132kV step down at Kwale and establishment of new 132kV line from Kwale to Likoni.
x) Installing second circuit to Lunga Lunga (Shimoni - Lunga Lunga second circuit).

xi) Reconductoring using high capacity low sag conductors for increased transfer capacities for the following transmission lines will ensure adequacy and improved security in transmission service when one of the circuits is put out of service.
- 220kV Mariakani-Kwale-Dongo Kundu.
- 220kV evacuation for Dongo Kundu LNG.
- 220kV Weru-Malindi-Garsen-Lamu-Lamu Coal.
- 132kV Kipevu-Mbaraki.
- 132kV Voi-Maungu-New Maungu-Mackinnon-Samburu-Kokotoni-Mariakani.

5.4 Chapter Conclusion

The results have been discussed highlighting the performance of the regions transmission system performance. The projects proposed to mitigate the network constraints and improve the regions transmission network have been identified. Having included the proposed reinforcement projects, Figures 5-1 and 5-2, presents a summary of the transmission lines projects proposed for implementation within the planning horizon for improved system adequacy, increased efficiency and system security. The project details and the transmission network diagrams included in Appendix 6.

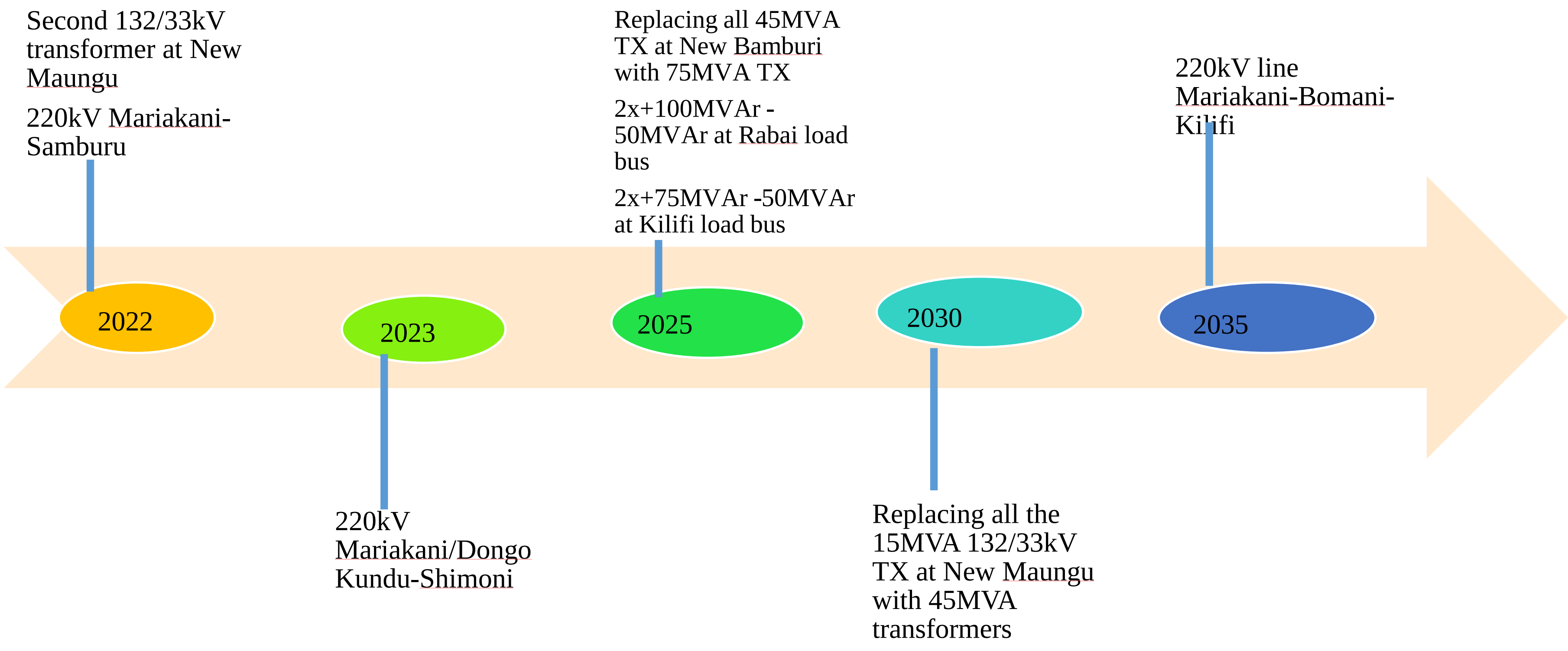

Figure 5-1:Projects Required for System Adequacy in Coast Region between 2019 and 2039

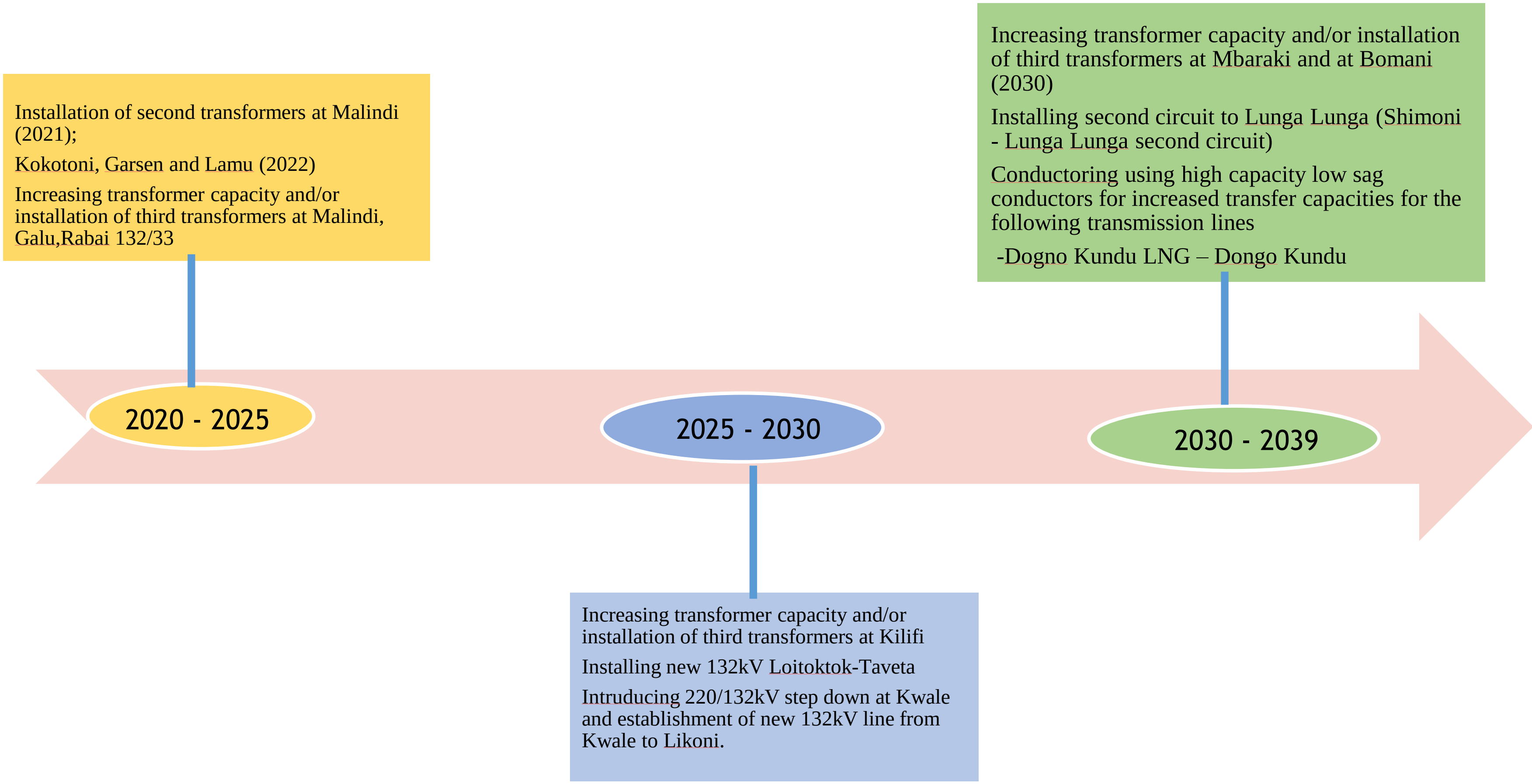

Figure 5-2:Projects Required for System Security and Compliance to N-1 Contingency Criteria in Coast Region between 2019 and 2039

CHAPTER 6

6. Conclusions & Recommendation

6.1 Conclusions

The power network for Coast region has been modelled. The system performance has been analyzed. The transmission system losses in 2019 are high (6.9%). This reduces to 3.4% in 2039.

Constraints in voltages management at Kilifi (0.947 p.u) and Mombasa Cement (0.94) with overloading of transformers at New Bamburi (117% in 2019 and 140% in 2020) form the main bottlenecks for improved system performance for the years between 2022 and 2030.

As at 2019, the transmission system was not compliant to the N-1 Security criterion as fourteen (14) loads are shed and four (4) buses violate the voltage requirements. Transmission lines and substations are overloaded beyond their rated capacities during N-1 security contingency.

Installation of Reactive Power Compensation (RPC) devices at Kilifi and construction of new 220kV Kwale -Shimoni will assist in alleviating the voltage constrains on these areas and improve system efficiency.

The fault levels for the substations in the region have been determined and in the period leading to 2039, the anticipated maximum fault currents for all the substations are within the equipment designed maximum short circuit currents as given in Chapter 3. No remedial actions will be required to reduce the fault levels at these substations.

Additional projects are required in the region to ensure transmission network satisfactorily and reliably meets the demand for the period 2019-2039. These are presented in Appendix 6. For example, in order to meet the demand at Shimoni, a new 220kV line off the Dongo Kundu Mariakani line and a substation in Shimoni is proposed, likewise to cater for the growing demand in Bamburi area owing to increasing number of industries and factories, a new 220kV line from Mariakani to Bamburi and Kilifi to Bamburi is recommended. The projects required to ensure security of supply are additionally compiled to form a pipeline of projects to be implemented in the region. The cost of the additional projects has been estimated to cost USD 299.7 Million.

6.2 Contributions

The current network model for Coast Region has been updated to incorporate the most recent developments and changes in topology. This is available for future analysis. In addition, the network models for 2022,2025,2030, 2025 and 2039 have been developed. The performance of the region's network in terms of reliability and efficiency has been carried out and documented. The challenges and network constraints in the region have been identified and mitigation measures proposed. These, if implemented, will ensure that the region's transmission network performs in an efficient and reliable manner.

6.3 Recommendations for Further Work

For the current network, it is recommended that network stability issues be assessed by performing stability studies for the region. This will identify and document the impact of disturbances on the region network elements to the voltage and frequency stability to the region's network.

Regarding the identified projects considered for inclusion in the region's transmission investment plan, it is recommended that detailed system studies and feasibility studies to be carried for each of the projects identified so as establish and document the technical, economic, financial, social and environmental viability for the proposed transmission lines' projects.

Further to this, it is recommended that as the region's transmission system develops and once the investment schedule is adopted, additional network security analysis such as (N-1-1) and (N-2) be considered for critical network elements such as evacuation systems for the large power plants expected in the region such as Lamu Coal, Nuclear Power Plant and Dongo Kundu LNG.

Lastly, it is recommended that the performance of the transmission network be established and N-1 security criteria studied for the other regions; especially the West Kenya region's transmission network and the evacuation system for the generators in the Central Rift region.

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Appendices

1. Incorporation of Comments
2. Recorded 2017 -2018 loadings, 2018-2020 Network Topology
3. Review of Sector Planning Reports and Findings from the CIDPs
4. Results (Demand data, Generation data and Power System Simulation Results)
5. Kenya Power Regions' Details
6. Recommended Project, Coast Region Transmission Lines and Coast Region Transmission Network Topology.
7. IEEE Power Africa Conference Paper prepared from this research work titled,

   '*Analysis of the Network Performance and Development of Electricity Transmission Plan: A Case Study of Kenya's Coast Region'*.
8. Turnitin receipts of submission and similarity check results.

APPENDIX 1: INCORPORATION OF COMMENTS:

Following the defence of this work on 18th May 2021, the following comment was received from the panel for incorporation. This was incorporated as detailed below.

S/n	**Comment**	**How it was incorporated**	**Section, Page and Paragraph**
1.	Inclusion of additional recommendation that provides for the need to carry out a similar research for the other regions	The following was added in the report to address this comment. … *"Lastly, it is recommended that the performance of the transmission network be established and N-1 security criteria studied for the other regions; especially the West Kenya region's transmission network and the evacuation system for the generators in the Central Rift region"* …	Section 6.3: Recommendations for Further Work, Page 41, Paragraph 4.

APPENDIX 2A: COAST REGION SUBSTATIONS WITH MV FEEDER LOADING FOR YEAR 2017/2018

SUBSTATION NAME	TX No:	VOLTAGE RATIO	TX Rating	Fdr No:	Feeder Name	Peak Demand (MW)
KAKUYUNI	1	220/33	23	1	Kakoneni	
				2	Baricho	3.12
				3	Kilifi	3.54
				4	Malindi	7.45
				5	Garsen	3.91
					0	18.02
GARSEN	1	220/33	23	1	Malindi	0.87
				2	Wema	1.88
				3	Hola	0.95
					0	3.70
LAMU	1	220/33	23	1	Island	1.50
				2	Mpeketoni	0.81
				3	Hindi	0.70
					0	3.02
JOMVU	1	132/33	23	1	KPRL	0.21
	2	132/33	23	2	Miritini	19.13
					0	19.34
KIPEVU	1	132/33	60	1	Bamburi 1	
	2	132/33	30	2	Bamburi 2	9.45
	3	132/33	60	3	Bamburi 3	9.18
	4	132/33		4	Refinery 1	
	5	132/33	23	5	Refinery 2	12.25
				6	Refinery 3	
				7	Mbaraki 1	
				8	Mbaraki 2	16.84
				9	Changamwe	8.71
				10	Port	
				11	Tononoka	9.98
				12	Island 1	
				13	Island 2	
					0	66.42
KILIFI	1	132/33	23	1	Malindi 1	0.59
	2	132/33	23	2	Malindi 2	0.29
	1	33/11	7.5	3	Bamburi	2.87
				4	Baricho	0.44
				5	Jaribuni	1.66
				6	Town	7.07
				7	Sea horse	0.38
				8	Kanamai	6.61
					0	19.90
RABAI	1	132/33	45	1	South Coast Connector	8.00
	2	132/33	45	2	Bamba	6.00
				3	Athi River Mining 1	0.47
				4	Athi River Mining 2	7.49
				5	Tamal	4.00
					0	25.96
NEW BAMBURI	1	132/33	23	1	Bamburi 1	11.55
	2	132/33	45	2	Bamburi 2	17.76
	1	33/11	7.5	3	Bamburi 3	8.31
				4	Utange	2.42
				5	Kinagoni	
				6	Nyali	11.79
				7	Mishomoroni	7.32
				8	Vikwatani	6.88
				9	Kashani	0.79
				10	Kiambeni	3.68
					0	70.49
VOI	1	132/33	15	1	Taveta/Loitoktok	
	1	33/11	7.5	2	Ashton	
				3	Town 1	1.29
				4	Town 2	0.76
					0	2.04
MAUNGU	1	132/33	15	1	Maungu	10.85
				2	FAHIM KHALID MBARAI	1.10
				3	Voi	5.65
					0	17.60
GALU	1	132/33		1	Diani	9.62
	2	132/33		2	Msambweni	3.49
					0	13.11
TOTAL			544.5	0	0	259.60

APPENDIX 2B – 2018-2020 COAST REGION NETWORK TOPOLOGY

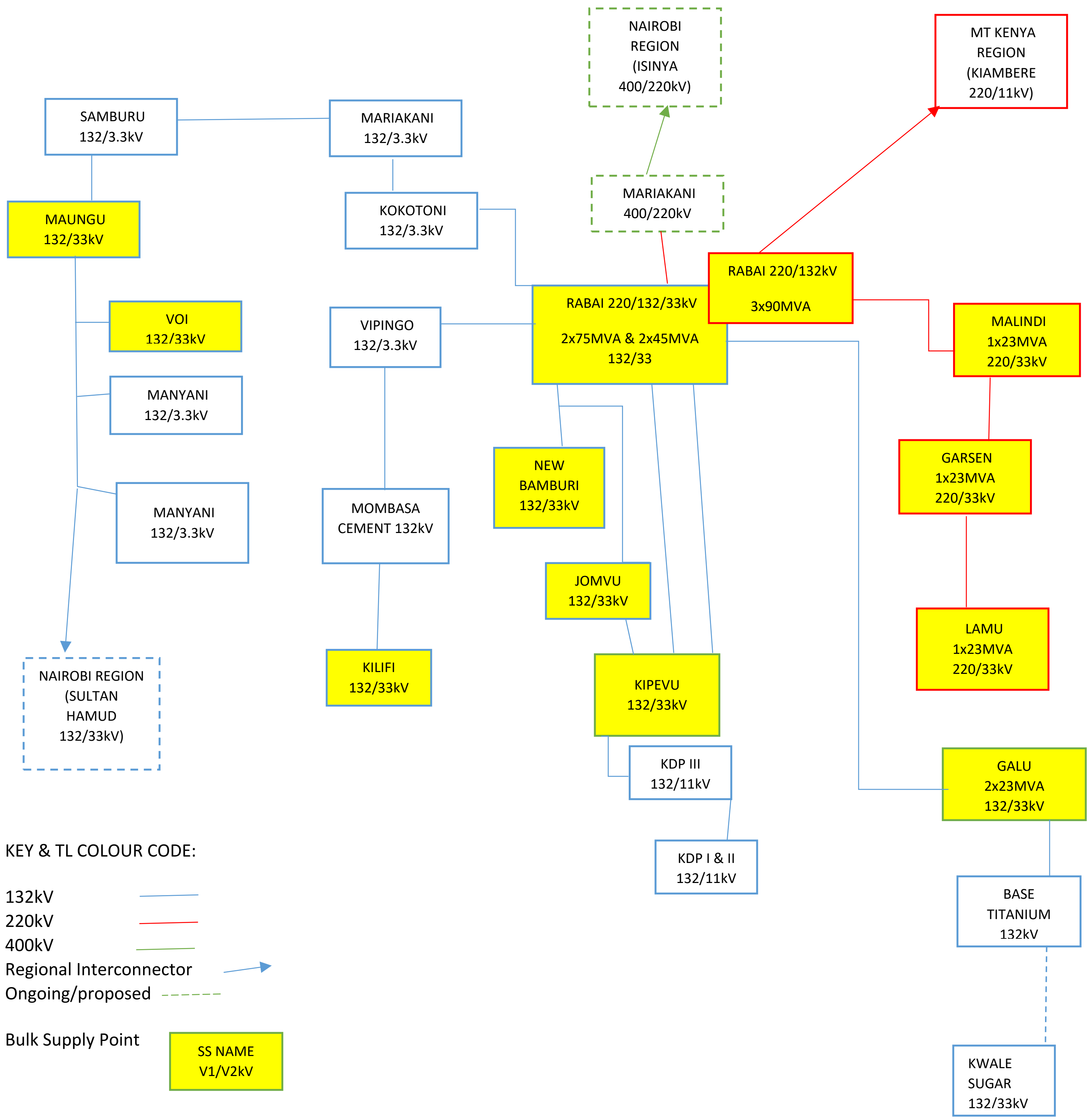

Figure 1: Coast Region Transmission Network Topology – 2018-2020

NB: The complete tabulation of transmission lines, substation and outgoing medium and low voltage feeders are given Appendix 2A.

APPENDIX 3A: REVIEW OF SECTOR PLANNNING REPORTS

1.1 POWER SECTOR DOCUMENTS

1.1.1 Kenya Electricity Supply Study

The Kenya Electricity Supply Study by Parsons Brinkerhoff for ERC/EPRA was also done in the same period as the Distribution Master Plan. The report provided rich information of then existing transmission network that were either been undocumented or if documented, the documents was domiciled in different locations/regions of the power system/country. The report provided the transmission line parameters and transformer parameters that were used to model the then transmission network in PSS/E. The models were suitable for both steady state and dynamic simulations and analyses.

Simulations and reports were provided for various network analyses that focused on inter regional power flows with greater emphasis of the countries regional tie lines

The reports analysed, in a general way, the power flows within the region with less focus on the specific regional transmission requirements or constraints. The then recommendations were made over five (5) years ago. There is therefore need to update the models and carry out analyses that are region specific analyses with the objective of providing optimized network development for the regions.

1.1.2 Distribution Master Plan

The Distribution Master Plan (by Parsons Brinkerhoff, PB for KPLC) sought to provide the regional information and categorically pre-empt on the future needs of distribution expansion by identifying the new/upcoming bulk supply points to cater for the demand increase in the load centres and beyond. The report in a way related the location of bulk supply points to the then prevailing network developments program which may now be superseded by events and time. This report however provided invaluable input with regards to locations and technical details of existing substations.

1.1.3 LCPDP & MTP

The Ministry of Energy, through ERC/EPRA has been preparing the subsector planning reports whose main objective is to provide information on the prevailing electric energy situation in the country, highlight on the major achievements with regards to demand creation/growth, generation capacity increase including penetration of renewable energy in the energy mix and improvement in the distribution and transmission networks.

The reports also seek to provide and coordinate the future projects in the sector as aligned to the Vision 2030 projects among other projects as focused upon by the Government of the day.

