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

2021 IEEE PES/IAS PowerAfrica | 978-1-6654-0311-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/POWERAFRICA52236.2021.9543132

the transmission grid at the Coast region as at 2019, the region's is seen to comprise 132,220 and 400kV by this period.

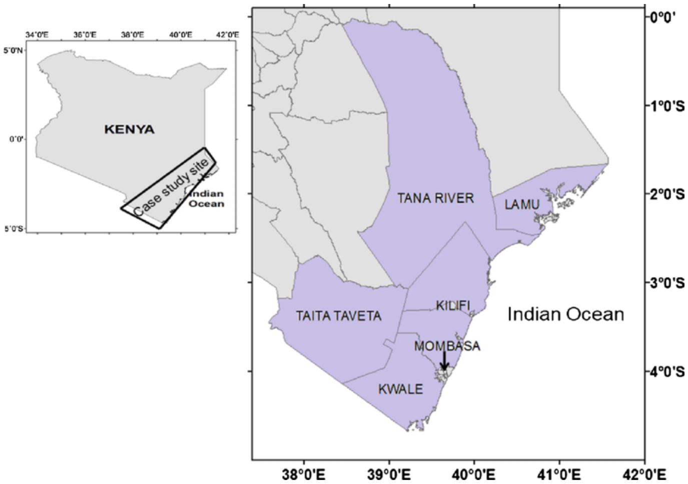

Figure 1:Kenya's Coast Region

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.

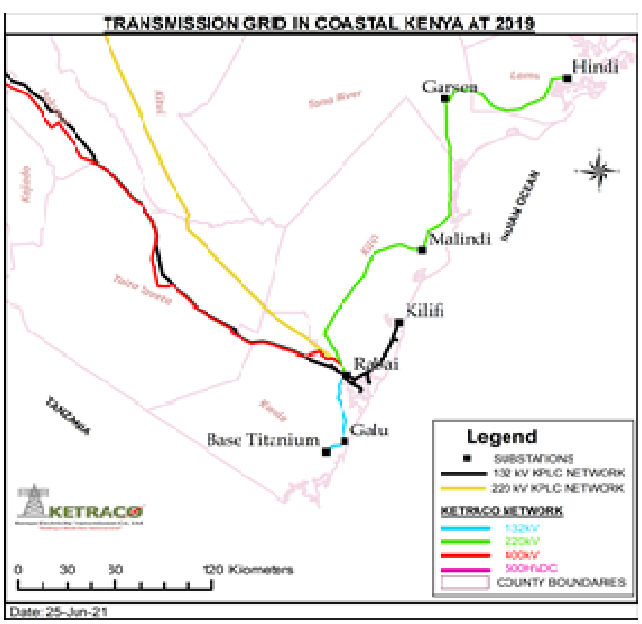

Figure 2: Coast Region Transmission Grid 2019

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.

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III. METHODOLOGY - SYSTEM STUDIES FOR ELECTRICITY 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:

$$I_n = Y_{nn} * V_n \tag{1}$$

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

$$P_k + jQ_k = V_k I_k \tag{2}$$

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: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)

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

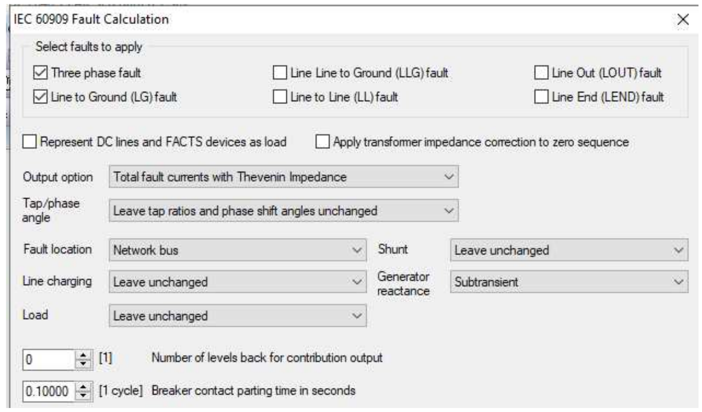

Figure 3:Fault Calculation Parameter Setting

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.

