Static Security Assessment of the Kenyan Power System Using Contingency Analysis of Newton Raphson Approach

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Abstract: This paper aims to evaluate the static security of the Kenyan Power System using Contingency Analysis (CA) and offer recommendations to mitigate the vulnerabilities of the power system. To achieve this, the System was modelled into the equivalent IEEE -39 Bus System and a CA done for different operating scenarios factoring in generators and transmission lines and considering an outage level of (N-1) using DIgSILENT Power Factory software. Newton Raphson (NR) Method was used to perform the CA since it was able to give information on the reactive energy flows and the bus voltages in the system. The component loading was between 80 -90% which operated closer to their loading limit thus limiting the load expansion and ability to withstand loading in case of a contingency. The bus voltages before CA was done ranged from 0.99 p.u. to 1.02 p.u and a loss of transmission line caused them to drop to as low as 0.6 p.u due to a decrease of reactive power injection. Recommendations to correct these violations without load shedding have been suggested to enable the system handle an outage level of (N-1).

Keywords: Contingency Analysis, Newton Raphson, Power System Security

I: INTRODUCTION

Power system security is defined as the magnitude of probability to navigate contingencies without interference of customer service [1]. According to Stott et al. [1] steady state security assessment is a violation detection process under actual operating states and contingencies. The security of a power system is determined through assessment in consideration to the given contingencies [2]. The magnitude of survival through contingencies while ensuring no interruption to customer service is elaborated as power system security according to IEEE/CIGRE. Therefore, it is clear with consideration to prior research that contingency is a critical bit of power system security analysis [2]. In Power Systems, a contingency is the event where a component of the electric grid breaks down. The element that fails could be a generator, transmission line, substation or transformer. A Contingency Analysis is executed on simulations of the electric grid to establish the cause to a specific component malfunctioning. If a system is (N-1) Contingent or secure, it states that the system can carry on with operations within normal limits if 1 element fails. Moreover, a contingency commences and winds up at a breaking device such as a circuit breaker [3].

Contribution: This paper for the first time provides recommendations that can be implemented to the Kenyan Power System to attain the (N-1) security level using Newton Raphson (NR) method.

II: LITERATURE REVIEW

A: Review of Some (N-1) Security Cases in the World

A contingency analysis was done on the Nigerian Power System using the Electrical Transient Analyser Programme (ETAP). This was because Nigerian Government needed various amendments in the power sector leading to privatisation of the power sector. They however, did not exhibit any improvement on the same quest. Voltage instability stood out as the primary cause behind outages the on Kaduma Transmission Network. Thus having an evaluation on power flow and contingency for the expanding 330kV Nigeria grid through simulation on the Power World Simulator. The outcome from the said assessment stated Damaturu and Gombe bus voltages had variances with per unit and actual values of 0.94432, 311.63Kv and 0.94497, 311.84Kv respectively [1].A contingency analysis and reliability assessment was also done on the Bangladesh Power System (BPS) using Newton Raphson (NR) approach in executing the contingency survey on the PSAF. The outcome indicated a 2.06% probability of load loss in BPS. NR was also used to perform an analysis on the Maryland Transmission Station (MTS) and the outcome exhibited that a compensation was needed on the line. Contingency Study using MATLAB Simulink model was also proposed for a limited 220kV KPTCL system. A 15-bus system comprising 5 generators, 13 loads and 20 transmission lines was modelled and simulated using NR technique and the results indicated that the proposed method successfully reduced the computation time for contingency analysis as compared to other typical methods [1]. Analysis of the above-named systems were done in other software other than Power Factory. Comparison of the results from various software helps to determine the accuracy levels in analysis. Some of the software used were unable to give data on loadability hence making the study difficult. IN DIgSILENT has a vast range of functions it can perform with a user-friendly experience in terms of design and analysis [4].

III: NEWTON RAPHSON(NR) METHOD

A: Newton Raphson (NR)

A bus in power systems refers to a node that connects one or more lines and can also contain multiple components like loads and generators as shown in Figure 1. Merits and demerits of NR as in [5-6].