The findings are recorded and presented in the Least Cost Power Development Plan (LCPDP) report which is prepared by a multi-disciplinary team comprising generation, distribution and transmission planners (mainly economists and engineers) sought from the various agencies in the energy sector (electricity sub sector) including representation from the COFEK and KAM.

The study normally presents the country needs at a broader level and barely focus on the regional and sub-regional issues. Furthermore, the projects as identified and reported are pegged to national/global objectives that may at times neglect the most nerving challenges and issues in regional level.

1.2 COUNTY INTEGRATED DEVELOPMENT PLANS

The 2013-2017 County Integrated Development Plans (CIDPs) including the updates for the counties in the region have were reviewed.

The CIDPs remain a key source of information for the planned socio-economic activities that include new project that impact on the production and use of electric energy.

The 2018-2024 CIDPs (CIDP II) are seemingly revised and updated to align the county plans with the Big 4 Agenda of the Central Government. The CIDP II articulate medium term strategies, programmes and projects to be implemented under the Medium Term The CIDPs for the following counties in Coast Region were reviewed. Appendix 2B gives details a summary of the counties.

- Mombasa County
- Kwale
- Tana River
- Lamu
- Kilifi

The reviewed CIDPs provided rich information on the way the counties tend to improve the living standards for the people in the counties. They present thorough review of the achievements or performance of the counties in undertaking projects as planned in the previous CIPDs, while at the same time providing information on the counties natural resources and ways in which the various socio economic activities can be improved for the betterment of the county. The key enablers that are required to ensure that the vision 2030 objectives and the Big 4 Agenda projects are achieved are also highlighted (11-16).

Electric power being one of the major enablers, the CIDPs, in a way, indicated the expected projects and activities that the county has planned. These may form a future demand that may be required to be served by the grid or through off grid networks. Such activities/projects include: - mining, development of industrial parks, academic intuition, special economic zones, water projects (11-16). In other instances, power generation projects either grid connected or off grid solutions formed part of the county's plans towards provision of electric power to the homes within the respective county. It has also been documented that, implementation of off grid supply solutions, with support from development partners, has been proposed in these counties to provide homesteads with affordable power from renewable sources such as solar, biomass etc. Supply from the grid however remain the main source of electric power expected to supply the planned activities.

Although it has been mentioned (10) that some of the counties have initiated development of power master plans, it was confirmed that none of the counties within the Coast region has started developing its county power master plan. None of the counties has developed an energy balance statement to provide information of the amount of electric energy, generated within the county, imported from other counties, consumed within the counties and/or exported to other counties.

1.3 PROJECT FEASIBILITY STUDIES' REPORTS

Project feasibility studies for transmission lines in the area have also been reviewed. It is noted that the reports are specific to the particular project areas and in a many occasion, lack the overall picture or fail to subject the projects impacts to the entire region. The project whose feasibility study reports were reviewed include: -

- 132kV Voi Taveta by PB for KETRACO
- 132kV Rabai-Bamburi-Kilifi by PB for KETRACO
- 132kV Galu Lunga Lunga by PB for KETRACO
- 132kV Rabai/Galu-Likoni by Feedback Infra for KETRACO
- 400kV Dongo Kundu- Mariakani by PB for KETRACO
- 220kV Dongo Kundu /Mariakani- Kwale by JICA
- 400kV Lamu-Nairobi East (Malaa) and Lamu –Lamu Hindi by PB for KETRACO.

APPENDIX 3B- FINDINGS FROM THE CIDPs: COUNTY SUMMARY

A summary per county's given below, these were derived from the CIPDs for the respective counties and formed key planning input in the decision process with regards to the aggregation of demand and location of future bulk supply points. The summary for each county in the region is additionally given thereafter in this appendix.

County	**Area (km sq)**	**Population**	**Sub counties**	**Key Economic activity**	**Electricity Access/Use**
Tana River	38,862.2	349,338	Bura, Galole and Tana Delta	tourism and wildlife, blue economy, farming(agriculture) via irrigation, mining (sand mining and gypsum).	Limited to less than 1% of the households, main sources of energy is wood fuel, while kerosene is used for lighting.
Mombasa	229.2	1,266,358	Nyali, Mvita, Changamwe, Jomvu, Kisauni and Likoni,	• Development of Special Economic Zones or Export processing at Dongo Kundu, Limestone and cement processing • Transport-upgrading of Likoni port • Power generation – Dongo Kundu	**Over 70%**

Kwale	8,270	642,607	Matuga, Kinango, Msambweni and Lunga Lunga,	• Food security – irrigation schemes, green irrigation technologies, grain handling facilities, food processing plants • Development of Special Economic Zones or Export processing at Mariakani • Mining: - titanium, coal, gypsum, oil, iron ore, manganese ore, Zinc, Silver, sand, coral rock), limestone and cement processing	

				• Transport- upgrading of Ukunda Airstrip to a fully-fledged Diani airport and development of port facility at Shimoni • Power generation- Mwache Dam	
Kilifi	12,370	1,498,674	Kilifi North, Kilifi South, Magarini, Kaloleni, Ganze, Rabai and Malindi	• Food security – irrigation schemes, green irrigation technologies, grain handling facilities, • Mining: - titanium, coal, gypsum, oil, iron ore, manganese ore, Zinc,	

				Silver, sand, coral rock). • Desalination plants • Power generation – Vipingo, Dua proposed power plants	
Lamu	6,607	137,053	Bura, Galole and Tana Delta	• Food security – minor irrigation schemes, major irrigation schemes, green irrigation technologies, grain handling facilities and value addition for agricultural produce. • Desalination plants • Power generation Lamu Coal and Bahari Wind • Transport- Lamu port as the start of the Lamu Port South Sudan Ethiopia (LAPSSET) transport corridor.	

Tana River County

The county is composed of three sub-counties namely: Bura, Galole and Tana Delta. Has three (3) constituencies Bura, Galole and Garsen with fifteen (15) electoral wards.

The county spans about 38,862.2 sq. km and has an estimated (projected) population of 349,338 (12).Electricity access is limited to less than 1% of the households, main sources of energy is wood fuel, while kerosene is used for lighting.

Key economic activities include:-tourism and wildlife, blue economy, farming (agriculture) via irrigation, mining (sand mining and gypsum).Projects in the midterm include food security – minor irrigation schemes, major irrigation schemes, green irrigation technologies, grain handling facilities,

Mombasa County

The county is composed of six sub-counties namely: - Nyali, Mvita, Changamwe, Jomvu, Kisauni and Likoni, with thirty (30) electoral wards.The county spans about 229.2 sq. km and has an estimated (projected) population of 1,266,358 (12). This being a major urban centre electricity access is over 70% of the households.Key economic activities include: -transport (port facilities) tourism and wildlife, blue economy, limestone mining and cement processing

Projects in the midterm include: -

- Development of Special Economic Zones or Export processing at Dongo Kundu, Limestone and cement processing
- Transport- upgrading of Likoni port
- Power generation – Dongo Kundu

Kwale County

The county is composed of four sub-counties namely: - Matuga, Kinango, Msambweni and Lunga Lunga, with twenty (20) electoral wards.The county spans about 8,270 sq. km and has an estimated (projected) population of 642,607 (12).

Key economic activities include:-tourism and wildlife, blue economy, farming, cement processing, titanium mining, sugar cane processing, transport activities – port facilities

Projects in the midterm include: -

- Food security –irrigation schemes, green irrigation technologies, grain handling facilities, food processing plants
- Development of Special Economic Zones or Export processing at Mariakani

- Mining: -titanium, coal, gypsum, oil, iron ore, manganese ore, Zinc, Silver, sand, coral rock), limestone and cement processing
- Transport- upgrading of Ukunda Airstrip to a fully-fledged Diani airport and development of port facility at Shimoni
- Power generation- Mwache Dam,

Kilifi County

The county is composed of seven sub-counties namely: Kilifi North, Kilifi South, Magarini, Kaloleni, Ganze, Rabai and Malindi with thirty-five (35) electoral wards. The county spans about 12,370 sq. km and has an estimated (projected) population of 1,498,674 (12). Key economic activities include:-tourism and wildlife, blue economy, farming (agriculture), cement processing, mining salt

Projects in the midterm include: -

- Food security –irrigation schemes, green irrigation technologies, grain handling facilities,
- Mining: -titanium, coal, gypsum, oil, iron ore, manganese ore, Zinc, Silver, sand, coral rock).
- Desalination plants
- Power generation – Vipingo, Dua proposed power plants

Lamu County

The county is composed of three sub-counties namely: Bura, Galole and Tana Delta. Has two (2) constituencies Lamu East and Lamu West with ten (10) electoral wards.The county spans about 6,607sq km and has an estimated (projected) population of 137,053 (12).Key economic activities include: -tourism and wildlife, blue economy, farming (agriculture crops via irrigation and livestock keeping), mining (sand mining and gypsum).

Projects in the medium term include: -

- Food security – minor irrigation schemes, major irrigation schemes, green irrigation technologies, grain handling facilities and value addition for agricultural produce.
- Desalination plants
- Power generation Lamu Coal and Bahari Wind

- Transport- Lamu port as the start of the Lamu Port South Sudan Ethiopia (LAPSSET) transport corridor.

APPENDIX 4 (i) - RESULTS

A. DEMAND FORECAST

i) General

Table 1: Demand Growth in Coast Region

YEAR	Low Scenario		Reference Scenario		High Scenario	
	MW	Rate (%)	MW	Rate (%)	MW	Rate (%)
2017	265	-	265	-	265	-
2018	290.0	9.43%	290.0	9.43%	290	9.43%
2019	306.3	5.63%	310.0	6.90%	319.6	10.20%
2020	317.4	3.61%	326.4	5.30%	344.5	7.80%
2021	328.6	3.53%	342.4	4.90%	371.4	7.80%
2022	341.2	3.83%	366.7	7.10%	401.5	8.10%
2023	354.5	3.91%	384.7	4.90%	430.0	7.10%
2024	372.7	5.13%	407.8	6.00%	464.8	8.10%
2025	392.0	5.17%	442.1	8.40%	503.8	8.40%
2026	412.0	5.11%	473.9	7.20%	542.1	7.60%
2027	433.1	5.12%	503.7	6.30%	586.6	8.20%
2028	455.6	5.19%	541.0	7.40%	632.3	7.80%
2029	479.5	5.25%	578.9	7.00%	682.3	7.90%
2030	504.8	5.28%	615.4	6.30%	736.2	7.90%
2031	531.8	5.34%	653.5	6.20%	795.8	8.10%
2032	560.5	5.40%	694.0	6.20%	859.5	8.00%
2033	591.0	5.45%	737.1	6.20%	927.4	7.90%
2034	626.5	6.01%	782.8	6.20%	1001.6	8.00%
2035	661.0	5.50%	830.5	6.10%	1082.7	8.10%
2036	695.2	5.18%	878.7	5.80%	1171.5	8.20%
2037	732.7	5.39%	930.5	5.90%	1266.4	8.10%
2038	772.4	5.41%	978.9	5.20%	1368.9	8.10%
2039	814.1	5.41%	1029.8	5.20%	1479.8	8.10%
		5.24%		6.37%		8.13%

The regional demand was aggregated to the region's BSPs as given in Appendix 4A (ii).

B. GENERATION EXPANSION DATA

Table 2:Coast Region Generation Schedule

Year	**Plant Name**	**Type**	**Plant Capacity (MW)**	**Total Installed for Coast Region**
2018				357.5
2020	Malindi Solar Group	Solar PV	40	397.5
	DWA Estates Ltd (Rea Vipingo)	Biogas	1.44	398.94
2021	Kwale International Sugar Co Ltd (KISCOL)	Cogen	10	408.94
	Ray Power	Biomas	35	443.94
	Tsavo	Diesel Thermal	(74)	369.94
2022				
	Bahari Winds PH 1	Wind	50	419.94
2023				
	Bahari Winds PH 2	Wind	40	459.94
	Kipevu 1	Diesel Thermal	(60)	399.94
2024				
	Amu Coal	Coal Thermal	981	1380.94
2030	Rabai	Diesel Thermal	(90)	1290.94
2031	Kipevu 3	Diesel Thermal	(115)	1175.94
2034	Dongo Kundu CCGT 1	Natural Gas	375	1550.94
2037				
	Dongo Kundu CCGT 2	Natural Gas	375	1925.94

C. SYSTEM STUDIES SIMULATIONS RESULTS

i. SIMULATION RESULS FOR YEAR 2019

Normal operations

There were no overloaded branches and the bus voltages were within the operation thresholds. Certain buses however recorded bus voltages that were in the vicinity of the lower band. The fault levels are within the maximum equipment ratings.

N-1 Contingency operations

No branch overloads were recorded during N-1 contingency:

Voltage violations are noted at the following buses; these are however within the N-1 Voltage thresholds of 0.9≤ V ≥1.1 p.u

Table 3:2019 N-1 Voltage Violations

MONITORED BUS	BASE VOLTAGE	CONTIGENCY EVENT	BASE CASE VOLTAGE	N-1 CONTINGENCY	DEVIATION
KKILIFI	132	132kV RABAI-GALU	0.9582	0.9358	2.34%
KMSACEMTEE	132	132kV RABAI-GALU	0.9713	0.9492	2.28%
KKILIFI	33	132kV RABAI-GALU	0.9723	0.9482	2.48%
KKILIFI11	132	132kV RABAI/JOMVU TEE -BAMBURI	0.9582	0.9406	1.84%

The following gives the N-1 contingency events that resulted to load shedding:

Table 4:2019 N-1 Load Shedding

CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED LOAD BUS NAME	BUS VOLTAGE	LOAD SHED(MW)
132kV RABAI-GALU	KGALU31	33	7.88
	TITANIUM31	11	13.73
	GALU32	33	9.85
132kV RABAI-BAMBURI	KKILIFI31	33	30.22
	KVIPINGO91	11	0.37

	KMSACEM31	6.9	22.88
132kV BAMBURI- RABAI/JOMVU TEE	KBAMBURI31	33	31.22
	BAMBURI32	33	17.70
132kV VIPINGO-BAMBURI	KKILIFI31	33	30.22
	KVIPINGO91	11	0.37
	KMSACEM31	6.9	22.88
132kV MOMBASA CEMENT - VIPINGO	KKILIFI31	33	30.22
	KMSACEM31	6.9	22.88
132kV KILIFI - MOMBASA CEMENT	KKILIFI31	33	30.22

There was no power flow solution (solution failed to converge) for following the contingency events below.

Table 5:2019 N-1 Contingency Events Without Solution

S/N	FROM BUS		TO BUS		CKT	ISLAND
	NAME	**VOLTAGE**	**NAME**	**VOLTAGE**		
1	KKIPEVU11	132	KKIPEVUDII11	132	1	0
2	KKIPEVU11	132	KRABAI11	132	2	0
3	KKIPEVU11	132	KRABAI11	132	3	0
4	KKIPEVU11	132	KJOMVU	132	4	0
5	KKIPEVU11	132	KKIP31	33	1	0
6	KMANYANI11	132	KVOI11	132	1	0
7	KSAMBURU11	132	KTOP STEEL	132	1	0
8	KSAMBURU11	132	KNEWMAUNGU	132	1	0
9	KKIPEVUDII11	132	KRABAI11	132	1	0
10	KKOKOTONI11	132	KRABAI11	132	1	0
11	KKOKOTONI11	132	KMARIAKANI11	132	1	0
12	KKOKOTONI11	132	KKOKOTONI91	33	1	1
13	KRABAI11	132	TEE OFF	132	4	0
14	KRABAI11	132	KRABAI31	33	1	0
15	KRABAI11	132	KRABAI32	33	1	0
16	KKILIFI11	132	KKILIFI31	33	1	0
17	KKILIFI11	132	KKILIFI31	33	2	0

18	KBAMBURI11	132	BAMBURI32	33	1	0
19	KVOI11	132	KMAUNGU11	132	1	0
20	KVOI11	132	KVOI31	33	1	1
21	KMAUNGU11	132	KNEWMAUNGU	132	1	0
22	KMARIAKANI11	132	KTOP STEEL	132	1	0
23	KGALU11	132	TITANIUM11	132	1	2
24	KGALU11	132	KGALU31	33	1	0
25	KGALU11	132	GALU32	33	2	0
26	KJOMVU	132	TEE OFF	132	4	0
27	KJOMVU	132	KJMOMVU33	33	1	0
28	KJOMVU	132	KJMOMVU33	33	2	0
29	KRABAI21	220	KMALINDI21	220	1	6
30	KRABAI21	220	TESTBUS	220	2	0
31	KMALINDI21	220	KGARSEN21	220	1	4
32	KMALINDI21	220	KMALINDI31	33	1	1
33	KGARSEN21	220	KLAMU21	220	1	2
34	KGARSEN21	220	KGARSEN31	33	1	1
35	KLAMU21	220	KLAMU31	33	1	1
36	KKIP31	33	KMAKANDE31	33	1	1
37	KRABAI31	33	KRABAI32	33	1	0
38	KRABAI32	33	BAMBA	33	1	1
39	KGALU31	33	GALU32	33	1	0
40	KMAUNGU31	33	KNEWMAUNGU	132	1	1

ii. SIMULATION RESULTS FOR YEAR 2020

Normal operations

There were no overloaded branches.

Voltage violations are noted at the following buses with certain buses also recording bus voltages that were in the vicinity of the lower band

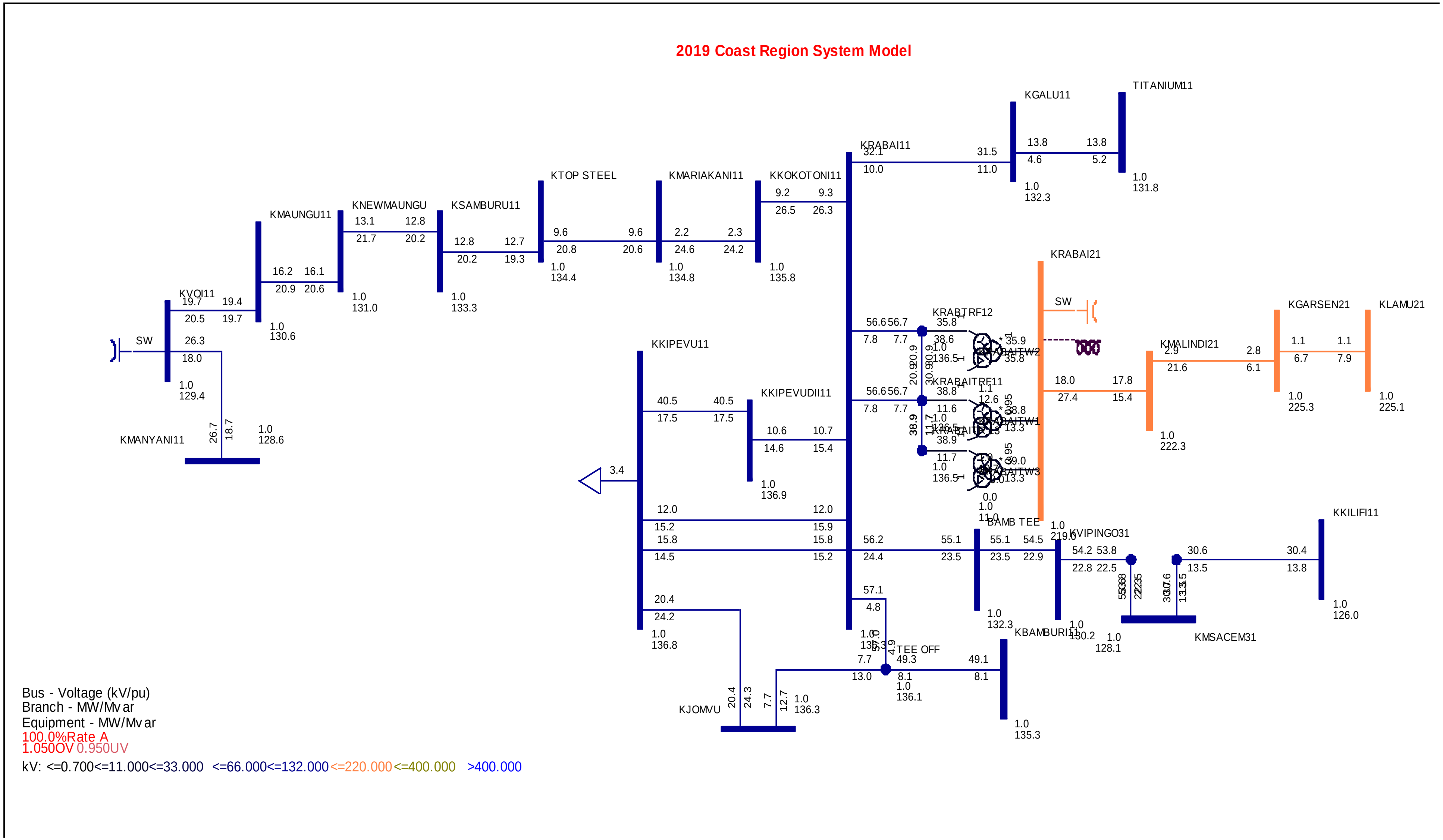

Figure 1: 2019 Coast Region Load Flow Solution

Table 6:2020 Voltage Violations During Normal System Operation

S/N	BUS NAME	BASE VOLTAGE	BUS VOLTAGE	
			V (kV)	V (PU)
1	MARIAKANI	220	231.66	1.053
2	KKILIFI11	132	124.28	0.9415
3	KMSACEMTE	132	125.06	0.9474

The fault levels for the substations are within the maximum equipment ratings.

