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A COMPARATIVE STUDY OF THE CONTINGENCY ASSESSMENT OF THE REFORMED NIGERIA 330KV POWER NETWORK UNDER NORMAL AND FORTIFIED CONDITIONS.

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ABSTRACT: *One of the most important requirements for effective performance of a power system network is to make the network secure against unanticipated outages. It is very important to be able to predict the extent of violations that can occur in the network in the event of unprecedented contingencies. Contingency Analysis is useful both in the network design stages and for programmed maintenance or network expansion works to detect network weaknesses. The weaknesses can be strengthened by transmission capacity increase, and shunt compensations at the buses. This work considers the simulation of single generators and transmission line outages so as to carry out a full AC load flow based contingency analysis on the Nigeria 330kv post-reform grid. The simulation results show severe bus violations with generator contingencies at Mambilla and line contingencies at Jos-Gombe and Damaturu-Mambilla lines. Under the same contingencies for the fortified grid, there were no violations on the network, indicating that the simulated fortification can be recommended for real time performance of the network.*

KEYWORDS: Contingency, Simulation, Violations, Post-reform grid, fortified grid

INTRODUCTION

One of the most important factors in the operation of a power system is the desire to maintain system security. System security involves practices designed to keep the system operating when components fail (Nonyelu & Madueme, 2013). A generating unit may have to be taken off-line because of auxiliary equipment failure. By maintaining proper amounts of spinning reserve, the remaining units on the system can make up the deficit without need to shed any load. Transmission line may be damaged by a storm and taken out by automatic relaying. If, in committing and dispatching generation, proper regard for transmission flows is maintained, the remaining transmission lines can take the increased loading and still remain within limit. (Ahmad, Zakria, Elahi & Biswas, 2011)

Power system equipments are designed to be operated within certain limits. If any event occurs in the system and these limits are violated the event may be followed by a series of cascading failures, a large part of the system may completely collapse. (Bakar, 2014).

The reformed Nigeria power system grid was initiated with system security on the mind of the planners. It has 20 grid connected generating plants with about 5523.8 km of 330kv transmission lines. The post reform grid provided remedies to the inadequacies associated with the pre-reform grid network. The power flow study of Nigeria 330Kv power grid is pertinent to ascertain the performance state of the network for a scheduled load and generation. (KPMG Handbook, 2013; Izuegbunam, Duruibe & Ojukwu, 2011; Onojo, Inyama & Ononiwu, 2015). Single line contingency analysis on the network has shown some residue weakness in the post reform grid system (Onojo *et al*, 2015).

This research is aimed at exploring uncertainties and effects of changes in the power system, recognising limitations that can affect the power reliability and security operations and identifying techniques to treat and minimize the effects of the risks related to the possible power system contingencies.

Power Flow Study

Power flow analysis is performed to investigate the magnitude and phase angle of the voltage at each bus and the real and reactive power flows in the system components. The load flow results are very valuable for setting the proper protection devices to ensure the security of the system. (Roy, 2011; Ahmad *et al*, 2011). The objective of any power flow program is to produce the following information:

• Voltage magnitude at each bus.

• Real and reactive power flowing in each line.

• Phase angle of voltage at each bus.

In numerical analysis for power flow, the Newton-Raphson method, is the best known method for finding successively better approximations to the zeroes (or roots) of a real-valued function. (Gupta, 2011; Roy, 2011)

If,

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \qquad (1)$$

Also

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad (2)$$

Expressing in polar form

$$I_i = \sum_{j=1}^{n} |V_{ij}||V_j| \angle \theta_{ij} + \delta_j \qquad (3)$$

Substituting for I_i from Eqn.3 in Eqn. 2

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

$$P_i = \sum_{j=1}^{n} |V_i||V_j||V_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (5)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||V_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad (6)$$

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{c|c} \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \end{pmatrix} \\ \hline \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{pmatrix} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix} \quad (7)$$

It can be written as

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (8)$$

Shunt Compensation

In order to solve the faulty conditions found in our network, we use a technique called “Shunt compensation”.