The current entering the bus 1 is given as

$$I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \quad for\ j \neq i \qquad (1)$$

Rewriting equation (2) in bus admittance matrix form, gives

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j = \sum_{j=1}^{n} |Y_{ij}||V_j| \angle(\theta_{ij} + \delta_j) \qquad (2)$$

The complex power at bus i is

$$P_i - jQ_i = V_i^* I_i = |V_i| \angle(-\delta_1) \sum_{j=1}^{n} |Y_{ij}||V_j| \angle(\theta_{ij} + \delta_j) \quad (3)$$

Splitting up real and imaginary part

$$P_i = \sum_{j=1}^{n} |Y_{ij}|\,|V_j|\,|V_i| cos(\theta_{ij} - \delta_i + \delta_j) \qquad (4)$$

$$Q_i = -\sum_{j=1}^{n} |Y_{ij}||V_j|\,|V_i| sin(\theta_{ij} - \delta_i + \delta_j) \qquad (5)$$

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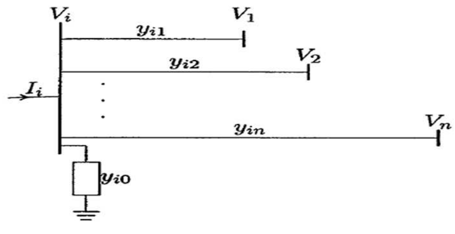

Figure 1: Typical Bus Bar of a Power System

Expanding P_i and Q_i in Taylor's series about the initial estimate and neglecting all higher order terms results in the following set of linear equations. The Jacobian matrix gives the linearized relationship between small changes in voltage angle $\Delta\delta_i^{(k)}$ and voltage magnitude $\Delta|V_i^{(k)}|$ with small changes in real and reactive power $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$.Elements of the Jacobian matrix are the partial derivatives of $P_i^{(k)}$ and $Q_i^{(k)}$, evaluated at $\Delta\delta_i^{(k)}$ and $|V_i^{(k)}|$ .In short form, it can be written as

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\delta} & J_{PV} \\ J_{Q\delta} & J_{QV} \end{bmatrix} = \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (6)$$

The diagonal and off diagonal elements of $J_{P\delta}$ are:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j\neq 1}^{n} |V_i||V_j||Y_{ij}|sin(\theta_{ij} - \delta_i + \delta_j) \quad (7)$$

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}|sin(\theta_{ij} - \delta_i + \delta_j) \quad j \neq i \quad (8)$$

The diagonal and the off-diagonal elements of J_{PV} are:

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ii}|\cos\theta_{ii} + \sum_{j\neq 1}^{n}|V_j||Y_{ij}|cos(\theta_{ij} - \delta_i + \delta_j) \quad (9)$$

$$\frac{\partial P_i}{\partial |V_j|} = |V_j||Y_{ij}|cos(\theta_{ij} - \delta_i + \delta_j) \quad j \neq i \quad (10)$$

The diagonal and the off-diagonal elements of $J_{Q\delta}$ are:

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j\neq 1}^{n} |V_i||V_j||Y_{ij}|cos(\theta_{ij} - \delta_i + \delta_j) \quad (11)$$

$$\frac{\partial Q_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|cos(\theta_{ij} - \delta_i + \delta_j) \quad j \neq i \quad (12)$$

The diagonal and the off-diagonal elements of J_{QV} are:

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}|\sin\theta_{ii} + \sum_{j\neq 1}^{n}|V_j||Y_{ij}|sin(\theta_{ij} - \delta_i + \delta_j) \quad (13)$$

$$\frac{\partial P_i}{\partial |V_j|} = |V_j||Y_{ij}|sin(\theta_{ij} - \delta_i + \delta_j) \quad j \neq i \quad (14)$$

The terms $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$are the difference between the scheduled and calculated values, known as the power residuals, given by

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)} \quad (15)$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \quad (16)$$

The new estimates for bus voltages are illustrated in equations (17) and (18) respectively

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \quad (17)$$

$$|V_i^{(k+1)}| = |V_i^{(k)}| + \Delta|V_i^{(k)}| \quad (18)$$

B: Contingency Ranking Approach (CRA)

In practice, not all contingencies cause system violations. The process of identifying the contingencies that actually leads to violation of operational limits is known as contingency selection [3], [7]. The contingencies are selected by either by calculating severity indices known as performance indices(PI)[8], sensitivity analysis[9] or through computer simulations[10]

C: Remedial Action Scheme (RAS)