N-1 Contingency operations

Voltage violations outside the N-1 Voltage thresholds of 0.9≤ V ≥1.1 p.u are noted as follows: -

Table 7:2020 N-1 Voltage Violations

MONITORED BUS	BASE VOLTAGE	CONTIGENCY EVENT	BASE CASE VOLTAGE	N-1 CONTINGENCY	DEVIATION
KNEWMAUNGU	132	132kV MARIAKANI-KOKOTONI	0.9733	0.4680	-52%
KMAUNGU11	132	132kV MARIAKANI-KOKOTONI	0.9719	0.4743	-51%
KVOI11	132	132kV MARIAKANI-KOKOTONI	0.9691	0.4968	-49%
KMANYANI11	132	132kV MARIAKANI-KOKOTONI	0.9696	0.5339	-45%
KTOP STEEL	132	132kV MARIAKANI-TOP STEEL	0.9844	0.8505	-14%
KSAMBURU11	132	132kV MARIAKANI-TOP STEEL	0.9813	0.8522	-13%
KNEWMAUNGU	132	132kV MARIAKANI-TOP STEEL	0.9733	0.8538	-12%
KMAUNGU11	132	132kV MARIAKANI-TOP STEEL	0.9719	0.8546	-12%
KVOI11	132	132kV MARIAKANI-TOP STEEL	0.9691	0.8588	-11%
KMANYANI11	132	132kV MARIAKANI-TOP STEEL	0.9696	0.8686	-10%
KNEWMAUNGU	132	132kV SAMBURU-MAUNGU	0.9733	0.8708	-11%
KMAUNGU11	132	132kV SAMBURU-MAUNGU	0.9719	0.8714	-10%

KVOI11	132	132kV SAMBURU-MAUNGU	0.9691	0.8751	-10%
KMANYANI11	132	132kV SAMBURU-MAUNGU	0.9696	0.8841	-9%
KMSCEMTEE31	132	132/33/11kV TX AT BAMBURI	0.9529	0.8887	-7%
KNEWMAUNGU	132	132kV TOP STEEL-SAMBURU	0.9733	0.8946	-8%
KMAUNGU11	132	132kV TOP STEEL-SAMBURU	0.9719	0.8947	-8%
KSAMBURU11	132	132kV TOP STEEL-SAMBURU	0.9813	0.8957	-9%
TITANIUM11	132	132/33/11kV TX AT BAMBURI	0.9569	0.8968	-6%
KVOI11	132	132kV MARIAKANI-TOP STEEL	0.9691	0.8968	-7%
KVIPINGO31	132	132/33/11kV TX AT BAMBURI	0.9600	0.8970	-7%
KMSCEMTEE31	132	132/33/11kV TX AT RABAI	0.9529	0.8999	-6%
KGALU11	132	132/33/11kV TX AT BAMBURI	0.9610	0.9012	-6%
KGARSEN21	220	220/33kV TX AT GARSEN	1.0476	1.1016	5%

The following gives the N-1 contingency events results to branch over-loading as follows:

Table 8:2020 N-1 Branch Overloading

S/n	**CONTINGENCY EVENT (OUTAGE OF LINE or TX)**	**MONITORED BRANCH**					**LOADING (MVA)**	**EQUIPMENT RATING (MVA)**	**PERCENT OVERLOAD**
		FROM BUS	**BUS VOLTAGE (kV)**	**TO BUS**	**BUS VOLTAGE (kV)**	**CKT**			
1	132/6.9kV TX 2 AT MOMBSASA CEMENT	MSACEM	132	MSACEM	6.9	1	26.25	25.00	104.99
2	132/6.9kV TX 1 AT MOMBSASA CEMENT	MSACEM	132	MSACEM	6.9	2	26.25	25.00	104.99
3	132/33kV TX AT BAMBURI	BAMBURI	132	BAMBURI	33	1	50.74	45.00	112.75
4	132/33kV TX AT BAMBURI	BAMBURI	132	BAMBURI	33	2	51.02	45.00	113.39
5	132kV RABAI-GALU	MALINDI	220	MALINDI	33	1	26.88	23.00	116.88
6	132kV VIPINGO- MOMBASA CEMENT	MALINDI	220	MALINDI	33	1	26.94	23.00	117.13

7	SINGLE 314032-314033(1)	MALINDI	220	MALINDI	33	1	26.95	23.00	117.18
8	132kV RABAI-VIPINGO (BAMBURI TEE)	MALINDI	220	MALINDI	33	1	26.95	23.00	117.18
9	132kV RABAI-VIPINGO (BAMBURI TEE)	MALINDI	220	MALINDI	33	1	26.99	23.00	117.35
10	132kV BAMBURI-JOMVU/RABAI TEE OFF	MALINDI	220	MALINDI	33	1	27.00	23.00	117.38
11	132/33KV TX AT KILIFI	KILIFI	132	KILIFI	33	1	-31.69	23.00	137.77
12	132/33kV TX 1 AT JOMVU	JOMVU	132	JOMVU	33	2	32.83	23.00	142.76
13	132/33kV TX 2 AT JOMVU	JOMVU	132	JOMVU	33	1	32.85	23.00	142.82

The following gives the N-1 contingency events that resulted to load shedding:

Table 9:2020 N-1 Load Shedding

S/N	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED LOAD BUS NAME	BUS VOLTAGE	LOAD SHED(MW)
1	132/11kV TX AT MARIAKNI	KMARIAKANI91	11	12.22
2	132/11kV TX AT TOPSTEEL	KTOPSTEEL11	11	3.02
3	132/11kV TX AT VIPINGO	KVIPINGO91	11	0.38
4	132/33kV TX AT KOKOTONI	KKOKOTONI91	33	7.18
5	132/33kV TX AT MAUNGU	KMAUNGU31	33	3.11
6	132/33kV TX AT VOI	KVOI31	33	6.79
7	132/6.6kV TX AT MAUNGU KPC	LINE 5	6.6	3.36
8	132kV BAMBURI-RABAI/JOMVU TEE	BAMBURI32	33	18.32
9	132kV BAMBURI-RABAI/JOMVU TEE	KBAMBURI31	33	32.31
10	132kV GALU-TITANIUM	TITANIUM31	11	14.21
11	132kv KILIFI-MSA CEMENT	KKILIFI31	33	31.27
12	132kV RABAI-GALU	KGALU31	33	8.16
13	132kV RABAI-GALU	GALU32	33	10.19
14	132kV RABAI-GALU	TITANIUM31	11	14.21
15	132kV RABAI-VIPINGO	KVIPINGO91	11	0.38
16	132kV RABAI-VIPINGO	KMSACEM31	6.9	23.68
17	132kV RABAI-VIPINGO	KKILIFI31	33	31.27
18	132kV VIPINGO-MSA CEMENT	KMSACEM31	6.9	23.68
19	132kV VIPINGO-MSA CEMENT	KKILIFI31	33	31.27
20	220/33kV TX AT GARSEN	KGARSEN31	33	4.35
21	220/33kV TX AT LAMU	KLAMU31	33	3.93
22	220/33kV TX AT MALINDI	KMALINDI31	33	15.40

23	220kV GARSEN-LAMU	KLAMU31	33	3.93
24	220kV MALINDI-GARSEN	KLAMU31	33	3.93
25	220kV MALINDI-GARSEN	KGARSEN31	33	4.35
26	220kV RABAI-MALINDI	KLAMU31	33	3.93
27	220kV RABAI-MALINDI	KGARSEN31	33	4.35
28	220kV RABAI-MALINDI	KMALINDI31	33	15.40
29	33kV RABAI-BAMBA	BAMBA	33	8.06

There was no power flow solution (solution failed to converge) for following the contingency events below.

Table 10:2020 N-1 Contingency Events without power flow solutions

S/N	FROM BUS		TO BUS		CKT	ISLAND
	NAME	VOLTAGE	NAME	VOLTAGE		
1	RABAI	220	MARIAKANI	220	2	0
2	RABAI	220	MARIAKANI	220	1	0
3	KKIPEVU1BB3	11	KKIPEVU11	132	1	1
4	KKIPIVE1BB1	11	KKIPEVU11	132	1	1
5	KKIPEVUIIBB2	11	KKIPEVUDII11	132	1	1
6	KKOKOTONI11	132	KRABAI11	132	1	0
7	KRABAI21	220	TESTBUS	220	2	0

iii. SIMULATION RESULTS FOR YEAR 2022

Normal operations

Overloads were recorded at the following branches:

Table 11:2022 Branch Overloading

S/n	Branch	Rated (MVA)	Loading (MW)	Percentage Loading
1	132/33 New Maungu Transformer	15	29.2	194.7

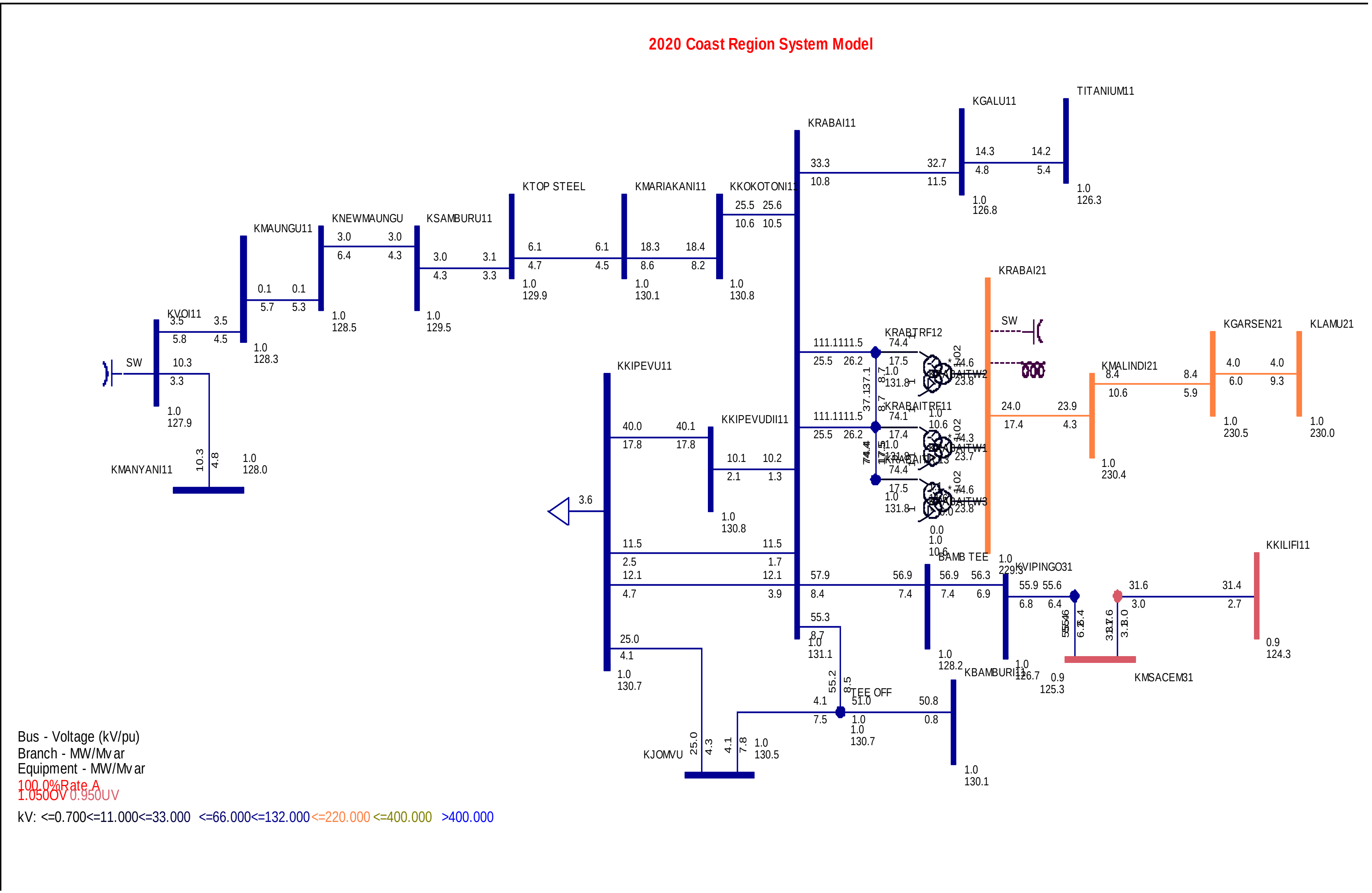

Figure 2: 2020 Load Flow Solution

No voltage violations were noted on the transmission buses and the fault levels for all substations are within the maximum equipment ratings.

N-1 Contingency operations

Voltage violations outside the N-1 Voltage thresholds of 0.9≤ V ≥1.1 p.u are noted as follows: -

Table 12:2022 N-1 Voltage Violations

S/n	MONITORED BUS	BASE VOLTAGE	CONTIGENCY EVENT	BASE CASE VOLTAGE	N-1 CONTINGENCY	DEVIATION
1	NEW MAUNGU	132	132kV MARIAKANI-KOKOTONI	0.961	0.859	-11%
2	SAMBURU 132	132	132kV MARIAKANI-KOKOTONI	0.980	0.860	-12%
3	MARIAKANI	132	132kV MARIAKANI-KOKOTONI	0.991	0.860	-13%
4	MAUNGU132	132	132kV MARIAKANI-KOKOTONI	0.963	0.866	-10%
5	VOI 132	132	132kV MARIAKANI-KOKOTONI	0.969	0.886	-9%
6	SAMBURU 132	132	132kV MARIAKANI-SAMBURU	0.980	0.850	-13%
7	NEW MAUNGU	132	132kV MARIAKANI-SAMBURU	0.961	0.850	-12%
8	MAUNGU132	132	132kV MARIAKANI-SAMBURU	0.963	0.857	-11%
9	VOI 132	132	132kV MARIAKANI-SAMBURU	0.969	0.879	-9%
10	KOKOTONI	132	132kV RABAI-KOKOTONI	0.995	0.819	-18%
11	MARIAKANI	132	132kV RABAI-KOKOTONI	0.991	0.821	-17%
12	SAMBURU 132	132	132kV RABAI-KOKOTONI	0.980	0.823	-16%
13	NEW MAUNGU	132	132kV RABAI-KOKOTONI	0.961	0.826	-14%
14	MAUNGU132	132	132kV RABAI-KOKOTONI	0.963	0.834	-13%
15	VOI 132	132	132kV RABAI-KOKOTONI	0.969	0.858	-11%
16	MANYANI	132	132kV RABAI-KOKOTONI	0.977	0.890	-9%
17	NEW BAMB 132	132	132kV RABAI-NEW BAMBURI	0.977	0.826	-15%
18	BOMANI	132	132kV RABAI-NEW BAMBURI	0.975	0.828	-15%
19	VIPINGO RANG	132	132kV RABAI-NEW BAMBURI	0.981	0.851	-13%
20	MBSACEM TEE1	132	132kV RABAI-NEW BAMBURI	0.982	0.857	-13%

21	MOMBASA CEM	132	132kV RABAI-NEW BAMBURI	0.983	0.861	-12%
22	MBSACEM TEE2	132	132kV RABAI-NEW BAMBURI	0.984	0.865	-12%
23	KILIFI	132	132kV RABAI-NEW BAMBURI	0.991	0.888	-10%
24	NEW MAUNGU	132	132kV SAMBURU-NEW MAUGU	0.961	0.846	-12%
25	MAUNGU132	132	132kV SAMBURU-NEW MAUGU	0.963	0.854	-11%
26	VOI 132	132	132kV SAMBURU-NEW MAUGU	0.969	0.876	-10%

The following gives the N-1 contingency events results to branch over-loading as follows:

Table 13:2022 N-1 Branch Overloads

S/n	**CONTINGENCY EVENT (OUTAGE OF LINE or TX)**	**MONITORED BRANCH**					**LOADING (MVA)**	**EQUIPMENT RATING (MVA)**	**PERCENT OVERLOAD**
		FROM BUS	**BUS VOLTAGE (kV)**	**TO BUS**	**BUS VOLTAGE (kV)**	**CKT**			
1	132/33kV TX2 AT KILIFI	KILIFI	132	KILIFI 33	33	1	29.74	23.00	129.30
2	132/33kV TX1 AT KILIFI	KILIFI	132	KILIFI 33	33	2	29.74	23.00	129.30
3	220/33kV TX2 at MALINDI	MALINDI	220	MALINDI	33	1	28.49	23.00	123.88
4	220/33kV TX 1 at MALINDI	MALINDI	220	MALINDI	33	2	28.49	23.00	123.88
5	132kV RABAI-BAMBURI	MBSACEM TEE2	132	KILIFI	132	1	98.42	97.20	101.26
6	132kV RABAI-KILIFI	NEW BAMB 132	132	RABAI 132	132	1	112.79	97.20	116.04
7	132kV RABAI-BAMBURI	RABAI 132	132	KILIFI	132	1	124.81	97.20	128.40

The following gives the N-1 contingency events that resulted to load shedding:

Table 14:2022 N-1 Load Shedding

S/N	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED LOAD BUS NAME	BUS VOLTAGE	LOAD SHED(MW)
1	132/3.3 TX AT VIPINGO	VIPINGO R LV	3.3	0.54
2	132/3.3 TX AT MAUNGU KPC	MAUNGU LV	3.3	1.04
3	132/6.6 TX AT MANYANI KPC	MANYANI LV	6.6	1.20
4	132/6.6 TX AT SAMBURU KPC	SAMBURU LV	6.6	1.23
5	132kV RABAI-GALU	LUNGA LUNGA3	33	3.52
6	132kV GALU-TITANIUM	LUNGA LUNGA3	33	3.52
7	132kV TITANIUM - KWALE SUGAR	LUNGA LUNGA3	33	3.52
8	132kV KWALE SUGAR- LUNGA LUNGA	LUNGA LUNGA3	33	3.52
9	132/33kV YX AT LUNGA LUNGA	LUNGA LUNGA3	33	3.52
10	132/11kV TA+X AT KOKOTONI	KOKOTONI 11	11	4.00
11	220kV ELEK WITU-GARSEN	LAMU 33	33	4.26
12	220kV ELEK WITU-LAMU	LAMU 33	33	4.26
13	220/33kV TX AT LAMU	LAMU 33	33	4.26
14	132kV RABAI-GALU	GALU 33	33	15.52
15	132kV RABAI-GALU	TITANIUM 132	132	17.00
16	132kV GALU-TITANIUM	TITANIUM 132	132	17.00
17	132/33kV TX AT MAUNGU	NEW MAUNGU33	33	24.87

There was no power flow solution (solution failed to converge) for following the contingency events below.

Table 15:2022 Contingency Events without Power flow solutions

S/N	FROM BUS		TO BUS		CKT	ISLAND
	NAME	VOLTAGE	NAME	VOLTAGE		
1	RABAI	220	MALINDI	220	2	0
2	MALINDI	220	GARSEN	220	1	0

iv. SIMULATION RESULTS FOR YEAR 2025

In order to cater for the new load expected at Shimoni by the year 2025, three options (scenarios) were checked. The scenarios as are as follow:

1) Opt 1: No New line to Shimoni
2) Opt 2: Introduction of 220/132kV at Kwale and with a 132kV double circuit line to Lunga Lunga

3) Opt 3: Similar to Option 2 but with a 220kV double circuit line to Shimoni instead of 132kV line to Lunga Lunga.

Scenario 3 above provided the best results, the following is a summary of how the three scenarios compared.