Voltage collapse is a type of system instability, and it is defined as the inability of power system to keep bus voltages at acceptable steady state values following a disturbance and under normal operating conditions. Main reason of voltage instability is an insufficient injection of reactive power to the system. Consequently, sufficient amount of reactive power reserve must be placed at suitable points. The load flow analysis involves the calculation of load flows and voltages of network for specified terminal and bus conditions. Shunt compensating is applied to electric power transmission system for effective transmission. They can be shunt capacitor or reactor compensations. (Ahmad *et al*, 2011).

Implementing Shunt Capacitance Compensation

To maintain least possible losses, our required per unit voltage solution for a certain bus ranges from 0.95 to 1.05. When any bus doesn’t meet these criteria, the bus is beyond our expected voltage limit. To get the voltage within the range, we include capacitor as a shunt to the specific bus using shunt capacitance technique.

$Q=V^2/X_c$

$X_c=V^2/Q$

Also, $C=1/(wX_c)$

$w= 2\pi f$

Therefore, $C= 1/(2\pi fX_c)$

This way, we get the exact value of the shunt capacitor needed for a specific bus.

Methodology

Power world simulator was a major tool to achieve the solution of the power flow problem. The 35 bus model for the post reform Nigeria 330kv grid was modelled on the edit mode of the power world simulator. The run mode of power world simulator enabled the simulation of the post reform grid models using Newton-Raphson iterative method to obtain the bus voltages, phase angles, line losses, real and reactive power flows after inputting line impedance data, load and generation schedules into the dialogue box of power world simulator in the edit mode.

Figure 1 shows the simulation mode of the normal post reform grid model.

During single line (N-1) outage contingency simulation of this grid, violations were observed in a lot of buses in the network. Severe violations were observed in many buses on jos-gombe and damaturu-mambilla line outages, then mambilla generator outage. (Onojo *et al*, 2015). These violations will be used as our case study in this work. Figure 2, 3 and 4 shows the fortified grid. Jos-gombe and damaturu-mambilla line were upgraded to double circuits each and shunt compensators were added at some of the buses that were vulnerable to violations during the contingency simulation.