This refers to the measures which the utilities need to take to get the system back to its normal operation after a contingency. The RAS is designed to mitigate the effects of critical contingencies that initiate the actual system problems. Each critical contingency may require a separate arming level and different remedial actions[10]. In the event of critical contingencies such as temporary faults during stressed operating conditions, automatic single-phase or three-phase recloser may prevent the system from undergoing catastrophic failure. This happens in most cases. However, appropriate RAS action may still be required if reclosing is unsuccessful[10-11].Corrective measures that are usually taken to mitigate the effects of contingency include Shunt capacitor switching, Generation Re-dispatch, Load shedding, Under load tap changing (ULTC) Transformer, Distributed Generation and Islanding. The effectiveness of RAS has been demonstrated in [12].

IV: KENYAN CASE STUDY

The Kenyan Power System (KPS) can be related to an IEEE 39 bus system as shown in Figure 2. Previous studies have been done on the voltage stability of the system to ensure the system is stable when the load flow is done using the Newton Raphson Method. The analysis was executed through simulations using MATLAB and MATPOWER. The design was evaluated with both AC and DC power flow, where the AC power flow is the accurate model of the power system in steady mode operation while the DC power flow is a linear approximation of the system in this mode of operation [4,11].The KPS was modelled from the Kenyan transmission system data on *DigSILENT Power Factory 15.1 Software*. Load, generation dispatch, transmission line data and bus data were used to come up with a model of the Kenyan Power System. At the transmission level, the voltage levels considered were 400kV, 220kV and 132kV. In the design process, factors considered from every component are crucial for better results. KPS has a set design rating for each component that was put into consideration during analysis. The (N-1) criterion will be run on the system considering only buses and transmission lines above 132Kv since they are more crucial than the other lines. The analysis is aimed at maintaining the voltage limits between 0.95p.u and 1.05p.u and ensure the loadability of every component is below 100%.

V: RESULTS AND ANALYSIS

A: Scenario I: Base Case Analysis

Following the load flow for the base case scenario of the KPS execution, the system summary is as shown in the Table I. In summary, the following voltage violations and loading violations were encountered; 0.69kV and 33Kv bus bar were 1.08p.u and 1.06p.u and the 2-winding transformer was overloaded by 233.04%. The other bus voltages were within the set limits of 0.95p.u and 1.05pu and no other components were overloaded beyond 100% of their rating. There were two types of contingencies, Generator outages and Transmission line outages are studied. These are discussed next.

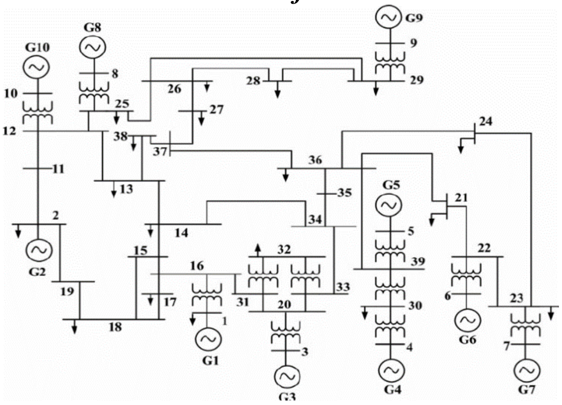

Figure 2: Single Line Diagram of IEEE -39 Bus System [11]

Table I: System Summary for the Kenya Power System Grid

Total	Generation	PQ Load	Line Charging	Losses
MW	1937.88	1873.30		64.58
MVAR	217.19	1078.30	-1893.33	-1391.98
Installed Capacity – 2815.50MW				
Spinning Reserve – 1041.46MW				

Generator Outages for Base Case

A contingency analysis of generator outages was done where 32 generator outages were simulated. This is as shown in Table II. There were 3 system violations found which affected the Kisumu- Kibos transmission line. They arose from outages of Sondu generator, Mumias Generator and Sangoro G generator. The maximum loading of the Kisumu – Kibos line was 108.0% which occurred when the Sondu generator was lost. The transmission line under normal operating condition is loaded to a maximum capacity of 87.1% and it can be seen that the line is operating close to its limit prior to a contingency occurring with a power of 85.3MW flowing through the 132Kv bus which is majorly flowing from the Olkaria II power plant. The loss of these generators trigger increased power flow from nearby power plants to meet the demand which leads to overloading of the line.