Table 16:2025 Case Scenarios Power Flow Results Comparison

Scenario	**Number of Bus Voltage Violations**	**Number of Overloading Violations**	**Transmission Losses (MW) Coast Subsystem**
Opt 1	10 (all are 132kV with the worst violation recorded at Shimoni 132kV = 0.81pu)	4: 132kV lines (Rabai-Likoni and Likoni –Galu) 2 No 132/33kV Transformers at new Bamburi	29.09
Opt 2	8 (all are 132kV with the worst violation recorded at New Bamburi 132kV = 0.9281pu)	2 :2 No 132/33kV Transformers at new Bamburi	21.85
Opt 3	3 (all are 132kV with the worst violation recorded at New Bamburi 132kV = 0.931pu)	2: 2 No 132/33kV Transformers at new Bamburi	19.57

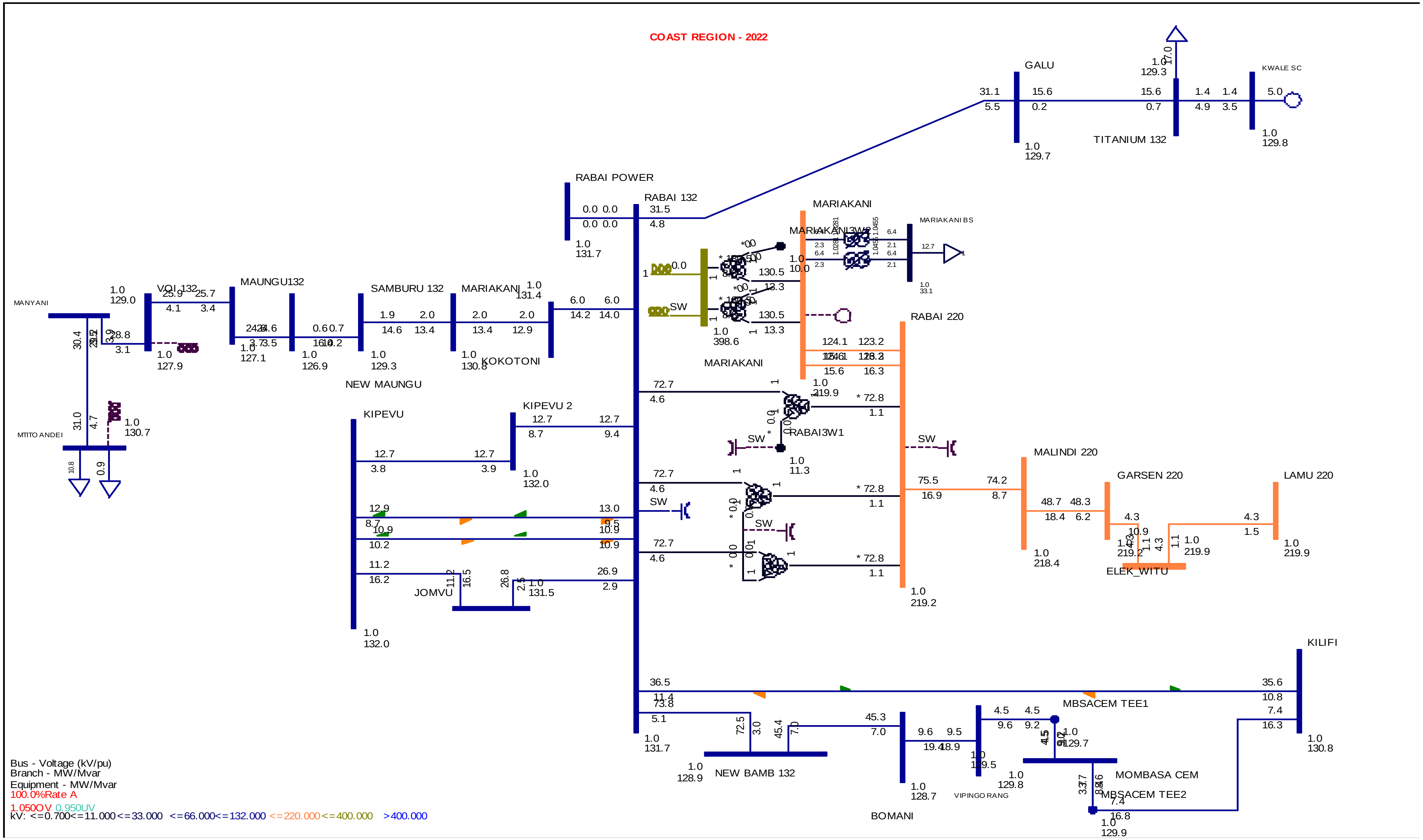

Figure 3: 2022 Power Solution Normal System Operation Conditions

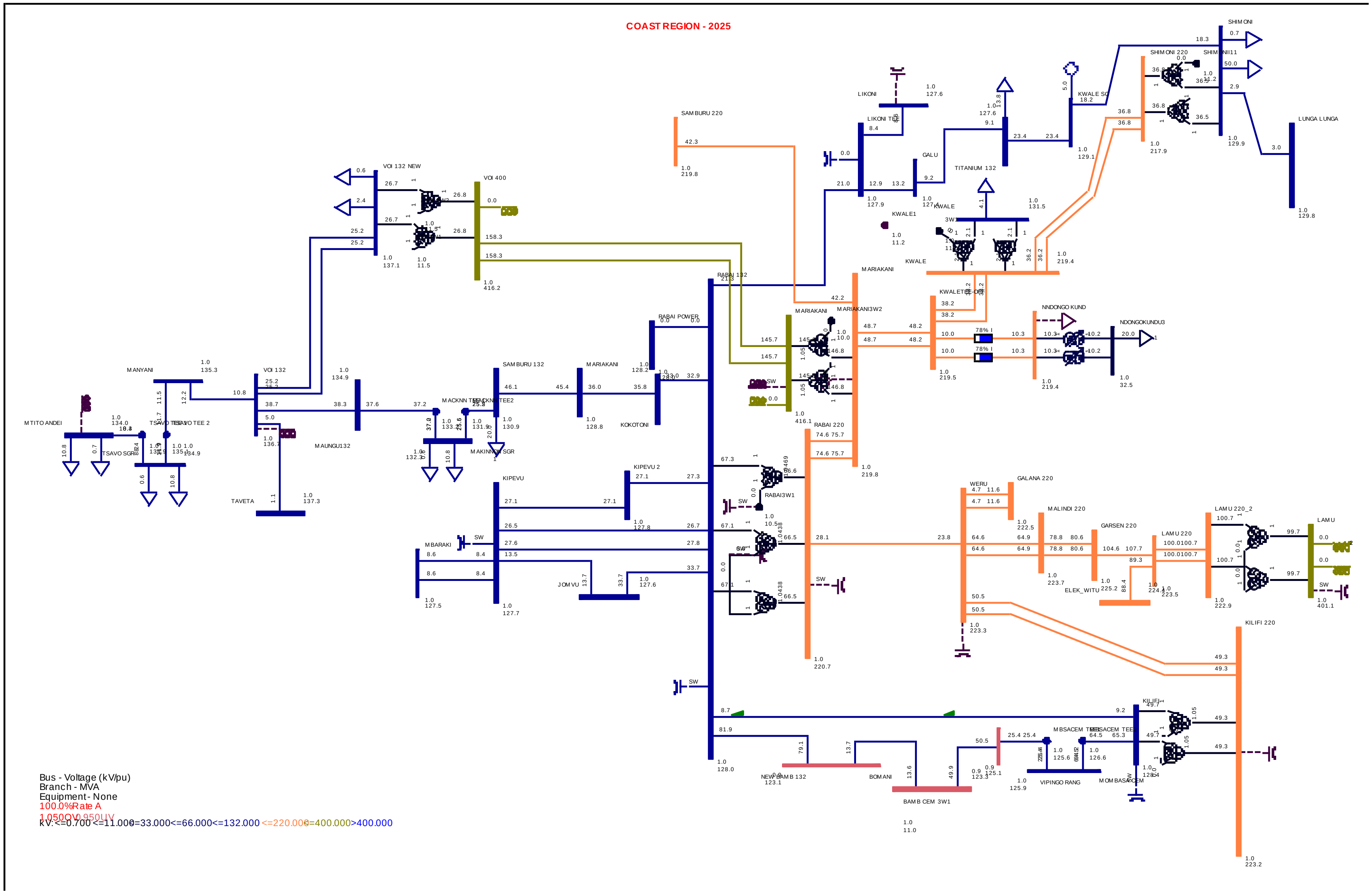

Figure 4: 2025 Power Flow Solution Results

Normal System Operations

Scenario 3 was considered for further simulations; the following gives the tabulated results record for Scenario 3.

Overloads are recorded at the following branches:

Table 17:2025 Branch Overloading

S/n	Branch	Rated (MVA)	Loading (MW)	Percentage Loading
1	132/33 New Bamburi Transformer 1	45	52.5	116.6
2	132/33 New Bamburi Transformer 2	45	52.5	116.6

Voltage violations are noted at the following buses with certain buses in the 132kV Rabai to Kilifi system also recording bus voltages that were in the vicinity of the lower band.

Table 18:2025 Voltage violations

S/N	BUS NAME	BASE VOLTAGE	BUS VOLTAGE	
			V (kV)	V (PU)
1	VIPINGO RANG	132	124.96	0.9466
2	BOMANI	132	123.07	0.9324
3	NEW BAMB	132	122.94	0.9313

The fault levels for the substations are within the maximum equipment ratings.

N-1 Contingency operations

Voltage violations outside the N-1 Voltage thresholds of 0.9≤ V ≥1.1 p.u are noted as follows: -

Table 19:2025 N-1 Voltage Violations

S/n	MONITORED BUS	BASE VOLTAGE	CONTIGENCY EVENT	BASE CASE VOLTAGE	N-1 CONTINGENCY	DEVIATION
1	NEW BAMB 132	132	132kV RABAI-NEW BAMBURI	0.972	0.798	-18%
2	BOMANI	132	132kV RABAI-NEW BAMBURI	0.972	0.809	-17%
3	VIPINGO RANG	132	132kV RABAI-NEW BAMBURI	0.984	0.859	-13%

4	MBSACEM TEE1	132	132kV RABAI-NEW BAMBURI	0.987	0.873	-12%
5	MOMBASA CEM	132	132kV RABAI-NEW BAMBURI	0.989	0.880	-11%
6	MBSACEM TEE2	132	132kV RABAI-NEW BAMBURI	0.993	0.897	-10%

The following gives the N-1 contingency events results to branch over-loading as follows:

Table 20:2025 N-1 Branch Overloading

S/n	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED BRANCH					LOADING (MVA)	EQUIPMENT RATING (MVA)	PERCENT OVERLOAD
		FROM BUS	BUS VOLTAGE (kV)	TO BUS	BUS VOLTAGE (kV)	CKT			
1	132kV RABAI-NEW BAMBURI	VIPINGO RANG	132	BOMANI	132	1	181.88	97.20	187.12
2	132kV RABAI-NEW BAMBURI	MOMBASA CEM	132	MBSACEM	132	2	196.55	97.20	202.22
3	132kV RABAI-NEW BAMBURI	MBSACEM TEE2	132	KILIFI	132	1	196.43	97.20	202.09
4	132kV BOMANI-VIPINGO	NEW BAMB 132	132	RABAI 132	132	1	146.60	97.20	150.83
5	132kV MOMB CEM _KILIFI	NEW BAMB 132	132	RABAI 132	132	1	162.11	97.20	166.78
6	132kV RABAI-NEW BAMBURI	NEW BAMB 132	132	BOMANI	132	1	133.81	97.20	137.67
7	132kV NEW BAMBURI-BOMANI	NEW BAMB 132	132	RABAI 132	132	1	100.44	97.20	103.34
8	132/33kV TX AT KILIFI	KILIFI	132	KILIFI 33	33	2	26.68	23.00	116.01

The following gives the N-1 contingency events that resulted to load shedding:

Table 21:2025 N-1 Load Shedding

S/N	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED LOAD BUS NAME	BUS VOLTAGE	LOAD SHED(MW)
1	132/3.3 TX AT VIPINGO R	VIPINGO R LV	3.3	0.33
2	132/3.3 TX AT MAUNGU KPC	MAUNGU LV	3.3	0.67
3	132/6.6 TX AT MANYANI KPC	MANYANI LV	6.6	0.74
4	132/6.6 TX AT SAMBURU KPC	SAMBURU LV	6.6	0.76
5	132kV VOI-TAVETA	TAVETA3	33	1.05
6	132kV SHIMONI-LUNGA LUNGA	LUNGA LUNGA3	33	2.85
7	132/33kV TX at LUNGA LUNGA	LUNGA LUNGA3	33	2.85
8	132/11kV TX AT KOKOTONI	KOKOTONI 11	11	2.90

S/N	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED LOAD BUS NAME	BUS VOLTAGE	LOAD SHED(MW)
9	220/33kV TX AT LAMU	LAMU 33	33	4.74
10	220/33kV TX AT GARSEN	GARSEN 33	33	5.82
11	132kV MARIAKANI-MARIAKANI SGR	MARIAKN SGR	132	9.35

There were no contingency events that failed to get converging solution

v. SIMULATION RESULTS FOR YEAR 2030

Building from the recommended model of 2025, (with 220kV link to Shimoni) and in order to mitigate against the voltage violations as noted on the Rabai-Kilifi system, two options (scenarios) were checked. The scenarios as are as follow: -

1) Opt 1: No voltage support devices at Rabai and Kilifi
2) Opt 2: With Voltage support devices (grid grade capacitors) installed at Rabai and Kilifi

Scenario 2 above provided the best results, the following is a summary of how the two scenarios compared.

Table 22:2030 Case Scenarios Power Flow Results Comparison

Scenario	Number of Bus Voltage Violations	Number of Overloading Violations	Transmission Losses (MW) Coast Subsystem
Opt 1	No voltage violations were noted (although some busses recorded voltages in the vicinity of 0.95p.u.	2 No 132/33kV Transformers at new Maungu	36.55
Opt 2	No voltage violations were noted, the buses have a better voltages.	2 :2 No 132/33kV Transformers at new Bamburi	35.97

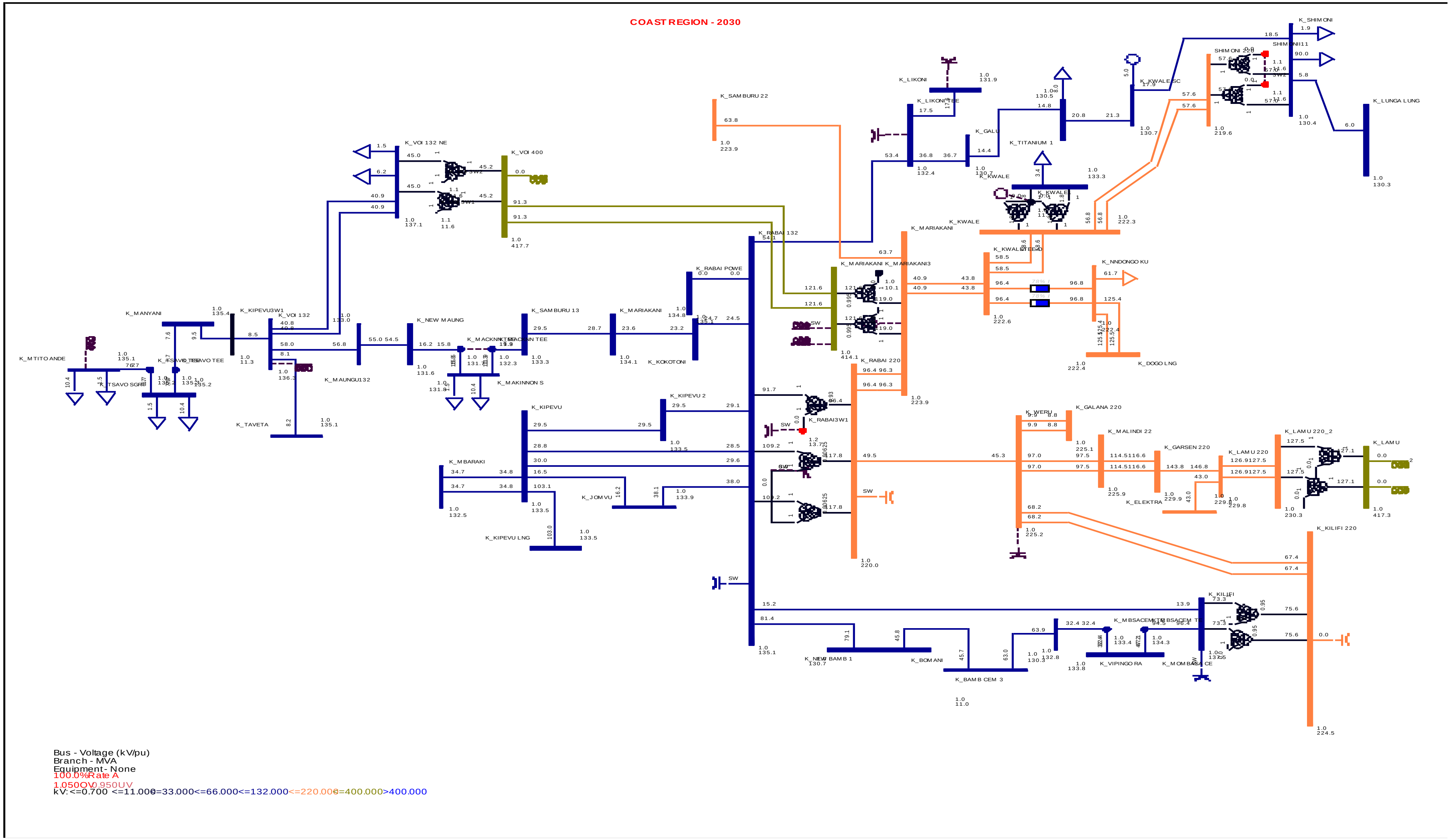

Figure 5: 2030 Power Flow Results

Normal System Operations

Scenario 2 was considered for further simulations; the following gives the tabulated results record for Scenario 2

Overloads are recorded at the following branches:

Table 23:2030 Branch Overloads

S/n	Branch	Rated (MVA)	Loading (MVA)	Percentage Loading
1	132/33 New Maungu Transformer 1	15	23.4	156.2
2	132/33 New Maungu Transformer 2	15	23.4	156.2

No Voltage violations were noted.

The fault levels for the substations are within the maximum equipment ratings.

N-1 Contingency operations

Voltage violations outside the N-1 Voltage thresholds of 0.9≤ V ≥1.1 p.u are noted as follows: -

Table 24:2030 N-1 Bus Voltage Violations

S/n	MONITORED BUS	BASE VOLTAGE	CONTIGENCY EVENT	BASE CASE VOLTAGE	N-1 CONTINGENCY	DEVIATION
1	MAUNGU132	132	132kV VOI-MAUNGU	1.004	0.897	-11%
2	NEW MAUNG	132	132kV VOI-MAUNGU	0.993	0.897	-10%
3	VIPINGO RA	132	132kV RABAI-NEW BAMBURI	1.005	0.898	-11%
4	NEW BAMB 1	132	132kV RABAI-NEW BAMBURI	0.988	0.845	-14%
5	BOMANI	132	132kV RABAI-NEW BAMBURI	0.985	0.849	-14%
6	GALU	132	132kV RABAI-LIKONI	0.986	0.801	-19%
7	TITANIUM 1	132	132kV RABAI-LIKONI	0.985	0.822	-17%
8	KWALE SC	132	132kV RABAI-LIKONI	0.986	0.874	-11%
9	LIKONI	132	132kV RABAI-LIKONI	0.995	0.790	-21%
10	LIKONI TEE	132	132kV RABAI-LIKONI	1.000	0.795	-20%
11	GALU	132	132kV LIKONI-GALU	0.986	0.864	-12%
12	TITANIUM 1	132	132kV LIKONI-GALU	0.985	0.877	-11%

The following gives the N-1 contingency events results to branch over-loading as follows:

Table 25:2030 N-1 Branch Overloads

S/n	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED BRANCH					LOADING (MVA)	EQUIPMENT RATING (MVA)	PERCENT OVERLOAD
		FROM BUS	BUS VOLTAGE (kV)	TO BUS	BUS VOLTAGE (kV)	CKT			
1	132kV VOI-MAUNGU	NEW MAUNG	132	NEWMAUNGU	33	1	24.78	23.00	107.72
2	132kV VOI-MAUNGU	NEW MAUNG	132	NEWMAUNGU	33	2	24.78	23.00	107.72
3	132kV NEW MAUNGU-MAUNGU KPC	NEW MAUNG	132	NEWMAUNGU	33	1	24.67	23.00	107.28
4	132kV NEW MAUNGU-MAUNGU KPC	NEW MAUNG	132	NEWMAUNGU	33	2	24.67	23.00	107.28
5	132kV NEW MAUNGU-MAUNGU KPC	KILIFI	132	KILIFI 33	33	2	34.83	23.00	151.42
6	132/33kV TX AT BOMANI	BOMANI	132	BAMBURI CE	33	2	91.17	90.00	101.30
7	132/33kV TX AT BOMANI	BOMANI	132	BAMBURI CE	33	1	91.17	90.00	101.30
8	132/33kV TX AT MBARAKI	MBARAKI	132	MBARAKI3	33	2	72.01	60.00	120.01
9	132/33kV TX AT NEW MAUNGU	NEW MAUNG	132	NEWMAUNGU	33	2	47.06	23.00	204.63
10	132/33kV TX AT NEW MAUNGU	NEW MAUNG	132	NEWMAUNGU	33	1	47.06	23.00	204.63
11	132kV BOMANI-VIPINGO	NEW BAMB 1	132	RABAI 132	132	1	150.20	97.20	154.53
12	132kV BOMANI-VIPINGO	NEW BAMB 1	132	BOMANI	132	1	115.25	97.20	118.57
13	132kV KIPEVU-KIPEVU LNG	MBSACEMTE	132	KILIFI	132	1	101.41	97.20	104.33
14	132kV MSA CEMENT-KILIFI	NEW BAMB 1	132	RABAI 132	132	1	186.38	97.20	191.75
15	132kV MSA CEMENT-KILIFI	NEW BAMB 1	132	BOMANI	132	1	150.70	97.20	155.04
16	132kV RABAI-NEW BAMBURI	VIPINGO RA	132	BOMANI	132	1	168.29	97.20	173.13
17	132kV RABAI-NEW BAMBURI	MOMBASACE	132	MBSACEMTE	132	1	100.22	97.20	103.11

S/n	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED BRANCH					LOADING (MVA)	EQUIPMENT RATING (MVA)	PERCENT OVERLOAD
		FROM BUS	BUS VOLTAGE (kV)	TO BUS	BUS VOLTAGE (kV)	CKT			
18	132kV RABAI-NEW BAMBURI	MOMBASA CE	132	MBSACEM TE	132	2	100.22	97.20	103.11
19	132kV RABAI-NEW BAMBURI	MBSACEM TE	132	KILIFI	132	1	200.12	97.20	205.89
20	132kV NEW BAMBURI-BOMANI	VIPINGO RA	132	BOMANI	132	1	118.61	97.20	122.02
21	132kV NEW BAMBURI-BOMANI	MBSACEM TE	132	KILIFI	132	1	149.23	97.20	153.53
22	132kV RABAI-KILIFI	MBSACEM TE	132	KILIFI	132	1	101.59	97.20	104.52
23	220kV RABAI-WERU	MBSACEM TE	132	KILIFI	132	1	107.36	97.20	110.45

The following gives the N-1 contingency events that resulted to load shedding:

Table 26:2030 N-1 Load Shedding

S/N	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED LOAD BUS NAME	BUS VOLTAGE	LOAD SHED(MW)
1	132kV MARIAKANI-MARIAKANI SGR	K_MARIAKN SG	132	11.95
2	220/33kV TX AT GARSEN	K_GARSEN 33	33	5.22
3	220/33kV TX AT LAMU	K_LAMU 33	33	5.69
4	132kV VOI-TAVETA	K_TAVETA3	33	7.69
5	132kV SHIMONI-LUNGA LUNGA	K_LUNGA LUNG	33	5.60
6	132/33kV TX AT LUNGA LUNGA	K_LUNGA LUNG	33	5.60
7	132/33kV TX AT VIPINGO	K_VIPINGO R	33	0.86

There were no contingency events that failed to get converging solution

vi. SIMULATION RESULTS FOR YEAR 2035

In order to reinforce and increase transmission capacity for the Rabai-Kilifi system as a result of increased demand at Bamburi and Bomani and Mombasa Cement supply points, two options (scenarios) were considered and analysed/ checked. The scenarios as are as follow:

1) Opt 1: No new 220kV line to Bamburi

2) Opt 2: Introduction of 220/132kV at Bamburi with a 220kV double circuit line to Mariakani and Kilifi.