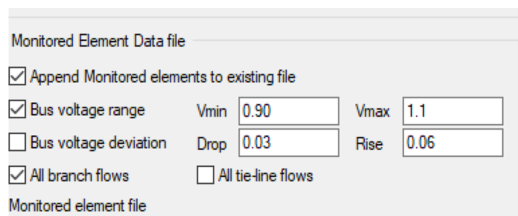

Figure 4:Setting for Voltage and Branch Violation Thresholds

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.

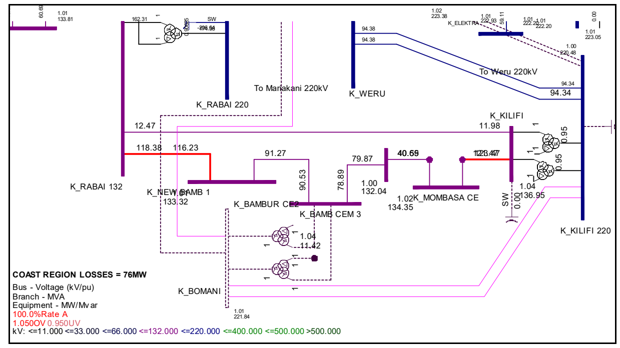

Figure 5:Section 2039 Network Model Without Proposed projects

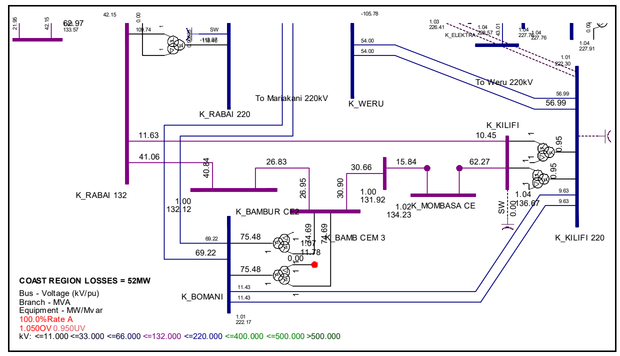

Figure 6:Section of 2039 Network Model with Proposed projects

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.

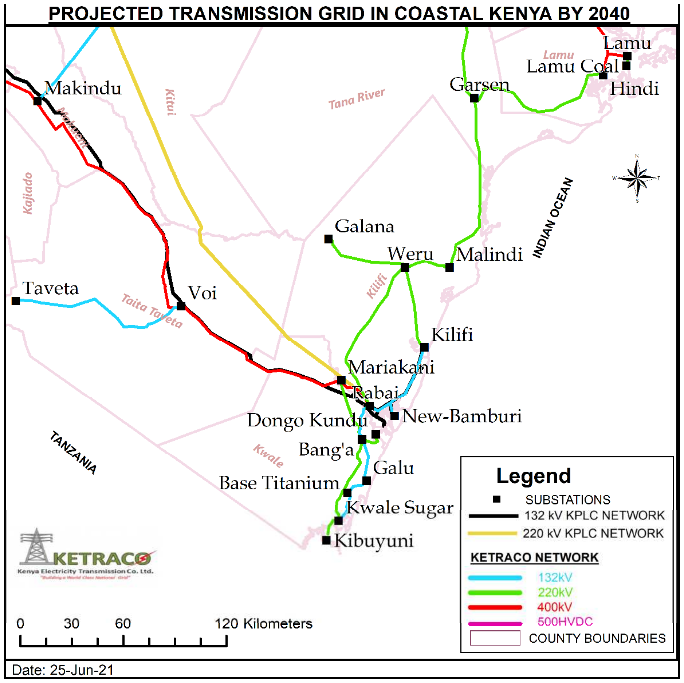

Figure 7: Coast Region Transmission Grid 2040

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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