Table II:Outages corresponding to Overloaded Components In Kisumu-Kibos Line and their violations.

Generator Lost	Loading :Contingency (%)	Loading: Base (%)
Sondu	108.0	87.1
Mumias	102.5	87.1
Sangoro G	100.9	87.1

Transmission Line Outages

The Kisumu –Kibos line is operating close to its operating capacity by 87.1% showing that future increase in loads will not be sustained considering it's a single circuit line. To curb this, doubling it's loadability is advised through adding another parallel line. This is achievable since the Kisumu- Kibos is only 2km long. This will go a long way in ensuring the reliability and continuity of the power supply for the Western Region. There is an overloading on the transformer connecting the 33kv bus to the Loiyalangani bus; hence 2 parallel transformers were added to assist in the loadability of the line which improved from 233.1% to 78.5%.A contingency analysis on line outages was performed and 183-line outages were simulated. The results were as shown in Table 3. The loss of the Tororo- Lessos Transmission Line affected the voltage at the Tororo bus to 0.031p.u. This is because the Bujagali generator is under excited hence draws reactive power from the Tororo bus. The Bujagali generator requires approximately 34.8MVAr in order for the bus voltages to be regulated to normal levels. A capacitor bank with a rating of 30MVAr is connected to the Tororo bus to regulate the voltages by supplying the required reactive power required to overcome the windage losses of the generator. The outage of the Tororo Lessos transmission line affected the voltage by 0,931 p.u at a base of 1.0 p.u. The loss of the Eldoret –Lessos transmission line caused the most severe under voltages with Eldoret North bus operating at the lowest voltage of 0.608 p.u. The Moi Barracks bus and Eldoret North bus are all connected to the Eldoret 132 bus which is supplied from the Lessos 132Kv via the Eldoret- Lessos transmission line. The loss of this transmission line alters the system's operation in that the Eldoret North and Moi Barracks buses are supplied from the Turkwell generator. In the base case scenario, the Eldoret 132Kv bus is supplied from the Lessos 132Kv bus with 27.4MVAr. With the loss of the Eldoret- Lessos line, the reactive power supply is lost. The reactive power received from Turkwell is not enough to meet the demand from Eldoret North and Moi Barracks buses resulting in under voltages in these buses. The outage of the Eldoret - Lessos transmission line affected three buses as shown in the Table III:

Table III: Buses Affected by the Eldoret – Lessos line Outage.

Buses affected by the Eldoret –Lessos line outage	Bus Voltage after the Contingency case (p.u)	Bus Voltage For Base Case (p.u)
Eldoret North	0.608	0.961
Eldoret 132	0.612	0.963
Moi Barracks	0.655	0.968

To curb this effect, it is recommended that and automatic switchable 30MVAr capacitor to be installed at the Eldoret 132kV bus or the Eldoret North bus to regulate the voltages of the adversely affected buses following the contingency. A more cost-effective short-term alternative with minimal supply interruption would be to take Eldoret North bus out of service following outage of the Eldoret- Lessos transmission line. This is because it reduces reactive power demand by 11.8MVAr and raises the bus voltages of Eldoret 132Kv and Moi Barracks buses to 0.99p.u. The voltages may be improved further by taking the Moi Barracks load out of service to serve as a remedial action. The second recommendation is not advisable since load shedding would not be taking care of the problem on a long-term basis and may affect the customer services in the load shedded areas. From the design, we can see that outage of any of the transmission lines isolates the Maralal load, Silali power plant and the Lake Turkana Wind farm from the rest of the grid. The loss of this plants will affect the Nyahururu bus which supplies other loads in the grid. Table 3 shows the bus voltages range from 0.686 to 0.854 p.u. The effect of the under voltages is also caused by the reactors placed on the Suswa and Rumuruti 400kv buses. The reactors initial use was to step down the voltages to acceptable levels at the receiving end of the Suswa-Loiyangalani line, Rumuruti line. Under normal operating conditions, high voltages from the Suswa and Loiyangalani buses arise from the Ferranti effect. Under normal operating conditions, the reactive power injected into the Rumuruti 400Kv bus is 132.5MVAr of which 106.1MVAr is absorbed by the 100MVAr reactor that is installed at the bus. The Gilgil – Naivasha transmission line consists of 2 parallel lines that inject 16.6MVAr that is absorbed by the loads in the Nakuru West bus and Lanet 132 bus. This makes Gilgil- Naivasha transmission line very crucial, since loss of either of the lines causes a deficit of supply of reactive power to these loads. Since when the reactive power reduces, the bus voltages in these buses also reduces. The results are as shown in Table IV.