Scenario 2 above provided the best results, the following is a summary of how the two scenarios compared.

Table 27:2035 Case Scenarios Power Flow Results Comparison

Scenario	**Number of Bus Voltage Violations**	**Number of Overloading Violations**	**Transmission Losses (MW) Coast Subsystem**
Opt 1	No voltage violations were recorded	1No - 132kV line (Rabai-New Bamburi)	49.76
Opt 2	No voltage violations were recorded	No overloading was recorded	42.8

Normal System Operations

Scenario 2 was considered for further simulations; the simulation results did not show any violations in branch loading. There were no voltage violations either during normal system operations.

The fault levels for the substations are within the maximum equipment ratings.

N-1 Contingency operations

Voltage violations outside the N-1 Voltage thresholds of 0.9≤ V ≥1.1 p.u are noted as given in Table 4

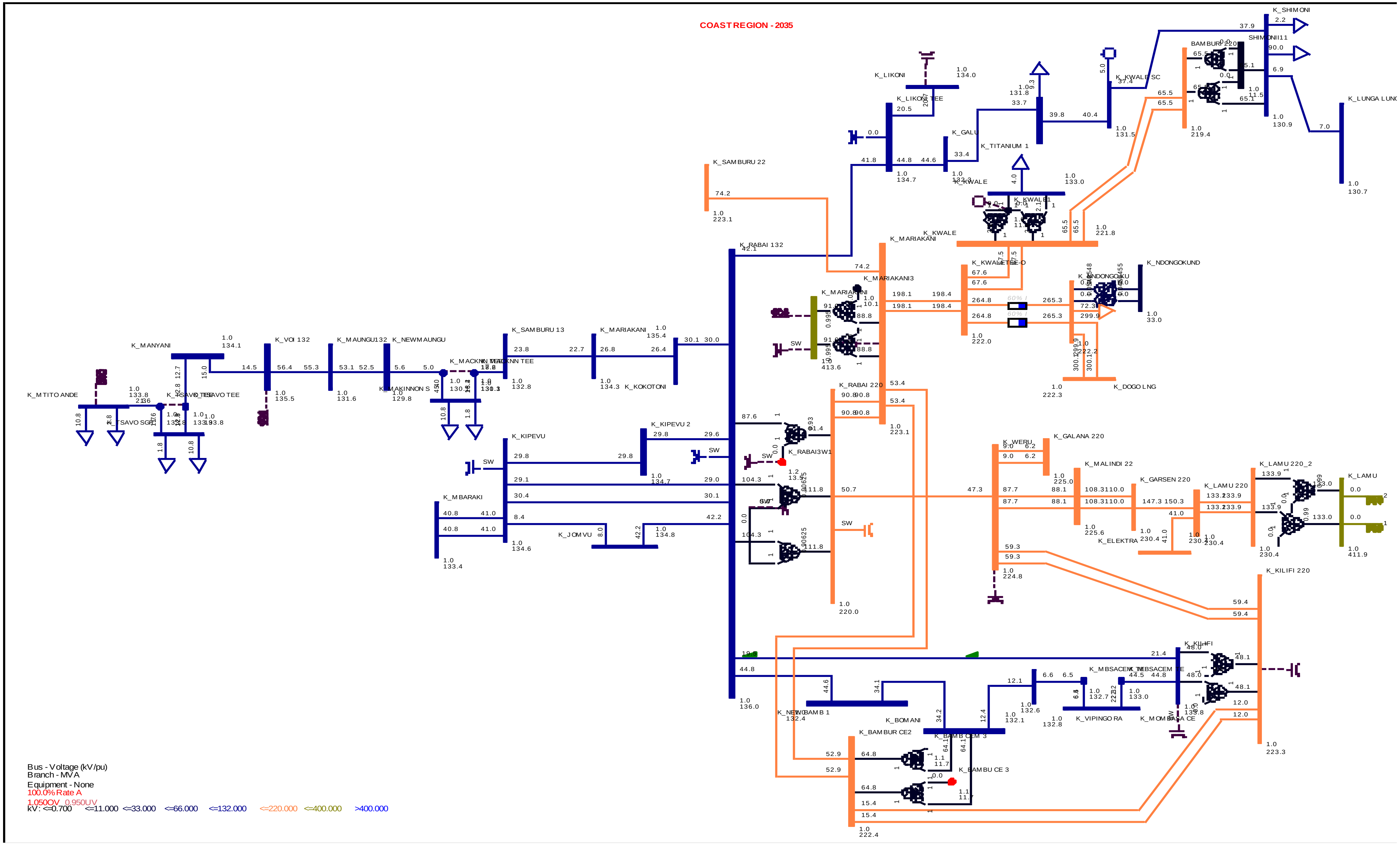

Figure 6: 2035 Load Flow Solutions Results

Table 28:2035 N-1 Voltage Violations

S/n	MONITORED BUS	BASE VOLTAGE	CONTIGENCY EVENT	BASE CASE VOLTAGE	N-1 CONTINGENCY	DEVIATION
1	GALU	132	132kV GALU-LIKONI	1.002	0.840	-16%
2	TITANIUM 1	132	132kV GALU-LIKONI	0.998	0.857	-14%
3	MAUNGU132	132	132kV VOI-MAUNGU	0.996	0.866	-13%
4	NEWMAUNGU	132	132kV VOI-MAUNGU	0.983	0.867	-12%
5	NEWMAUNGU	132	132kV MAUNGU-NEW MAUNGU	0.983	0.871	-11%
6	GALU	132	132kV RABAI -LIKONI	1.002	0.886	-12%
7	MACKNN TEE	132	132kV VOI-MAUNGU	0.985	0.886	-10%
8	LIKONI	132	132kV RABAI -LIKONI	1.014	0.886	-13%
9	MACKNN TEE	132	132kV MAUNGU-NEW MAUNGU	0.985	0.890	-10%
10	LIKONI TEE	132	132kV RABAI -LIKONI	1.020	0.892	-12%
11	TITANIUM 1	132	132kV RABAI -LIKONI	0.998	0.896	-10%

Table 29 gives the N-1 contingency events results to branch over-loading as follows:

Table 29: 2035 N-1 Loading Violations

S/n	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED BRANCH					LOADING (MVA)	EQUIPMENT RATING (MVA)	PERCENT OVERLOAD
		FROM BUS	BUS VOLTAGE (kV)	TO BUS	BUS VOLTAGE (kV)	CKT			
1	220/132/33kV TX 1 AT BOMANI	BAMBURCE2	220	WBAMBHTR-	33	2	90.32	90.00	100.36
2	220/132/33kV TX 2 AT BOMANI	BAMBURCE2	220	WBAMBHTR-	132	2	90.32	90.00	100.36
3	220/132/33kV TX 1AT BAMBURI	BOMANI	132	NEWBAMBHTR-	33	2	90.32	90.00	100.36
4	220/132/33kV TX AT BAMBURI	BOMANI	132	NEWBAMBHTR-	33	2	90.32	90.00	100.36
5	220kV LAMU_GARSEN CCT 1	GARSEN 220	220	LAMU 220	220	2	239.00	236.60	101.01
6	220kV LAMU_GARSEN CCT 2	GARSEN 220	220	LAMU 220	220	1	239.00	236.60	101.01
7	220kV LAMU COAL-LAMU CCT 1	LAMU 220	220	LAMU 220_2	220	2	246.60	236.60	104.23

8	220kV LAMU COAL-LAMU CCT 1	LAMU 220	220	LAMU 220_2	220	1	246.60	236.60	104.23
9	132/33kV TX 1 AT BAMBURI	NEW BAMB 1	132	NEWBAMB TR-2	33	2	47.36	45.00	105.25
10	132/33kV TX 2 AT BAMBURI	NEW BAMB 1	132	NEWBAMB TR-1	33	1	47.36	45.00	105.25
11	220/33kV TX 2 AT MARIAKANI	MARIAKAN I	220	MARIAKAN I	33	1	25.96	23.00	112.89
12	220/33kV TX 1 AT MARIAKANI	MARIAKAN I	220	MARIAKAN I	33	2	25.96	23.00	112.89
13	132/33kV TX 1 AT GALU	GALU	132	GALU 33	33	2	51.42	45.00	114.27
14	132/33kV TX 2 AT GALU	GALU	132	GALU 33	33	1	51.42	45.00	114.27
15	220kV MARIAKANI-KWALE CCT 1	MARIAKAN I	220	KWALETEE-O	132	2	377.30	326.00	115.73
16	220kV MARIAKANI-KWALE CCT 2	MARIAKAN I	220	KWALETEE-O	220	1	377.30	326.00	115.73
17	132kV BOMANI-BAMBURI CEMENT	BOMANI	132	BAMBURI CE	33	2	106.07	90.00	117.86
18	132kV BOMANI-BAMBURI CEMENT	BOMANI	132	BAMBURI CE	33	1	106.07	90.00	117.86
19	132/33kV TX 1 AT NEW MAUNGU	NEWMAUN GU	132	NEWMAUN G	33	1	29.10	23.00	126.50
20	132/33kV TX 2 AT NEW MAUNGU	NEWMAUN GU	132	NEWMAUN G	33	2	29.10	23.00	126.50
21	132/33kV TX2 AT MBARAKI	MBARAKI	132	MBARAKI3	33	2	84.58	60.00	140.97
22	220kV DONGO KUNDU-KWALE CCT1	NNDONGO KU	220	KWALETEE-O	220	4	526.14	326.00	161.39
23	220kV DONGO KUNDU-KWALE CCT2	NNDONGO KU	220	KWALETEE-O	220	3	526.14	326.00	161.39
24	132/33kV TX 1 AT KILIFI	KILIFI	132	KILIFI 33	33	2	39.98	23.00	173.83
25	220kV DONGO KUNDU LNG-DONGO KUNDU CCT1	NNDONGO KU	220	DOGO LNG	220	2	594.42	326.00	182.34
26	220kV DONGO KUNDU LNG-DONGO KUNDU CCT2	NNDONGO KU	220	DOGO LNG	220	1	594.42	326.00	182.34

Table 30 gives the N-1 contingency events that resulted to load shedding:

Table 30:2035 N-1 Branch Overloads

S/N	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED LOAD BUS NAME	BUS VOLTAGE	LOAD SHED(MW)
1	132kV MARIAKANI-MARIAKANI SGR	MARIAKN SG	132	12.59
2	220/33kV TX AT GARSEN	GARSEN 33	33	6.11
3	220/33kV TX AT LAMU	LAMU 33	33	6.66
4	132kV VOI- TAVETA	TAVETA3	33	9.01
5	132kV SHIMONI- LUNGA LUNGA	LUNGA LUNG	33	6.56
6	132/33k TX AT LUMGA LUNGA	LUNGA LUNG	33	6.56
7	132/11kV TX AT KOKOTONI	KOKOTONI 1	11	8.79
8	132/33kV TX AT VIPINGO	VIPINGO R	33	1.01
9	132/3.3 TX AT MAUNGU KPC	MAUNGU LV	3.3	2.03
10	132/3.3 TX AT MTITO KPC	MTITOANDE	3.3	2.03
11	132/6.6kV TX AT SAMBURU KPC	SAMBURU LV	6.6	2.30
12	132/6.6kV TX AT MANYANI KPC	MANYANI LV	6.6	2.23

There were no contingency events that failed to get converging solution

vii. SIMULATION RESULTS FOR YEAR 2039

Normal System Operations

The simulation results did not show any violations in branch loading. There were also no voltage violations during normal system operations.

The fault levels for the substations are within the maximum equipment ratings.

N-1 Contingency operations

Voltage violations outside the N-1 Voltage thresholds of 0.9≤ V ≥1.1 p.u are noted as follows: -

Table 31:2039 N-1 Voltage Violations

S/n	MONITORED BUS	BASE VOLTAGE	CONTIGENCY EVENT	BASE CASE VOLTAGE	N-1 CONTINGENCY	DEVIATION
1	MAUNGU132	132	132kV VOI-MAUNGU	0.987	0.790	-20%
2	MACKNN TEE	132	132kV VOI-MAUNGU	0.975	0.822	-16%
3	MACKNN TEE	132	132kV VOI-MAUNGU	0.987	0.885	-10%
4	MAKINNON S	132	132kV VOI-MAUNGU	0.980	0.852	-13%

S/n	MONITORED BUS	BASE VOLTAGE	CONTIGENCY EVENT	BASE CASE VOLTAGE	N-1 CONTINGENCY	DEVIATION
5	NEWMAUNGU	132	132kV VOI-MAUNGU	0.969	0.791	-18%
6	MACKNN TEE	132	132kV MAUNGU-NEW MAUNGU	0.975	0.831	-15%
7	MACKNN TEE	132	132kV MAUNGU-NEW MAUNGU	0.987	0.891	-10%
8	MAKINNON	132	132kV MAUNGU-NEW MAUNGU	0.980	0.860	-12%
9	NEWMAUNGU	132	132kV MAUNGU-NEW MAUNGU	0.969	0.801	-17%
10	GALU	132	132kV RABAI-LIKONI	0.985	0.706	-28%
11	TITANIUM 1	132	132kV RABAI-LIKONI	0.982	0.733	-25%
12	KWALE SC	132	132kV RABAI-LIKONI	0.982	0.811	-17%
13	LIKONI	132	132kV RABAI-LIKONI	1.000	0.695	-31%
14	LIKONI TEE	132	132kV RABAI-LIKONI	1.007	0.705	-30%
15	LUNGA LUNG	132	132kV RABAI-LIKONI	0.977	0.873	-11%
16	SHIMONI	132	132kV RABAI-LIKONI	0.979	0.875	-11%
17	GALU	132	132kV GALU-LIKONI	0.985	0.759	-23%
18	TITANIUM 1	132	132kV GALU-LIKONI	0.982	0.783	-20%
19	KWALE SC	132	132kV GALU-LIKONI	0.982	0.847	-14%
20	LUNGA LUNG	132	132kV GALU-LIKONI	0.977	0.895	-8%
21	SHIMONI	132	132kV GALU-LIKONI	0.979	0.897	-8%

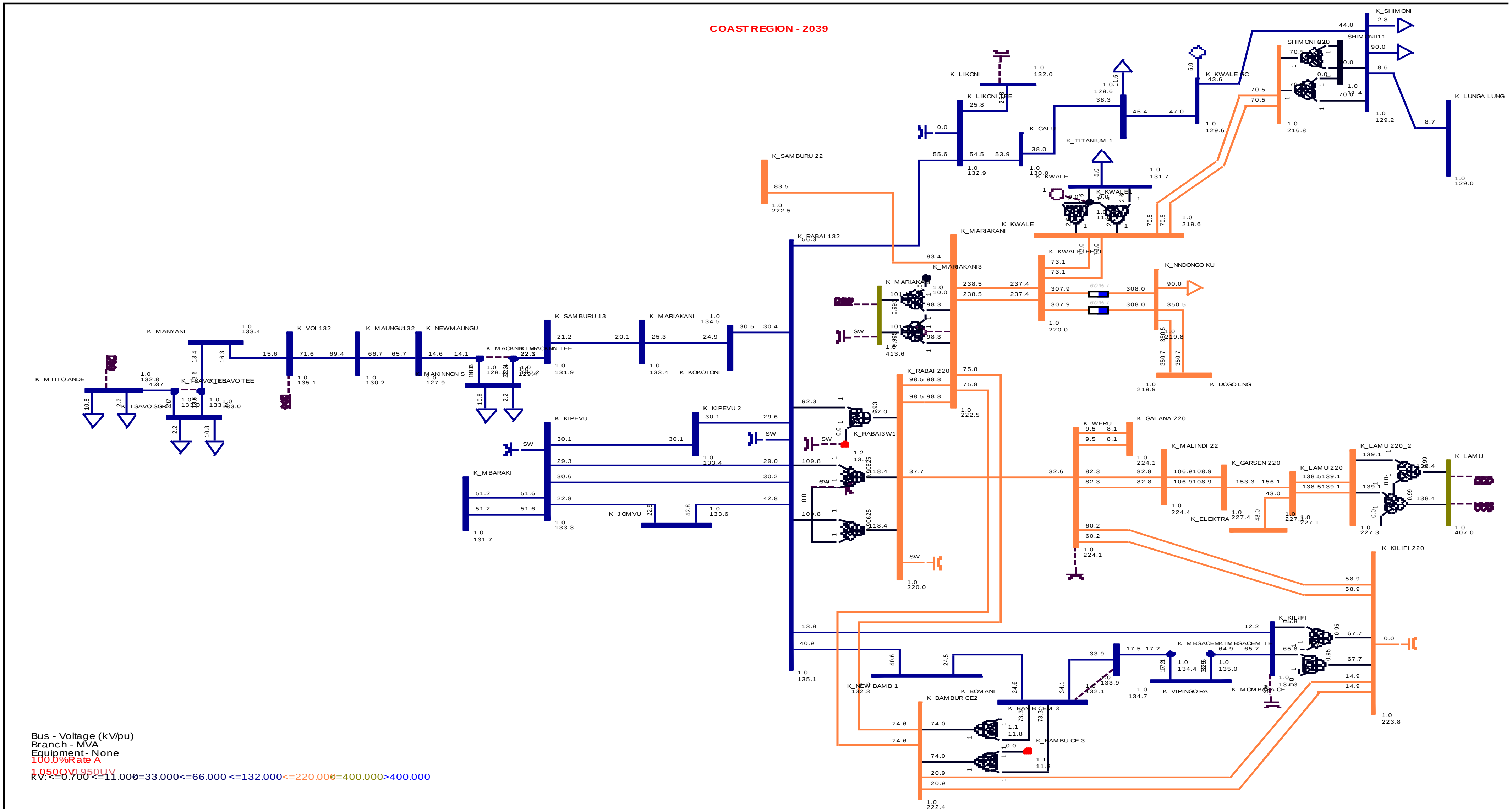

Figure 7: 2039 Load Flow Results

Table 32 gives the N-1 contingency events results to branch over-loading as follows:

Table 32:2039 N-1 Branch Overloads

S/n	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED BRANCH					LOADING (MVA)	EQUIPMENT RATING (MVA)	PERCENT OVERLOAD
		FROM BUS	BUS VOLTAGE (kV)	TO BUS	BUS VOLTAGE (kV)	CKT			
1	132kV VOI-MAUNGU	SAMBURU 13	132	MACKNN TEE	132	1	115.33	97.20	118.65
2	132kV VOI-MAUNGU	MACKNN TEE	132	MAKINNONS	132	2	101.92	97.20	104.86
3	132kV VOI-MAUNGU	MACKNN TEE	132	NEWMAUNGU	132	1	102.11	97.20	105.06
4	132kV VOI-MAUNGU	MACKNN TEE	132	MAKINNONS	132	1	115.54	97.20	118.87
5	132kV VOI-MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	1	24.67	23.00	107.25
6	132kV VOI-MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	2	24.67	23.00	107.25
7	132kV VOI-MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	3	24.67	23.00	107.25
8	132kV VOI-MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	4	24.67	23.00	107.25
9	132kV VOI-VOI NEW	VOI 132	132	VOI 132 NE	132	2	102.45	97.20	105.40
10	132kV VOI-VOI NEW	VOI 132	132	VOI 132 NE	132	1	102.45	97.20	105.40
11	132/33kV TX 1 AT VOI	VOI 132	132	VOI 33	33	2	12.49	10.00	124.93
12	132/33kV TX 2 AT VOI	VOI 132	132	VOI 33	33	1	12.49	10.00	124.93
13	132kV KIPEVU - MBARAKI CCT 1	KIPEVU	132	MBARAKI	132	2	104.27	97.20	107.27
14	132kV KIPEVU - MBARAKI CCT 2	KIPEVU	132	MBARAKI	132	1	104.27	97.20	107.27
15	132kV MAUNGU-N_MAUNGU	SAMBURU 13	132	MACKNN TEE	132	1	110.45	97.20	113.63
16	132kV MAUNGU-N_MAUNGU	MACKNN TEE	132	NEWMAUNGU	132	1	97.33	97.20	100.14
17	132kV MAUNGU-NEW MAUNGU	MACKNN TEE	132	MAKINNONS	132	1	110.63	97.20	113.82
18	132kV MAUNGU-N_MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	1	24.23	23.00	105.37

S/n	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED BRANCH					LOADING (MVA)	EQUIPMENT RATING (MVA)	PERCENT OVERLOAD
		FROM BUS	BUS VOLTAGE (kV)	TO BUS	BUS VOLTAGE (kV)	CKT			
19	132kV MAUNGU-NEW MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	2	24.23	23.00	105.37
20	132kV MAUNGU-NEW MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	3	24.23	23.00	105.37
21	132kV MAUNGU-NEW MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	4	24.23	23.00	105.37
22	132kV MSA CEMENT-KILIFI	BOMANI	132	WBAMB HTR-	WND 2	2	91.40	90.00	101.56
23	132kV MSA CEMENT-KILIFI	BOMANI	132	WBAMB HTR-	WND 2	2	91.40	90.00	101.56
24	132/33/11KV TX 1 AT NEW BAMBURI	NEW BAMB 1	132	WBAMB TR-2	WND 1	2	59.89	45.00	133.09
25	132/33/11KV TX 2 AT NEW BAMBURI	NEW BAMB 1	132	WBAMB TR-1	WND 1	1	59.89	45.00	133.09
26	132kV RABAI-LIKONI	GALU	132	TITANIUM 1	132	1	120.62	97.20	124.09
27	132kV RABAI-LIKONI	GALU	132	GALU 33	33	1	45.49	45.00	101.08
28	132kV RABAI-LIKONI	GALU	132	GALU 33	33	2	45.49	45.00	101.08
29	132kV RABAI-LIKONI	TITANIUM 1	132	KWALE SC	132	1	137.31	97.20	141.26
30	132kV RABAI-LIKONI	KWALE SC	132	SHIMONI	132	1	130.27	97.20	134.03
31	132/33kV TX1 AT RABAI	RABAI 132	132	RABAI 33B	33	2	51.05	45.00	113.45
32	132/33kV TX2 AT RABAI	RABAI 132	132	RABAI 33B	33	1	51.05	45.00	113.45
33	132/33kV TX2 AT RABAI	RABAI 132	132	RABAI 33B	33	1	45.81	45.00	101.79
34	132/33kV TX1 AT RABAI	RABAI 132	132	RABAI 33B	33	2	45.81	45.00	101.79
35	132kV SAMBURU-MACKINNON	VOI 132	132	MAUNGU132	132	1	97.31	97.20	100.12
36	132kV LIKONI-GALU	TITANIUM 1	132	KWALE SC	132	1	100.14	97.20	103.03
37	132/33kV TX1 AT GALU	GALU	132	GALU 33	33	2	66.23	45.00	147.17
38	132/33kV TX2 AT GALU	GALU	132	GALU 33	33	1	66.23	45.00	147.17
39	132/33kV TX 1 AT KILIFI	KILIFI	132	KILIFI 33	33	2	49.72	23.00	216.19
40	132/33kV TX 2 AT KILIFI	KILIFI	132	KILIFI 33	33	1	50.70	45.00	112.67
41	132/33kV TX 1 AT JOMVU	JOMVU	132	JOMVU3	33	2	48.47	45.00	107.71
42	132/33kV TX 2 AT JOMVU	JOMVU	132	JOMVU3	33	1	48.47	45.00	107.71
43	132/33kV TX 1 BOMANI	BOMANI	132	BAMBURI CE	33	2	134.66	90.00	149.62
44	132/33kV TX 2 BOMANI	BOMANI	132	BAMBURI CE	33	1	134.66	90.00	149.62

S/n	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED BRANCH					LOADING (MVA)	EQUIPMENT RATING (MVA)	PERCENT OVERLOAD
		FROM BUS	BUS VOLTAGE (kV)	TO BUS	BUS VOLTAGE (kV)	CKT			
45	220/132/33kV TX1 AT BOMANI	BOMANI	132	WBAMB HTR-	WND 2	2	102.54	90.00	113.93
46	220/132/33kV TX1 AT BOMANI	BOMANI	132	WBAMB HTR-	WND 2	2	102.54	90.00	113.93
47	132/33kV TX 1 AT MBARAKI	MBARAKI	132	MBARAKI3	33	2	109.33	60.00	182.22
48	132/33kV TX 2 AT MBARAKI	MBARAKI	132	MBARAKI3	33	1	105.21	90.00	116.90
49	132kV MAKINNON-SAMBURU	VOI 132	132	MAUNGU132	132	1	97.64	97.20	100.45
50	132/33kV TX 1 AT NEW MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	2	26.76	23.00	116.36
51	132/33kV TX 2 AT NEW MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	1	26.76	23.00	116.36
52	132/33kV TX 3 AT NEW MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	4	26.76	23.00	116.36
53	132/33kV TX 4 AT NEW MAUNGU	NEWMAUNGU	132	NEWMAUNG	33	3	26.76	23.00	116.36
54	132kV MSA CEMENT-KILIFI	BAMBUR CE2	220	WBAMB HTR-	WND 1	2	91.41	90.00	101.56
55	132kV MSA CEMENT-KILIFI	BAMBUR CE2	220	WBAMB HTR-	WND 1	2	91.41	90.00	101.56
56	220/132/33kV TX1 AT BOMANI	BAMBUR CE2	220	WBAMB HTR-	WND 1	2	102.53	90.00	113.93
57	220/132/33kV TX2 AT BOMANI	BAMBUR CE2	220	WBAMB HTR-	WND 1	2	102.53	90.00	113.93
58	220kV GARSEN-LAMU CCT1	GARSEN 220	220	LAMU 220	220	2	250.56	236.60	105.90
59	220kV GARSEN-LAMU CCT2	GARSEN 220	220	LAMU 220	220	1	250.56	236.60	105.90
60	220kV LAMU-LAMU COAL CCT1	LAMU 220	220	LAMU 220_2	220	2	257.97	236.60	109.03
61	220kV LAMU-LAMU COAL CCT2	LAMU 220	220	LAMU 220_2	220	1	257.97	236.60	109.03
62	220/33kV TX1 AT MALINDI	MALINDI 22	220	MALINDI 33	33	2	54.46	45.00	121.03
63	220/33kV TX2 AT MALINDI	MALINDI 22	220	MALINDI 33	33	1	54.46	45.00	121.03
64	220kV MARIAKANI-KWALE CCT1	MARIAKANI	220	KWALETEE-O	220	21	456.47	326.00	140.02
65	220kV MARIAKANI-KWALE CCT2	MARIAKANI	220	KWALETEE-O	220	1	456.47	326.00	140.02

S/n	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED BRANCH					LOADING (MVA)	EQUIPMENT RATING (MVA)	PERCENT OVERLOAD
		FROM BUS	BUS VOLTAGE (kV)	TO BUS	BUS VOLTAGE (kV)	CKT			
66	220/33kV TX1 AT MARIAKANI	MARIAKANI	220	MARIAKANI	33	2	32.84	23.00	142.78
67	220/33kV TX2 AT MARIAKANI	MARIAKANI	220	MARIAKANI	33	1	32.84	23.00	142.78
68	220kV KWALE-DONGO K CCT1	NNDONGO KU	220	KWALETEE-O	220	4	617.57	326.00	189.44
69	220kV KWALE-DONGO K CCT2	NNDONGO KU	220	KWALETEE-O	220	3	617.57	326.00	189.44
70	220kV DONGO K-LNG PP CCT1	NNDONGO KU	220	DOGO LNG	220	2	701.90	400.00	175.47
71	220kV DONGO K-LNG PP CCT2	NNDONGO KU	220	DOGO LNG	220	1	701.90	400.00	175.47

Table 33 gives the N-1 contingency events that resulted to load shedding:

Table 33:2039 N-1 Load Shedding

S/N	CONTINGENCY EVENT (OUTAGE OF LINE or TX)	MONITORED LOAD BUS NAME	BUS VOLTAGE	LOAD SHED(MW)
1	132kV MARIAKANI-MARIAKANI SGR	MARIAKN SG	132	13.03
2	220/33kV TX AT GARSEN	GARSEN 33	33	7.62
3	220/33kV TX AT LAMU	LAMU 33	33	8.31
4	132kV VOI-TAVETA	TAVETA3	33	11.23
5	132kV SHIMONI- LUNGA LUNGA	LUNGA LUNG	33	8.18
6	132/33kV TX AT LUNGA LUNGA	LUNGA LUNG	33	8.18
7	132/22kV TX AT KOKOTONI	KOKOTONI 1	11	10.96
8	132/33kV TX AT VIPINGO	VIPINGO R	33	1.26

There were no contingency events that failed to get converging solution.

APPENDIX _ 4A (ii) DEMAND FORECAST – COAST REGION BSPs YEARS 2017-2039

YEAR	Low Scenario		LOW SCENARIO BULK SUPPLY POINTS LOAD FORECCAST											BIG 4 AGENDA & VISION POINT LOADS					TOTAL
	MW	Rate	VOI	LAMU	GARSEN	GALU	MAUNGU	KAKUYUNI	JOMVU	KILIFI	RABAI	KIPEVU	NEW BAMBURI	TIOMIN	SHIMONI	GALANA	SAMBURU	DONGO KUNDU	
2017	265	-	2.09	3.08	3.78	13.38	17.97	18.40	19.74	20.32	26.50	67.80	71.95	17.00	0.00	0.00	0.00	0.00	282.00
2018	290.0	9.43%	2.28	3.37	4.13	14.64	19.66	20.13	21.60	22.23	29.00	74.19	78.74	17.00	0.00	0.00	0.00	0.00	307.00
2019	306.3	5.63%	2.41	3.56	4.37	15.47	20.77	21.27	22.82	23.49	30.63	78.37	83.17	17.00	0.00	0.00	0.00	0.00	323.33
2020	317.4	3.61%	2.50	3.69	4.53	16.03	21.52	22.08	23.64	24.33	31.74	81.20	86.18	17.00	0.00	0.00	0.00	0.00	334.39
2021	328.6	3.53%	2.59	3.82	4.69	16.59	22.28	22.81	24.48	25.19	32.86	84.06	89.22	17.00	0.00	0.00	0.00	0.00	345.59
2022	341.2	3.83%	2.69	3.96	4.86	17.23	23.13	23.69	25.42	26.16	34.12	87.28	92.64	17.00	0.00	0.00	10.00	15.00	383.17
2023	354.5	3.91%	2.79	4.12	5.05	17.90	24.04	24.61	26.41	27.18	35.45	90.70	96.26	17.00	0.00	0.00	10.00	15.00	396.51
2024	372.7	5.13%	2.94	4.33	5.31	18.82	25.27	25.88	27.77	28.57	37.27	95.35	101.20	17.00	0.00	0.00	10.00	15.00	414.70
2025	392.0	5.17%	3.09	4.55	5.59	19.79	26.58	27.21	29.20	30.05	39.20	100.28	106.43	17.00	50.00	7.00	20.00	20.00	505.97
2026	412.0	5.11%	3.25	4.79	5.87	20.80	27.94	28.60	30.69	31.59	41.20	105.40	111.87	17.00	50.00	7.00	20.00	20.00	526.00
2027	433.1	5.12%	3.41	5.03	6.18	21.87	29.37	30.07	32.26	33.20	43.31	110.80	117.59	17.00	50.00	7.00	20.00	20.00	547.09
2028	455.6	5.19%	3.59	5.29	6.50	23.00	30.89	31.63	33.94	34.93	45.56	116.55	123.70	17.00	50.00	7.00	20.00	20.00	569.57
2029	479.5	5.25%	3.78	5.57	6.84	24.21	32.51	33.29	35.72	36.76	47.95	122.67	130.19	17.00	50.00	7.00	20.00	20.00	593.49
2030	504.8	5.28%	3.98	5.86	7.20	25.49	34.23	35.05	37.61	38.70	50.48	129.15	137.07	17.00	90.00	12.00	38.00	60.00	721.81
2031	531.8	5.34%	4.19	6.18	7.58	26.85	36.06	36.92	39.62	40.77	53.18	136.04	144.39	17.00	90.00	12.00	38.00	60.00	748.76
2032	560.5	5.40%	4.41	6.51	7.99	28.30	38.00	38.91	41.75	42.97	56.05	143.39	152.18	17.00	90.00	12.00	38.00	60.00	777.48
2033	591.0	5.45%	4.66	6.86	8.43	29.84	40.08	41.03	44.03	45.31	59.10	151.20	160.48	17.00	90.00	12.00	38.00	60.00	808.02
2034	626.5	6.01%	4.94	7.28	8.93	31.64	42.48	43.50	46.68	48.04	62.65	160.29	170.12	17.00	90.00	12.00	38.00	60.00	843.54
2035	661.0	5.50%	5.21	7.68	9.42	33.38	44.82	45.89	49.24	50.68	66.10	169.11	179.48	17.00	90.00	12.00	45.00	70.00	895.00
2036	695.2	5.18%	5.48	8.08	9.91	35.10	47.14	48.27	51.79	53.30	69.52	177.87	188.77	17.00	90.00	12.00	45.00	70.00	929.24
2037	732.7	5.39%	5.77	8.51	10.45	37.00	49.68	50.87	54.59	56.17	73.27	187.45	198.95	17.00	90.00	12.00	45.00	70.00	966.72
2038	772.4	5.41%	6.08	8.97	11.01	39.00	52.37	53.62	57.54	59.21	77.24	197.60	209.71	17.00	90.00	12.00	45.00	70.00	1006.36
2039	812.5	5.20%	6.40	9.44	11.59	41.03	55.10	56.41	60.53	62.29	81.25	207.87	220.62	17.00	90.00	12.00	45.00	90.00	1066.52
Average Growth		5.23%																	

YEAR	Reference Scenario		REFERENCE SCENARIO BULKSUPPLY POINTS LOAD FORECCAST											BIG 4 AGENDA & VISION POINT LOADS					
	MW	Rate(%)	VOI	LAMU	GARSEN	GALU	MAUNGU	KAKUYUNI	JOMVU	KILIFI	RABAI	KIPEVU	NEW BAMBURI	TIOMIN	SHIMONI	GALANA	SAMBURU	DONGO KUNDU	TOTAL
2017	265	-	2.09	3.08	3.78	13.38	17.97	18.40	19.74	20.32	26.50	67.80	71.95	17.00	0.00	0.00	0.00	0.00	282.00
2018	290.0	9.43%	2.28	3.37	4.13	14.64	19.66	20.13	30.00	22.23	29.00	74.19	78.74	17.00	0.00	0.00	0.00	0.00	315.40
2019	310.0	6.90%	2.44	3.60	4.42	15.65	21.02	21.52	32.07	23.77	31.00	79.31	84.17	17.00	0.00	0.00	0.00	0.00	335.98
2020	326.4	5.30%	2.57	3.79	4.65	16.48	22.14	22.66	33.77	25.08	32.64	83.51	88.64	17.00	0.00	0.00	0.00	0.00	352.89
2021	342.4	4.90%	2.70	3.98	4.88	17.29	23.22	23.77	35.42	26.25	34.24	87.61	92.98	17.00	0.00	0.00	0.00	0.00	369.35
2022	366.7	7.10%	2.89	4.26	5.23	18.52	24.87	25.46	37.94	28.12	36.67	93.83	99.58	17.00	0.00	0.00	10.00	15.00	419.37
2023	384.7	4.90%	3.03	4.47	5.49	19.43	26.09	26.71	39.80	29.50	38.47	98.42	104.46	17.00	0.00	0.00	10.00	15.00	437.86
2024	407.8	6.00%	3.21	4.74	5.81	20.59	27.65	28.31	42.19	31.26	40.78	104.33	110.73	17.00	0.00	0.00	10.00	15.00	461.61
2025	442.1	8.40%	3.48	5.13	6.30	22.32	29.98	30.69	45.73	33.89	44.21	113.09	120.03	17.00	50.00	7.00	20.00	20.00	568.86
2026	473.9	7.20%	3.73	5.50	6.76	23.93	32.13	32.90	49.02	36.33	47.39	121.24	128.67	17.00	50.00	7.00	20.00	20.00	601.61
2027	503.7	6.30%	3.97	5.85	7.18	25.43	34.16	34.97	52.11	38.62	50.37	128.87	136.78	17.00	50.00	7.00	20.00	20.00	632.32
2028	541.0	7.40%	4.26	6.28	7.71	27.32	36.69	37.56	55.97	41.48	54.10	138.41	146.90	17.00	50.00	7.00	20.00	20.00	670.68
2029	578.9	7.00%	4.56	6.72	8.25	29.23	39.25	40.19	59.89	44.38	57.89	148.10	157.18	17.00	50.00	7.00	20.00	20.00	709.65
2030	615.4	6.30%	4.85	7.15	8.77	31.07	41.73	42.72	63.66	47.18	61.54	157.43	167.08	17.00	90.00	12.00	38.00	60.00	850.17
2031	653.5	6.20%	5.15	7.59	9.32	33.00	44.31	45.37	67.60	50.10	65.35	167.19	177.44	17.00	90.00	12.00	38.00	60.00	889.43
2032	694.0	6.20%	5.47	8.06	9.90	35.04	47.06	48.18	71.80	53.21	69.40	177.56	188.44	17.00	90.00	12.00	38.00	60.00	931.12
2033	737.1	6.20%	5.81	8.56	10.51	37.22	49.98	51.17	76.25	56.51	73.71	188.57	200.13	17.00	90.00	12.00	38.00	60.00	975.40
2034	782.8	6.20%	6.17	9.09	11.16	39.52	53.08	54.34	80.97	60.01	78.28	200.26	212.54	17.00	90.00	12.00	38.00	60.00	1022.42
2035	830.5	6.10%	6.54	9.65	11.84	41.93	56.31	57.66	85.91	63.67	83.05	212.47	225.50	17.00	90.00	12.00	45.00	70.00	1088.55
2036	878.7	5.80%	6.92	10.21	12.53	44.37	59.58	61.00	90.90	67.37	87.87	224.80	238.58	17.00	90.00	12.00	45.00	70.00	1138.11
2037	930.5	5.90%	7.33	10.81	13.27	46.98	63.10	64.60	96.26	71.34	93.05	238.06	252.66	17.00	90.00	12.00	45.00	70.00	1191.45
2038	978.9	5.20%	7.71	11.37	13.96	49.43	66.38	67.96	101.27	75.05	97.89	250.44	265.79	17.00	90.00	12.00	45.00	70.00	1241.24
2039	1029.8	5.20%	8.11	11.96	14.68	52.00	69.83	71.50	106.53	78.95	102.98	263.46	279.62	17.00	90.00	12.00	45.00	90.00	1313.62
Average Growth		6.43%																	

YEAR	High Scenario													BIG 4 AGENDA & VISION POINT LOADS					
	MW	Rate	VOI	LAMU	GARSEN	GALU	MAUNGU	KAKUYUNI	JOMVU	KILIFI	RABAI	KIPEVU	NEW BAMBURI	TIOMIN	SHIMONI	GALANA	SAMBURU	DONGO KUNDU	TOTAL (MW)
2017	265	-	2.09	3.08	3.78	13.38	17.97	18.40	19.74	20.32	26.50	67.80	71.95	17.00	0.00	0.00	0.00	0.00	282.00
2018	290.0	9.43%	2.28	3.37	4.13	14.64	19.66	20.13	21.60	22.23	29.00	74.19	78.74	17.00	0.00	0.00	0.00	0.00	307.00
2019	319.6	10.20%	2.52	3.71	4.56	16.14	21.67	22.19	23.81	24.50	31.96	81.76	86.77	17.00	0.00	0.00	0.00	0.00	336.58
2020	344.5	7.80%	2.71	4.00	4.91	17.39	23.36	23.92	25.67	26.41	34.45	88.14	93.54	17.00	0.00	0.00	0.00	0.00	361.51
2021	371.4	7.80%	2.93	4.31	5.30	18.75	25.18	25.78	27.67	28.47	37.14	95.01	100.84	17.00	0.00	0.00	0.00	0.00	388.38
2022	401.5	8.10%	3.16	4.66	5.72	20.27	27.22	27.87	29.91	30.78	40.15	102.71	109.01	17.00	0.00	0.00	10.00	15.00	443.46
2023	430.0	7.10%	3.39	4.99	6.13	21.71	29.16	29.85	32.03	32.96	43.00	110.00	116.75	17.00	0.00	0.00	10.00	15.00	471.96
2024	464.8	8.10%	3.66	5.40	6.63	23.47	31.52	32.27	34.63	35.63	46.48	118.91	126.20	17.00	0.00	0.00	10.00	15.00	506.79
2025	503.8	8.40%	3.97	5.85	7.18	25.44	34.16	34.98	37.54	38.63	50.38	128.90	136.80	17.00	50.00	7.00	20.00	20.00	617.83
2026	542.1	7.60%	4.27	6.30	7.73	27.37	36.76	37.64	40.39	41.56	54.21	138.69	147.20	17.00	50.00	7.00	20.00	20.00	656.13
2027	586.6	8.20%	4.62	6.81	8.36	29.62	39.77	40.72	43.70	44.97	58.66	150.07	159.27	17.00	50.00	7.00	20.00	20.00	700.58
2028	632.3	7.80%	4.98	7.34	9.02	31.93	42.88	43.90	47.11	48.48	63.23	161.77	171.69	17.00	50.00	7.00	20.00	20.00	746.33
2029	682.3	7.90%	5.37	7.92	9.73	34.45	46.26	47.37	50.83	52.31	68.23	174.55	185.26	17.00	50.00	7.00	20.00	20.00	796.29
2030	736.2	7.90%	5.80	8.55	10.50	37.17	49.92	51.11	54.85	56.44	73.62	188.34	199.89	17.00	90.00	12.00	38.00	60.00	953.19
2031	795.8	8.10%	6.27	9.24	11.35	40.18	53.96	55.25	59.29	61.01	79.58	203.60	216.08	17.00	90.00	12.00	38.00	60.00	1012.82
2032	859.5	8.00%	6.77	9.98	12.25	43.40	58.28	59.67	64.03	65.89	85.95	219.89	233.37	17.00	90.00	12.00	38.00	60.00	1076.48
2033	927.4	7.90%	7.31	10.77	13.22	46.83	62.88	64.38	69.09	71.10	92.74	237.26	251.81	17.00	90.00	12.00	38.00	60.00	1144.38
2034	1001.6	8.00%	7.89	11.63	14.28	50.57	67.91	69.54	74.62	76.79	100.16	256.24	271.95	17.00	90.00	12.00	38.00	60.00	1218.57
2035	1082.7	8.10%	8.53	12.58	15.44	54.67	73.42	75.17	80.66	83.01	108.27	276.99	293.98	17.00	90.00	12.00	45.00	70.00	1316.70
2036	1171.5	8.20%	9.23	13.61	16.70	59.15	79.44	81.33	87.27	89.81	117.15	299.71	318.08	17.00	90.00	12.00	45.00	70.00	1405.48
2037	1266.4	8.10%	9.98	14.71	18.06	63.94	85.87	87.92	94.34	97.09	126.64	323.98	343.85	17.00	90.00	12.00	45.00	70.00	1500.37
2038	1368.9	8.10%	10.78	15.90	19.52	69.12	92.83	95.04	101.99	104.95	136.90	350.22	371.70	17.00	90.00	12.00	45.00	70.00	1602.95
2039	1479.8	8.10%	11.66	17.19	21.10	74.72	100.34	102.74	110.25	113.45	147.98	378.59	401.81	17.00	90.00	12.00	45.00	90.00	1733.83
Average Growth		8.13%																	

APPENDIX 5 - SUMMARY OF KENYA POWER REGIONS

Mt Kenya Region: Counties covered include Kiambu, Nyeri, Muranga, Laikipia, Mwingi, Kitui, Meru, Kirinyaga, Garissa, Tharaka-Nithi and Nyandarua and some parts of Samburu.