Table IV: Effect of Outage of Gilgil – Naivasha Line

Buses Affected by outage	Bus Voltages after Contingency (p.u.)	Bus Voltage for Base Case (p.u.)
Gilgil Tee1	0.889	1.004
Gilgil Tee2	0.890	1.005
Lanet 132	0.893	0.994

There are two ways to solve the under voltages experienced. The most cost effective and quickest action to remedy the under voltages following the contingency is load shedding. That is by either disconnecting the Lanet 132 load or the Nakuru West load, which will minimize the reactive power demand by 24.6MVAr and 14.8MVAr respectively. From Table V, simultaneously taking both loads out of service or either of the loads will improve the system voltages of the affected buses and return them to stable values. The Lanet load also serves as a proper location for injection of additional generation or a shunt capacitor of 20MVAr to help in stabilizing the voltages at the affected buses. This will maintain bus voltages of Lanet 132, Gilgil Tee1, Gilgil Tee 2 and also Nakuru West buses to acceptable levels. The addition of a generator or a shunt capacitor maybe costly but is a long term solution to the contingency and will avoid customer complains due to load shedding. Load shedding may also reduce revenues from utility companies and also violates the N-1 criterion since it interrupts continuity of supply and service.

Table V: Effect of Loss of Loads on the Bus Voltage.

Scenario 1 : Lanet Load offline			
Bus	Gilgil Tee1	Gilgil Tee 2	Lanet 132
Voltage (p.u.)	1.03	1.03	1.03
Scenario 1 : Nakuru West Load offline			
Bus	Gilgil Tee1	Gilgil Tee 2	Lanet 132
Voltage (p.u.)	1.02	1.02	1.01
Scenario 1 : Lanet & Nakuru West Loads offline			
Bus	Gilgil Tee1	Gilgil Tee 2	Lanet 132
Voltage (p.u.)	1.05	1.05	1.05

For results analysis, 183 line outages were simulated. The individual contingencies, overloaded components affected by this contingency, their impacts and recommendations on how to mitigate these effects have been discussed as follows: The effect of the outage of Naivasha-Olkaria 1 transmission line is a major one because the Naivasha – Olkaria I transmission line has only one line and the Olkaria transformer is only one. The overloading would lead to tripping of the Olkaria II transformer and later on isolation of the Olkaria 1 – Olkaria 2 transmission line due to overheating of the line. This will inevitably lead to the 206.9MW from Olkaria 1 being lost hence blackouts from very many regions in the system. Table VI shows the overloaded components resulting from the loss of Naivasha-Olkaria 1 line.

Table VI: Overloaded Components for outage of the Naivasha – Olkaria 1 transmission line

Overloaded Components	Loading Contingency case (%)	Loading Base Case (%)
Olkaria II Transformer	230.2	59.5
Olkaria 1 – Olkaria 2 transmission line	125.9	32.5