The region has estimated 1,058,178 customers. The regions boast of installed generation capacity of about 757.0 MW, mainly from hydro resource. The region has an estimated peak demand of 175MW.The load is mainly agri-industrial, industrial (Thika) and domestic. The bulk supply points in the region include 132/33kV substations at Kiganjo, Githambo, Gatundu, Mang'u Garissa, Mwingi, Kitui, Wote Nanyuki, Kutus and Kamburu.

Nairobi Region: Counties covered include Nairobi, Machakos, Kajiado and some section of Kiambu County. The region has an estimated 2,099,574 customers. The region has an installed generation capacity of about 297.3 MW, mainly from diesel powered generators. The region has an estimated peak demand of 846MW. The load is mainly heavy industrial, small industrial and domestic. The bulk supply points in the region include 220/66kV Nairobi North, 220/66kV Embakasi, 132/33kV Juja Rd, 132/33kV Ruaraka ,132/33kV Machakos and 220/66kV City Square substations.

West Region: The region is divided into three sub regions as follows:

Western – Counties covered include Kisii, Kisumu, Kakamega, Vihiga, Bungoma, Naymira, Busia, Siaya, Homabay and Migori, some parts of Kericho.

Central Rift-Counties covered include Nakuru, Narok, Bomet, some parts of: - Nyandarua and Kericho.

North Rift- Uasin Gishu, Baringo, Elgeyo Marakewet, Nandi, Trans Nzoia and Turkana.

The entire region has an estimated 1,755,020 customers. The region has an installed generation capacity of about 902.1MW, mainly from geothermal (654.1MW), other sources include Cogen, hydro and kerosene powered gas turbines (CCGTs). The region has an estimated peak demand of 417MW. The load is mainly medium industrial, agri-industrial and domestic. The bulk supply points in the region include 132/33kV substations at Kitale, Eldoret, Mamboleo,132/33kV Chemosit, Muhoroni, Bomet, Kisii, Awendo, Lanet, Naivasha and 220/132/33kV Lessos.

Off Grid Region: Counties considered to be off grid include Wajir, Mandera. Marsabit and some parts of the vast Samburu, Tana River, Isiolo and Turkana. Here, KPLC and REA have installed about 23 off grid stations that are largely diesel and few solar powered. The installed capacity is about 21 MW and a peak demand of 10MW

Coast Region: Counties considered to be within Coast region, include Mombasa, Kwale, Kilifi, Taita Taveta and some sections of Tana River Counties and some parts of Makueni County.Coast Region is one of the major sources of power supply with an installed generation capacity of about 357MW that is mainly produced by Heavy fuel oil (HFO) powered medium speed diesel (MSD) generators. Currently, the region has an estimated peak demand of about 294MW and hence makes the area a net exporter of power to the National grid. There are 490,290 customers connected on the power grid in this region.

APPENDIX 6 (i): RECOMMENDED ADDITIONAL PROJECTS:

Table 1: Project for Inclusion in the Regional Transmission Plan with Cost Estimates

S/n	Transmission Project (transmission lines Projects	km		MVA / Circuit	Estimated Cost (MUSD)	Year
1	220kV Mariakani-Samburu	50		326	29.4	2022
2	Addition of second 132/33kV transformer at New Maungu (2022)	-		15	2.29	2022
3	Replacing all the 15MVA 132/33kV TX at New Maungu with 45MVA transformers (2030).	-		45	1.6	2030
4	Replacing all the 45MVA 132/33kV TX at New Bamburi with 75MVA transformers (2025)	-		75	4	2025
5	Installation of dynamic reactive power devices as follows: • 2x+100MVAr -50MVAr at Rabai load bus (2025) • 2x+75MVAr -50MVAr at Kilifi load bus (2025)	-		-	60	2025
6	Reconductoring or installing new transmission lines using high capacity low sag conductors for increased transfer capacities for the following transmission lines: • 132kV Voi-Maungu-New Maungu-Mackinnon-Samburu-Kokotoni-Mariakani	- 120		200	3.24	TBD
7	• 220kV evacuation for Dongo Kundu LNG	10		800	0.84	TBD
8	Installing second circuit 220kV Weru-Malindi-Garsen-Lamu-Lamu Coal	282		265	103.17	TBD
9	Installing second circuit 132kV Kipevu-Mbaraki	7		97	4.74	TBD
10	Installing second circuit to Taveta (132kV Voi -Taveta second circuit or new 132kV Loitoktok-Taveta or both)	120		97	16	TBD

11	Installing second circuit to Galu (132kV Rabai-Likoni-Galu second circuit or introducing 220/132kV step down at Kwale and establishment of new 132kV line from Kwale to Likoni	100		97	24.13	2035
12	Installing second circuit to Lunga Lunga (Shimoni - Lunga Lunga second circuit)	15		97	5.54	TBD
13	Increasing transformer capacity and/or installation of third transformers at Malindi	-		TBD	2.4	2035
14	Increasing transformer capacity and/or installation of third transformers at Galu	-		TBD	1.8	2030
15	Increasing transformer capacity and/or installation of third transformers at Mbaraki	-		TBD	1.8	2025
16	Increasing transformer capacity and/or installation of third transformers at Bomani	-		TBD	2.0	2027
17	Replacing all the 45MVA 132/33kV TX at Rabai with 75MVA	-		TBD	2.4	TBD
18	Replacing the 23MVA 132/33kV TX at Kilifi with 60MVA and installation of third transformer at Kilifi	-		60	1.8	TBD
19	Installation of second transformers at Garsen	-		23	3.81	2025
20	Installation of second transformers at Lamu	-		23	3.81	2027
21	Installation of second transformers at Kokotoni, Manyani, Maungu, Voi, Mariakani, Samburu, Mackinnon Road, Maungu, Voi and Mtito Andei and Manyani KPC pumping stations	-		TBD	24.95	TBD
TOTAL					299.7	

TBD - To be decided once projected demand matches the actual demand and the feasibility studies are done to ascertain that the projects are feasible.

Appendix 6 (ii)

Table1:Coast Region Proposed Transmission Elements/Projects 2019-2039

S/n	Transmission Lines' Projects.	km	Description	Year
1	Substation Extensions works for improved reliability (Malindi ,Garsen)	-	220 and 33kV bay extension at Malindi and Garsen, supply and installation of second 220/33kV 23MVA transformers at Garsen and 45MVA 220/33kV at Malindi	2025
2	Voi –Taveta 132kV	110	132kV transmission line from Voi to Taveta, 132kV bay extension at Voi and new 132/33kV 23MVA substation at Taveta	2026
3	Weru – Kilifi 220kV	48.5	220kV transmission line from Weru to Kilifi, bay extension at Weru new 2x150 220/132 substation at Kilifi and 132kV bay extension at existing Kilifi 132/33kV substation.	2023
4	Malindi -Weru (Circuit II) 220kV	22	220kV overhead transmission line from Weru to Malindi and 220kV bay extensions at both Malindi and Weru.	2024
5	Mariakani – Dongo Kundu 220kV Line	55	220kV overhead transmission line from Mariakani to Dongo Kundu,220kV bay extension at Mariakani and new 220/33kV substation at Dongo Kundu	2023
6	Weru – Galana 220kV Line	51	220kV overhead transmission line from Weru to Galana,220kV bay extension at Weru and new 220/33kV substation at Galana	2024
7	Galu (from Kwale Sugar) - Lunga Lunga 132kV	49	132kV overhead transmission line from Kwale Sugar to Lunga Lunga,132kV bay extension at Kwale Sugar and new 132/33kV substation at Lunga Lunga	2025
8	Malindi-Garsen 220kV(circuit II)	104	220kV overhead line transmission line from Malindi to Garsen with 220kV bay extension at both Malindi and Garsen	2025
9	Garsen-Lamu 220kV (circuit II)	96	220kV overhead line transmission line from Lamu to Garsen with 220kV bay extension at both Lamu and Garsen	2025

10	Kwale Lilo (Mariakani/Dongo Kundu) -Shimoni	110	Establishment of a 220kV switch station, implementation of a Line In Line Out (LILO) on Mariakani-Dongo Kundu, establishment of 220kV overhead transmission line from Switch station to Kwale and new 220/132kV substation at Shimoni	2025
11	220kV Bomani - Kilifi	52	Establishment of 220kV overhead transmission line from Kilifi to Bomani 220kV bay extension at Kilifi and new 220/132kV substation at Bomani	2035
12	220kV Bomani - Mariakani	45	Establishment of 220kV overhead transmission line from Mariakani to Bomani 220kV bay extension at Mariakani and Bomani	2035
13	220kV Mariakani-Samburu	50	Establishment of 220kV overhead transmission line from Mariakani to Samburu, 220kV bay extension at Mariakani and new 220/132kV substation at Samburu	2022
14	Addition of second 132/33kV transformer at New Maungu (2022)	-	132kV and 33kV bay extension , supply and installation of a second 132/33kV 23MVA transformer at New Maungu	2022
15	Replacing all the 15MVA 132/33kV TX at New Maungu with 45MVA transformers (2030).	-	Supply and installation of 132/33kV 23MVA transformer at New Maungu and recovery of the 15MVA transformer.	2030
16	Replacing all the 45MVA 132/33kV TX at New Bamburi with 75MVA transformers (2025)	-	Supply and installation of two 132/33kV 75MVA transformers at New Bamburi and recovery of the 45MVA transformers.	2025
17	Installation of dynamic reactive power devices as follows: • 2x+100MVAr -50MVAr at Rabai load bus (2025) • 2x+75MVAr -50MVAr at Kilifi load bus (2025)	-	Supply and installation of dynamic reactive power as follows Two units with +100MVA and -50MVA at Rabai and Two units with 75MVAr and -50MVA at Kilifi	2025

18	Reconductoring using high capacity low sag conductors for increased transfer capacities for the following transmission lines: • 132kV Voi-Maungu-New Maungu-Mackinnon-Samburu-Kokotoni-Mariakani	-	Replacement of the existing 1xASCR Lynx conductor with high capacity low sag conductors e.g.ACCC for 132kV Voi-Maungu-New Maungu-Mackinnon-Samburu-Kokotoni-Mariakani	TBD
19	• 220kV evacuation for Dongo Kundu LNG	10	Installation of a transmission line with transfer capacity 800MVA per circuit.	TBD
20	• 220kV Weru-Malindi-Garsen-Lamu-Lamu Coal	210	Replacement of the existing 1xASCR 300/40 DIN conductor with high capacity low sag conductors e.g. ACCC for 220kV Weru-Malindi-Garsen-Lamu-Lamu Coal	TBD
21	• 132kV Kipevu-Mbaraki	7	Replacement of the existing 1xASCR Lynx conductor with high capacity low sag conductors e.g.ACCC for 132kV Kipevu-Mbaraki	TBD
22	Installing second circuit to Taveta (132kV Voi -Taveta second circuit or new 132kV Loitoktok-Taveta or both)	120	132kV bay extension at Voi and Taveta and establishment of a new 132kV line approximately 120km between Voi and Taveta.	TBD
23	Installing second circuit to Galu (132kV Rabai-Likoni-Galu second circuit or introducing 220/132kV step down at Kwale and establishment of new 132kV line from Kwale to Likoni	100	132kV bay extension at Rabai, Likoni, Galu and Shimoni and establishment of a new 132kV line between at Rabai, Likoni, Galu and Shimoni	2035
24	Installing second circuit to Lunga Lunga (Shimoni - Lunga Lunga second circuit)	15	132kV bay extension at Lunga Lunga and Shimoni and establishment of a new 132kV line between at Lunga Lunga and Shimoni	TBD
25	Increasing transformer capacity and/or installation of third transformers at Malindi	-	Supply and installation of two 220/33kV 75MVA transformers at Malindi and recovery of the existing transformers.	2035
26	Increasing transformer capacity and/or installation of third transformers at Galu	-	132kV and 33kV bay extensions, supply and installation of 132/33kV 23MVA transformer at Galu	2030
27	Increasing transformer capacity and/or installation of third transformers at Mbaraki	-	132kV and 33kV bay extensions, supply and	2025

			installation of 132/33kV 23MVA transformer at Mbaraki	
28	Increasing transformer capacity and/or installation of third transformers at Bomani	-	132kV and 33kV bay extensions, supply and installation of a third 132/33kV 45MVA transformer at Bomani.	2027
29	Replacing all the 45MVA 132/33kV TX at Rabai with 75MVA	-	Supply and installation of four 132/33kV 75MVA transformers at Rabai and recovering of the 132/33kV 45MVA transformers.	TBD
30	Replacing the 23MVA 132/33kV TX at Kilifi with 60MVA and installation of third transformer at Kilifi	-	Supply and installation of two 132/33kV 60MVA transformers at Kilifi and recovering of the 132/33kV 23MVA transformers.	TBD
31	Installation of second transformers at Garsen	-	220kV and 33kV bay extension at Garsen, supply and installation of one 220/33kV 23MVA transformer at Garsen	2025
32	Installation of second transformers at Lamu	-	220kV and 33kV bay extension at Lamu, supply and installation of one 220/33kV 23MVA transformers at Lamu.	2027
33	Installation of second transformers at Kokotoni, Manyani, Maungu, Voi, Mariakani, Samburu, Mackinnon Road, Maungu, Voi and Mtito Andei and Manyani KPC pumping stations	-	220kV and 33kV bay extension at Lamu, supply and installation of one 220/33kV 23MVA transformers at Lamu.	TBD

TBD - To Be Decided by additional analysis and confirmation of schedule of demand projects.

APPENDIX 6 (iii) – COAST REGION NETWORK TOPOLOGY OUTLOOK FOR YEARS 2030 & 2039

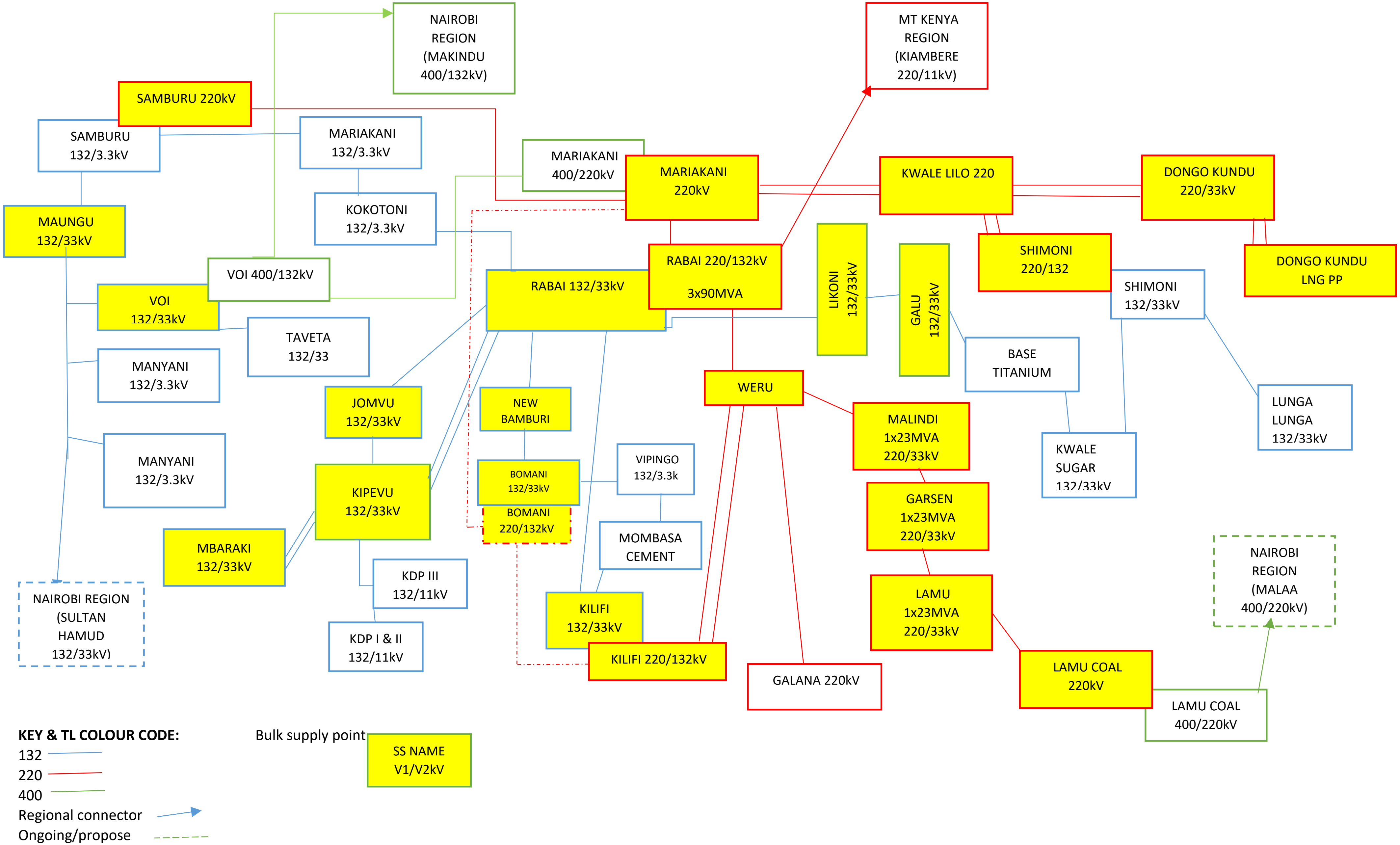

Figure 1: Coast Region Transmission Network Topology – 2030

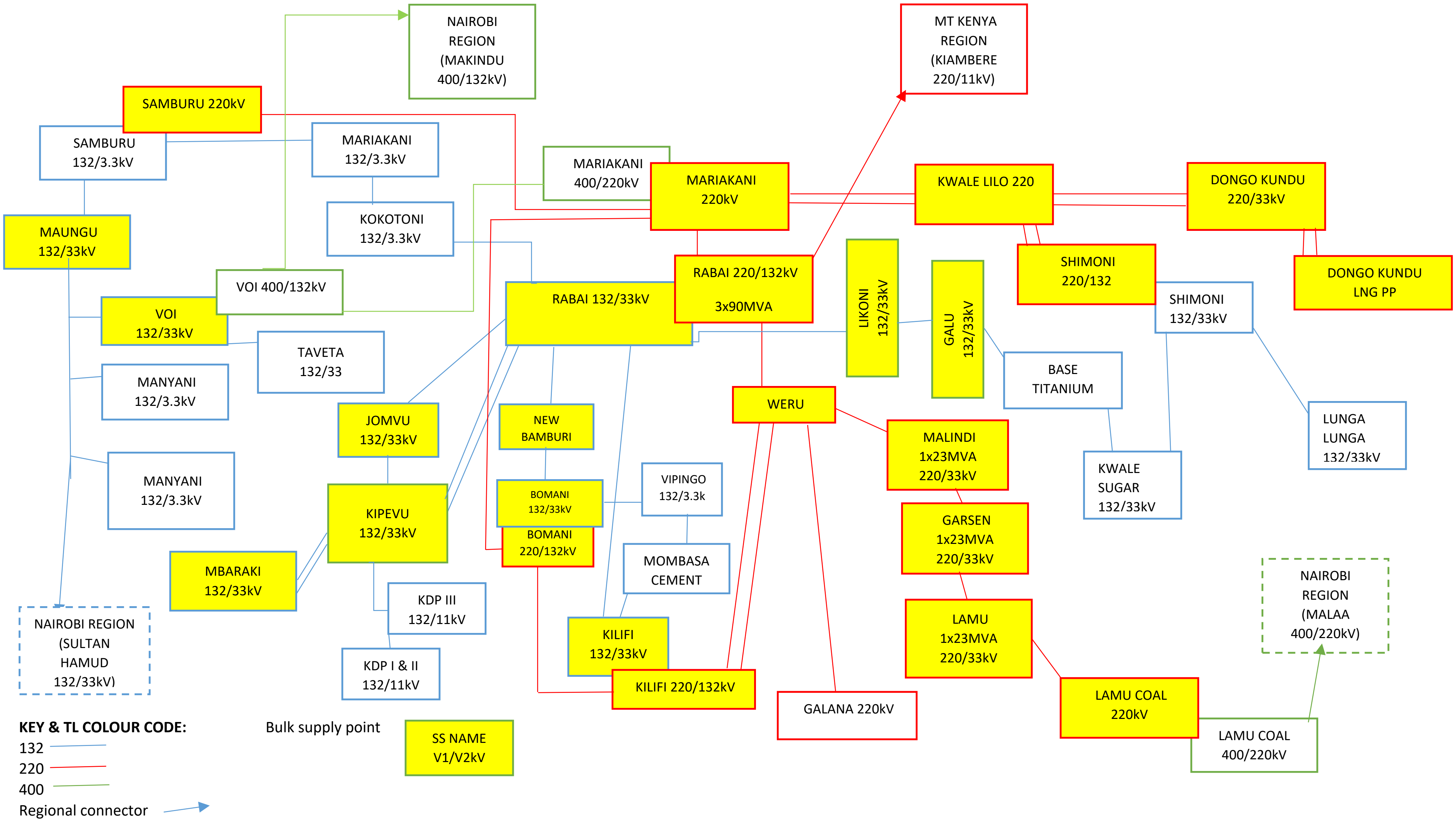

Figure 2: Coast Region Transmission Network Topology – 2039

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Analysis of the Network Performance and Development of Electricity Transmission Plan: A Case Study of Kenya's Coast Region

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***Abstract*—Performance of the Transmission network for Kenya's Coast region: Pertinent data from the transmission utilities in Kenya was collected and used to develop Coast region' s electricity network models for years 2039 (the target year), 2035, 2030,2025,2022, 2020 and 2019 in PSS/E. Loadflow calculation using Newton Raphson was employed to analyze the models for both normal and contingency conditions. The performance of the regional network in terms of efficiency and security was determined. Results indicated an above 95% efficiency, the network however does not meet N-1 security requirement. Additional reinforcements are suggested to improve the network. An improved network was later developed by modelling the suggested elements into the initial models and the models analyzed once again. With the reinforcements, 97% efficiency and compliance to N-1 security requirement is achieved. Subsequently, a transmission plan with an implementation schedule and estimated project costs was developed.**

***Index Terms*— Fault Level, N-1 Contingency Criteria, Powerflow.**

I. INTRODUCTION

POWER systems elements include generation facilities, transmission, distribution facilities and the connected loads. Transmission system comprises network of subsystems comprising substations, transmission lines, voltage support and reactive power equipment.