It is thus necessary to add another set of parallel lines to offer backup protection for the Naivasha – Olkaria 1 transmission line in case other lines fail. Addition of a parallel transformer to the Olkaria II transformer is also required to go hand in hand but the solution will not hold but will be a temporary solution. Alternatively, a new generation should be injected at Naivasha 132 bus to reduce dependency of Ruaraka, Lanet and Nakuru West loads on supply from Olkaria 1 A.U. A new generator injecting 70MW into the Naivasha 132Kv bus at a voltage of 1 p.u. was added as the Olkaria A.U. was reduced to 130MW. This is done simultaneously with the addition of parallel transmission line for Olkaria 1 – Olkaria 2 transmission and Olkaria II transformer. Doing this averted the overload on the two parts and handled the contingency. The Kisumu – Kibos transmission line serves as a crucial link between the loads in Western Kenya and the generation from the Olkaria geothermal fields, delivering 95.4MW from these fields to the loads in Western Kenya. An outage of this line triggers increased generation from other nearby generators which are the Sondu generator and the Sangoro generator. The power from Olkaria II generator and OR power that supply the Olkaria II bus is redirected and flows to the Lessos 132 bus hence overloading the Lessos transformer by 50%. Under normal operating conditions, the Kisumu – Kibos transmission line transmits 95.7MW (93.6% loading) injected on the Kibos bus to Kisumu. This implies that the line operates close to its limits prior to the contingency. Thus a slight increase in loading could cause it to be overloaded. It was also noted that the outage of the Kisumu – Kibos transmission line causes an overload of the Lessos transformers. Taking into consideration the costs, the most economical option to tackle the violations arising from the outage of the Kisumu – Kibos transmission line or overloading of the Kisumu – Kibos transmission following other contingencies is to strengthen this line. This can be done through increasing its loadabillity by stringing an additional parallel line. Doing this doubles its loadability and allows it to ride out increased power flow arising from other contingencies. Additionally, the extra line serves as a backup line in case the other one fails thus improving the reliability of supply of power to the Western region of Kenya. The Lessos transformers are also affected not only by the Kisumu – Kibos line, but also other interconnected lines. Increasing the number of Lessos transformers increased the loadability. This contingency removes Lake Turkana Wind Power, Silali Generator and the Maralal load from the system resulting in a net loss of 448.2MW of generation. In practice, the sudden loss of 448.2MW of generation would likely throw the entire Kenyan power system and the Ugandan power system into instability because of their interconnection.

B: Scenario 2: Minimal Generation from Thermal Plants

In this scenario, the system was modelled to incorporate little generation from thermal power Plants as possible. The following modifications were made to the base case to achieve optimal generation with minimal output from thermal sources: Load was scaled down to 87%; all generators were in service except Kipevu 1, Kipevu 2, Kipevu 3, Rabai power and Thika power thermal plants and finally the Ruaraka capacitor was taken out of service.32 generator outages were simulated and Kwale SC generator and Olkaria IV generator failed to converge. There were no components affected by maximum voltage violations but there were minimum voltage and loading violations observed. Following a simulation of the load flow of this system for Scenario 2, the system summary is as shown in Table VII.

Table VII: Total System Summary for the Kenyan Power System in Scenario 2

Total Energy	Power Generated	PQ Load	Line Charging	Grid Losses
MW	1710.20	1629.78	-	80.42
MVAR	507.84	1078.30	-1647.77	-1060.27
Installed Capacity – 2490.52MW Spinning Reserve – 908.33MW				

C: Scenario 3: (55% Loading)

In this scenario, it was intended to simulate low loading conditions (off – peak load) and assess the security of the system. It was also modelled to represent the system on light load. In this case; all capacitors were turned off; all loads were scaled to 55% and finally all generation apart from Lake Turkana plant was scaled to 55% .The system summary of the same is shown in Table VIII where installed capacity remained at 2815.5MW just as the initial point when the load flow analysis was performed. This is because no generator was added. However, the spinning reserve values decreased from 1041.35MW to 854.30MW. Grid losses increased from a value of 64.68 to a value of 182.16. MVAR values changed from 218.99 to -128.48, this is because all capacitors were turned off before running simulation. 32 generator outages were simulated. Lake Turkana wind plant and Olkaria 1 did not converge. There were maximum voltage violations and loading violations after the simulation.

Table VIII: Total System Summary for the Kenyan Power System

Total	Generation	PQ Load	Line Charging	Grid Losses
MW	2048.53	1866.37	-	182.16
MVAR	-128.48	1073.80	-2359.59	-1202.28
Installed Capacity – 2815.50MW Spinning Reserve – 854.30MW				

Due to reduced generation from the Sondu generator, loads connected to the Sondu 132 bus bar are affected leading to other generators stepping in to fill in for extra generation. 7.2 MW is received from the Kisumu 132 bus to assist in supplying the loads connected to the Sondu 132kV bus. Loss of Sondu generator will make generation from the Kisumu 132 bus should increase to cater for the load. This affects the loadability of the Kisumu – Kibos transmission line. The same goes for the lessos transformer, Olkaria 2- Suswa transmission line, Olkaria 2-Suswa 2 transmission line and the Silali 11/132kV transformer. Addition of parallel components in each case assist in loadability of the components and also security in cases of loss of one of the lines ensuring the customers are not left in a blackout or system operators are not forced to shed some loads; this improves the static security of the system. Table IX shows a list of overloaded components affected by the outage of Sondu Generator. The Silali generator supplies 74.9MW to the Loiyangalani- Suswa 400 transmission line at a distance of 107km which is then transmitted to loads connected to Suswa 400 bus. Loads connected to adjacent bus bars will draw power from other generator close to the Suswa 400 bus bar. This load strains the transformers transmitting the power; since their ratings are not able to handle such loading. Redundancy in components assists in handling loading and also act as a backup in cases of loss of a component. Table X shows a list of overloaded components affected by the outage of Silali Generator. Voltage violations experienced in this scenario greatly affect areas where reactors and capacitors were located due to *Ferranti effect.*

Table IX: Overloaded Components Affected by the Outage of Sondu Generator

Transmission Line /Transformer	Loading [%]	Base case
Kisumu- Kibos	145.0	131.1
Lessos transformer	128.5	122.1
Olkaria 2 – Suswa	107.6	106.0
Olkaria 2- Suswa 2	107.6	106
Silali 11/132Kv transformer	101.6	100.8

Table X: Overloaded Components Affected by the Outage of Silali Generator

Overloaded components affected by the outage of Silali Generator	Loading after the Contingency case[%]	Loading - Base case
2- winding transformer	105.5	99.2
Isinya 2 220/400 transformer	102.4	81.9
Rabai 220/132 transformer	102.3	93.2

VI: CONCLUSION

Most components in the Kenyan power system are operating close to their limits hence making the system unstable. During normal operations, most of the transformers and transmission lines are loaded between 80 – 90 %, which limits room for expansion in terms of addition of loads. This can also lead to loss of a line due to extreme temperatures caused by high currents that can lead to short circuiting of the line. Most of the generators have been overloaded following a contingency on the system making the system unreliable. There need to add more generation mainly renewable so as to curb the emissions to the ecosystem is a priority. This will also help in removing thermal plants from the system which emit gases that destroy the environment and global warming concern.

REFERENCES

[1] P. J. I. C. I. A.E. Airoboman, “Contingency Analysis on the Nigerian Power Systems Grid,” Institute of Electrical and Electronic Engineering (IEEE), Nigeria, 2019.

[2] J. E. C. CIGRE TF 38-03-12 (R.J. Marceau, “Power System Security Assessment: A Position Paper,” Vols. No. 175, Electra, pp. pp. 48-78, December 1997.

[3] K. Patra, Contigency Analysis in Power System using Load Flow Solution no. 0975-8887, International Journal of Computer Application, pp 1-4, 2015.

[4] O. A. A. M. B. Stott, “Security Analaysis and Optimization,” Proc. IEEE VOL 75, no. 12, 1987, pp. pp. 1623-1644.

[5] K. K. Patra, “Contigency Analysis in Power System using Load Flow Solution,” International Journal of Computer Applications, no. 0975-8887, pp. 1-4, 2015.

[6] C. C. e. al, “Analysis in Restructured Power Systems,” International Journal Research and Development, vol. volume 2, no. Issue 11, pp. 109-118, 2013.

[7] A. Roy, Contigency Analysis In Power System, Patiala: Thapar University, 2011.

[8] R. S. e. al, Sensitivity Factor For Power System Security Analysis Using Labview, Sidi- bel-Abbes, Algeria: University of Djillali Liabes.

[9] DigSILENT GmbH, “Contingency Analysis,” in DigSilent PowerFactory, Gomaringen, Germany, Digsilent Powerfactory, 2014, pp. 653-686.

[10] S. J. Mwale and I. E. Davidson, “Security analysis of electric power supply in SADC region,” Africon, vol. 10, no. 1109/AFRCON.2013.6757702, pp. 1-6, 2013.

[11] L. Wu, J. Gao, Y. Wang and R. G. Harley, "A survey of contingency analysis regarding steady state security of a power system" , 2017 North American Power Symposium (NAPS), 2017

[12] Y. Salami, “Multiple Contigency Analysis of Power Systems,” St Johns Newfoundland and Labrador, Canada, October 2017