Power system planning tends to answer key questions required to make sound investment decisions such as when and where an element is required; what, in terms of size and specifications, should the element be in order to satisfactorily meet the particular objective.

Planning for power systems expansion encompasses demand forecasting, generation planning, transmission and distribution system planning.

Uncertainties in planning for transmission expansion have become more pronounced in market-oriented environment where electricity is traded as a commodity; generated and retailed by more than one player. The physical aspects of supply and demand playing a prominent role in power markets [3].

The broader objectives for development of power transmission systems are: improve of the system adequacy so as to match the increase in demand, increase system efficiency, improve quality of supply and improve system security to fully satisfy the demand. The transmission investments can be capital intensive, thus is imperative that the development/expansion plan is deliberate and objective.

The paper has literature review section, where information as sought previously prepared materials are given with regards to the region in focus, approaches in system modelling and performance considered. The methodology employed in system planning encompassing load flow, fault level and contingency analysis is exemplified. The results are given and used to inform the transmission plan for this region.

II. LITERATURE REVIEW

A. *Coast Region of Kenya*

According to [9], the Electricity network in Kenya is divided into four main regions namely Nairobi, Western, Mt. Kenya and Coast. This region currently hosts major diesel power plants (totaling to about 357MW). The region possesses as a favorable site for proposed LNG, Coal and Nuclear power plants with cumulative installed capacity of 2.4 GW.

The region is additionally rich in renewable energy – wind, solar and biomass [11-15]. There is growing interest in developing industries in the region such as Cement processing, steel making, food processing and hotel industries are the key industrial loads in the region. Compounded by the need to increase electricity access to the approximately 2 million households in this region, the region requires a transmission development plan that will ensure adequacy, security and quality in the regions power supply.

Administratively, the region includes the following counties: -Mombasa, Kilifi, Kwale, Tana River, Taita Taveta and Lamu. covering an area of 83,422.40 square kilometers and hosting a population of 4.2 million people according to 2018 projections [16]. Figure 1 gives the map of Kenya with the Coast region depicted.

The bulk supply points in the region include: -Rabai, Malindi, New Bamburi, Kilifi, Galu, Voi, Kipevu, Garsen and Lamu. These are the key substations in the region [6]. Figure 2 shows the transmission grid at the Coast region as at 2019, the region's is seen to comprise 132,220 and 400kV by this period.

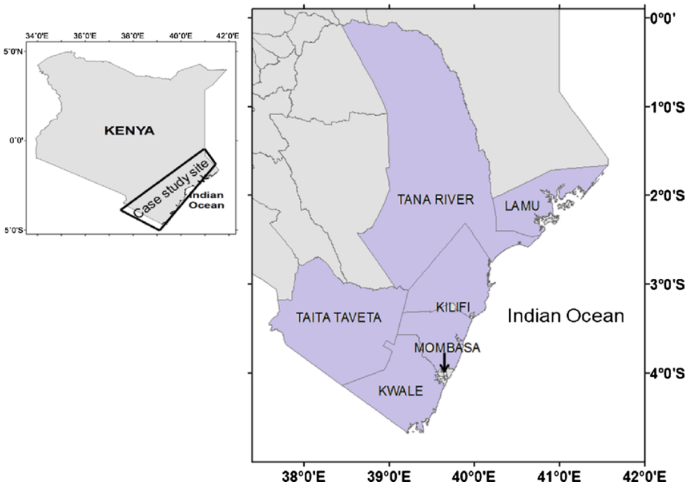

Figure 1:Kenya's Coast Region

Source: https://www.researchgate.net/figure/Map-of-coast-region-of-Kenya-covering-the-six-coastal-counties-Source-Hassan-et-al_fig1_330515086

At the regional perspective, very little is done to measure and address the transmission network inefficiencies and poor system security. The significance of the Coastal region of Kenya, presents the need to assess the region's network performance and recommend a transmission development plan that ensures efficiency and security of supply.

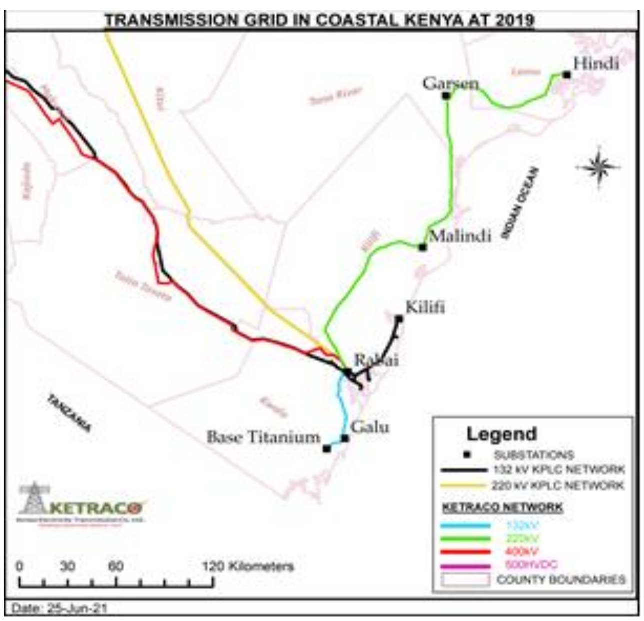

Figure 2: Coast Region Transmission Grid 2019

B. System Modelling and Performance Analysis Approach

Just like all other engineering sciences, power systems analysis commences with formulation of appropriate models that are mostly mathematical models defined by a set of equations or relations describing the interactions between various quantities in a time frame that are studied with a desired accuracy of a physical or engineered component or system [4,5].

Thus, before any analyses can be performed, the power system needs to be modelled to represent the actual system - system modelling of existing and futuristic/expected systems can be effected through various computer programs [1].

System modelling, simulations and analysis aids in understanding and recording of the expected system behavior and form key aspect of the system studies required in transmission expansion planning. For transmission system planning, this shall at the minimum, include load flows analysis, fault level calculation and contingency analysis.

According to [1], system modelling, simulations and analysis aids in understanding and recording of the expected system behavior and form key aspect of the system studies required in transmission expansion planning.

III. METHODOLOGY - SYSTEM STUDIES FOR TRANSMISSION PLANNINNG

For transmission system planning, studies majorly focused on load flows analysis, fault level calculation and contingency analysis.

A. Load Flow Studies

Load flow calculations/analysis (also power flow calculations) form a fundamental task in planning (during basic and system development planning phases) and operation of power systems. Load flow analysis primarily serves to determine the loading of equipment, calculation of active and reactive power flow through lines and transformers (branches) in the interconnected power system, determine voltage profiles and most importantly calculate system losses.

The key input data include: peak demand base, demand projections, generation and generation planting sequence.

Demand projections and Generation planning as given in the MTP 2018-2023 was used to medium term while LCPDP 2017-2037 was adopted as a reference for demand and generation planning data for Coast Region. Highest peak demand recorded in 2018/19 was used as the base and annual demand growth rates as presented in the above reports were applied to determine the demand for the next 20 years. Three scenarios namely: Low, Reference and High were considered.

The aggregation of load is also required to accurately represent the system loading for each substation or bulk supply point in the region.

Power flow Solution/Calculation is well defined [18,2] as network solution problem with the network of transmission line and transformers described by the linear equation below:

$$I_n = Y_{nn} * V_n \qquad (1)$$

I_n = vector of positive-sequence flowing into the network at its nodes(buses).

Y_{nn} = is the network admittance matrix.

V_n= vector of positive-sequence voltages at the network nodes(buses).

Complexity of the power flow is drawn from the fact that neither I_n nor V_n is known, thus requires iterative trial and error process/scheme or algorithm to try out successive values of I_n and V_n that satisfy the linear algebraic equation above hence determine the power flow solution. A typical iterative scheme/algorithm is given below:

1. Make initial estimate of the voltage at each bus
2. Build an estimated current inflow vector, In, at each bus from a boundary condition such as

$$P_k + jQ_k = V_k I_k \qquad (2)$$

With P_k+jQ_k as the net load and generation demand at bus k; V_k is the present estimate of voltage at bus k

3. Use equation Eq. 1 to obtain new estimate of voltage vector, V_n.
4. Return to Step 2 and repeat the cycle till it converges on unchanging estimate of voltage vector, v.

Full Newton-Raphson iterative scheme, owing to its rapidness in convergence and tight tolerance in mismatches for better network solutions is used.

B. *Fault Level Calculation:*

Fault level calculations (symmetrical and asymmetrical) are carried out for various system configuration (topology and dispatch) to determine the sequence impendences, fault levels and ensure correct selection of maximum short circuit rating for substation equipment.

Typical short circuit level for various system voltages are given in the Table 1 [18]. This is normally region specific and may vary from one power system to another. The same can be revised to meet the prevailing system conditions.

Table 1:Coast Region Base Demand Data

S/n	System Voltage Level (kV)	Short Circuit Level (kA)
1	66	25
2	132	31.5
3	220	31.5 or 40
4	400	40 or 63 (for some countries /systems)

In order to carryout fault level analysis the calculation setting in Figure 3.

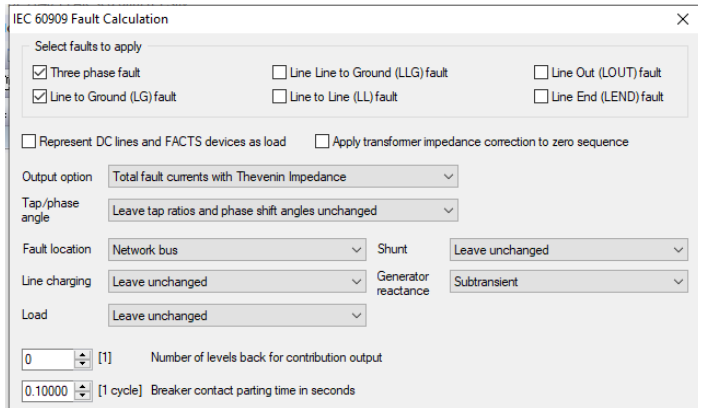

Figure 3:Fault Calculation Parameter Setting

C. *Contingency Analysis*

According to [20], contingency is the failure of any power system component on a network due to system related issues. This analysis can be involving and tedious in the absence of automatic screening approached. This the analysis is effectively carried out based on the stipulated contingency criteria, where one or more branches (transmission circuit or a transformer) is put out of service and the solution for power flow is determined with the aim of checking and monitoring specific network violations during contingency conditions. Figure 4 shows the solution parameters used.

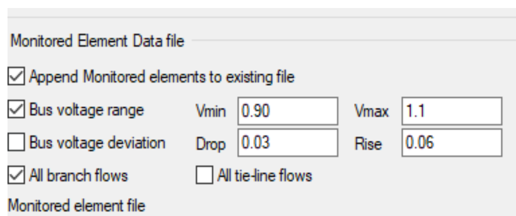

Figure 4:Setting for Voltage and Branch Violation Thresholds

IV. RESULTS AND ANALYSIS

A. *Demand and Generation Data for Coast Region*

Highest peak demand of 290MW was recorded in 2018/19. Table 1 gives the region's demand for 2018/19. New Bamburi and Kipevu are seen as the most loaded substations in the region, with Voi posting the lowest demand for the region.

Table 2:Coast Region Base Demand Data

S/n	Bulk Supply Point	2018 Peak Demand.
1	Voi	2.28
2	Lamu	3.37
3	Garsen	4.13
4	Galu	14.64
5	Maungu	19.66
6	Kakuyuni	20.13
7	Jomvu	21.60
8	Kilifi	22.23
9	Rabai	29.00
10	Kipevu	74.19

11	New Bamburi	78.74
Total (MW)		290.0

The regional peak demand as projected for selected years (Reference Scenario) is given in Table 2. From 290MW in 2018, the demand steadily increases to 1029 in 2039 at an average growth rate of 6.37%.

Table 3:Coast Region Peak Demand Projections

Year	Reference Scenario	
	MW	Growth Rate (%)
2017	265	-
2018	290.0	9.43%
2019	310.0	6.90%
2020	326.4	5.30%
2021	342.4	4.90%
2022	366.7	7.10%
2025	442.1	8.40%
2030	615.4	6.30%
2035	830.5	6.10%
2039	1029.8	5.20%
Average Growth Rate		6.37%

Cumulatively, 1907MW generation capacity is planned for the region, having excluded about 357MW that are to be decommissioned within the period. Table 3 illustrates the expected generation mix over the planning period. Coal and Natural gas sources are set to dominate the generation in this region. Renewable sources e.g. Cogen, Solar and Wind taking a percentage of 5%.

Table 4:Generation Mix 2017-2039

Technology	Capacity (MW)	Percentage
Diesel Thermal (Existing)	357.5	19%
Solar PV	40	2%
Biogas	36.44	2%
Cogen	10	1%
Wind	90	5%
Diesel Thermal (Decommissioned)	-357.5	-19%
Coal Thermal	981	51%
Natural Gas	750	39%
Total (MW)	**1907.44MW**	

B. Load Flow

The number of Voltage violations and the number of branch loading violation, during normal system operations are recorded as follows:

- 2020 - three (3) voltage violations were noted at Mariakani(1.053p.u.),Kilifi (0.94 p.u.) and MSA Cement (0.94 p.u.u)
- 2022 - branch laoding violations (194%) at 132/33kV transformers in Maungu Substation.
- 2025 - Branch loading violations (116%) at New Bamburi 132/33kV transfomers and three (3)
- voltage violation at Vipingo (0.94 p.u.), Bomani (0.93p.u.) and New Bamburi (0.93 p.u.).
- 2030 – Branch loading (156%) violations noted at the 132/33kV transformers in Muangu.

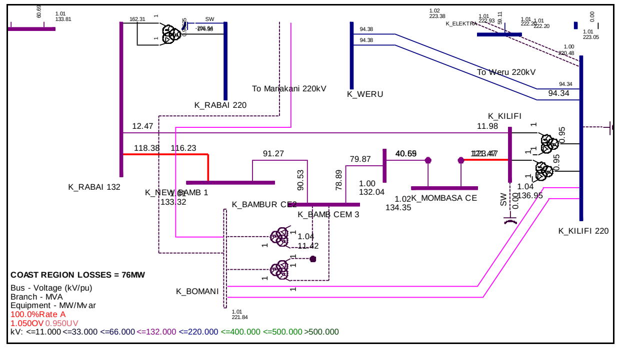

Figure 5:Section 2039 Network Model Without Proposed projects

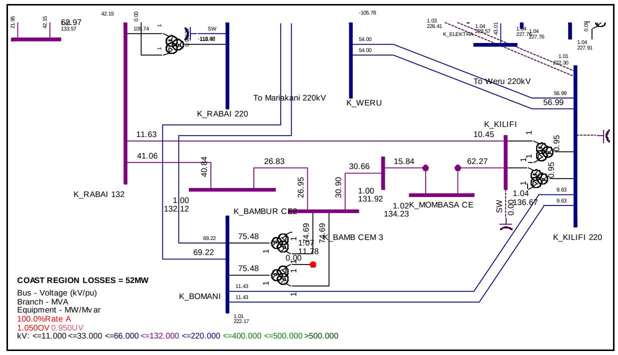

Figure 6:Section of 2039 Network Model with Proposed projects

The highest percentage system loses (7.7%) was recorded in the year 2019.The losses reduce with the development of the transmission lines over the planning period to settle at 3.8% in the year 2039.Figure 5 shows part of the network model without the proposed projects, while Figure 6 shows the model with the proposed projects. Network with proposed projects posted better loss performance 52MW compared with 76MW of losses posted in the network without proposed projects

C. Fault level Analysis

Over the years, the fault levels have increased, there are however no substations or buses that have the fault levels exceed the maximum short circuit ratings. All the fault levels are less than 70% of the maximum short circuit rating.

D. Contingecny Analysis

The number of voltage violations and the number of loading violations during N-1 contingency operations are recorded over the years. Despite the developments as expected in the planning period, in 2039 for instance, 21 voltage violations and 71 branch lading violations are recorded.

Loss of load is recorded in all the years, worst being year 2022 where 29 loads are affected.

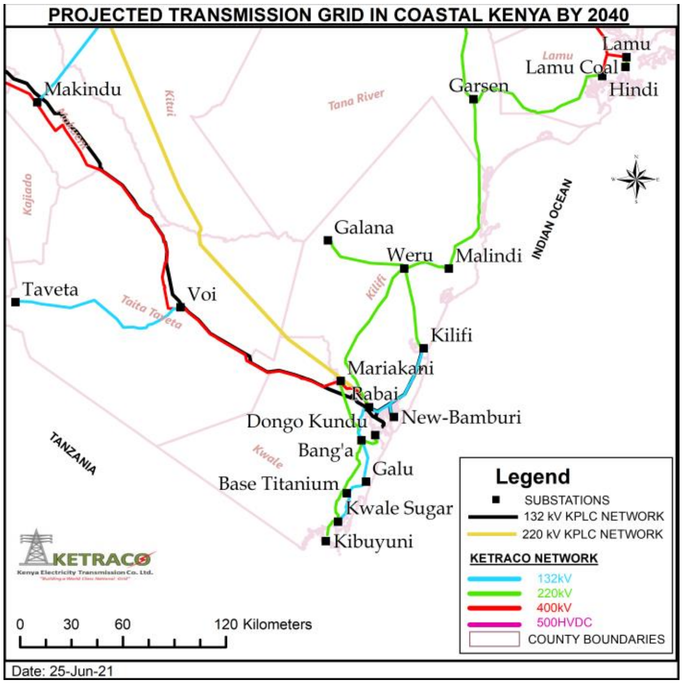

Figure 7: Coast Region Transmission Grid 2040

V. CONCLUSION

The power network for Coast region from 2020-2039 have been modelled and system performance analysed through this work.

The constraints have been equally identified and this work shows that the transmission system for Coast Region is not compliant to the N-1 system security requirement

The network model having incorporated the projects proposed from this work exhibit better loss performance and is more reliable compared to the system when the proposed projects are excluded. Figure 7 shows the proposed Coastal grid (PSS/E model in Figure 6). From this figure, the 220kV Galana-Weru Kilifi Rabai Mariakani loop is set to improve efficiency and reliability for the transmission system in this region.

The fault levels for the substations in the region have been determined through this work. and all the year's through to 2039, as the anticipated maximum fault currents for all the substations are within the respective designed maximum short circuit currents.

A set of new projects proposed to alleviate the network constraints have been identified and estimated to cost about USD 299.7 Million.

The identified projects range from addition of power transformers, increasing transformation capacities and development of new transmission lines to serve special loads to reinforce the grid for efficient and reliable evacuation and supply of power. This comprised the transmission master plan.

This work did not analyse for viability, thus to further this course, the proposed projects need to be appraised technically, economically and environmentally through detailed feasibility studies.

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A CASE STUDY OF KENYA'S COAST REGION.

By: Harrison Jerry Shiverenje Sungu (F56/87981/2016)

Masters of Science in Energy Management

Project Originality Report

Signed

Student Harrison Jerry Shiverenje Sungu .... 20/08/2021.

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