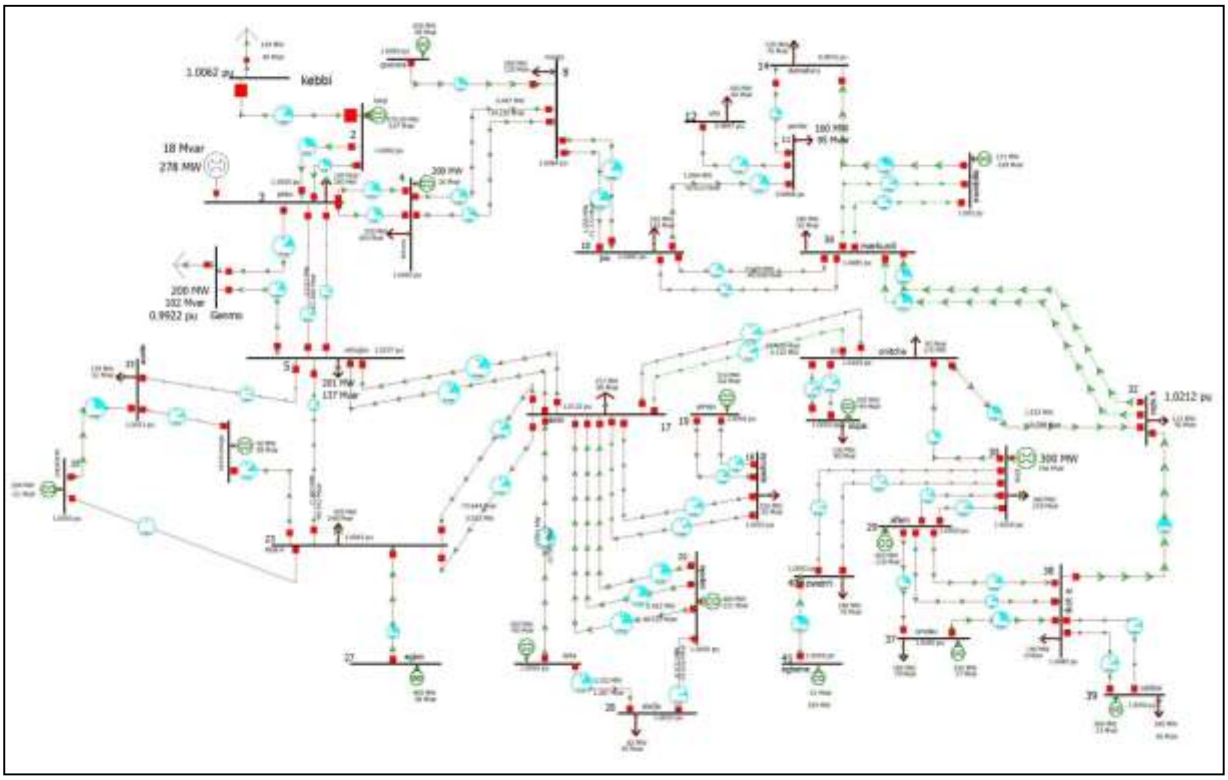

Figure 1. The simulated normal Nigeria 330kv grid on the Power world Platform

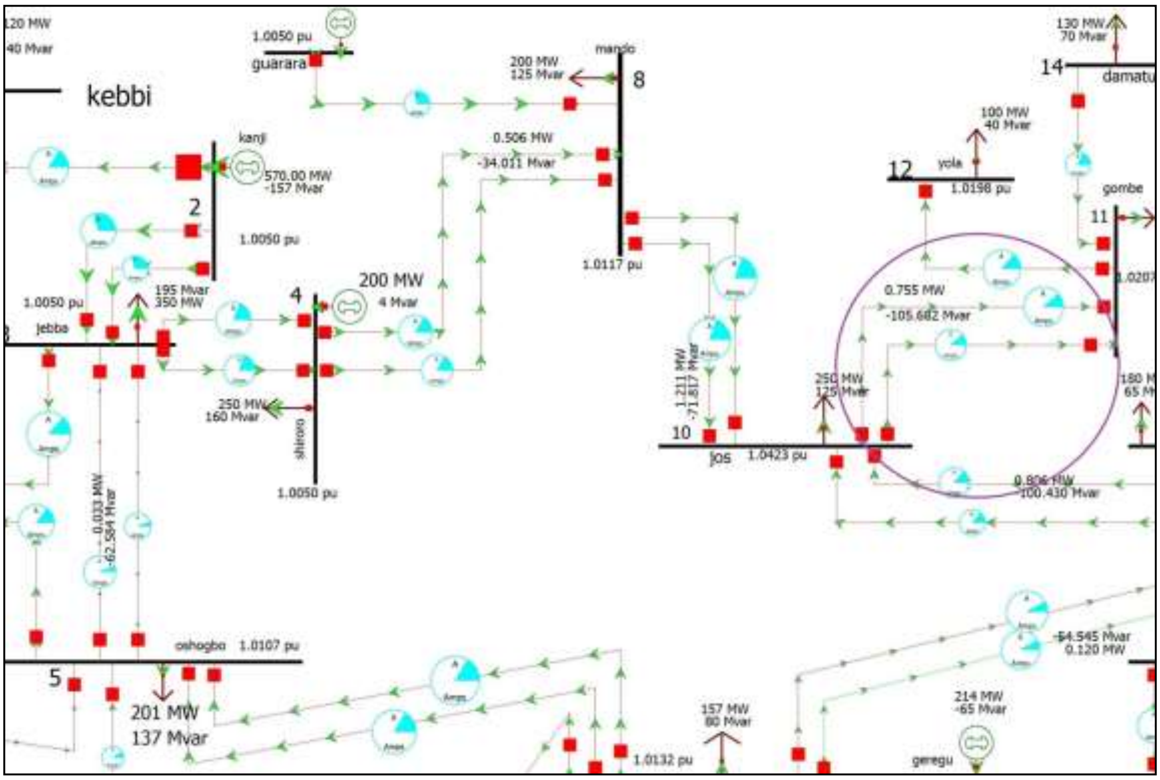

Figure 2. Fortified Jos-gombe line

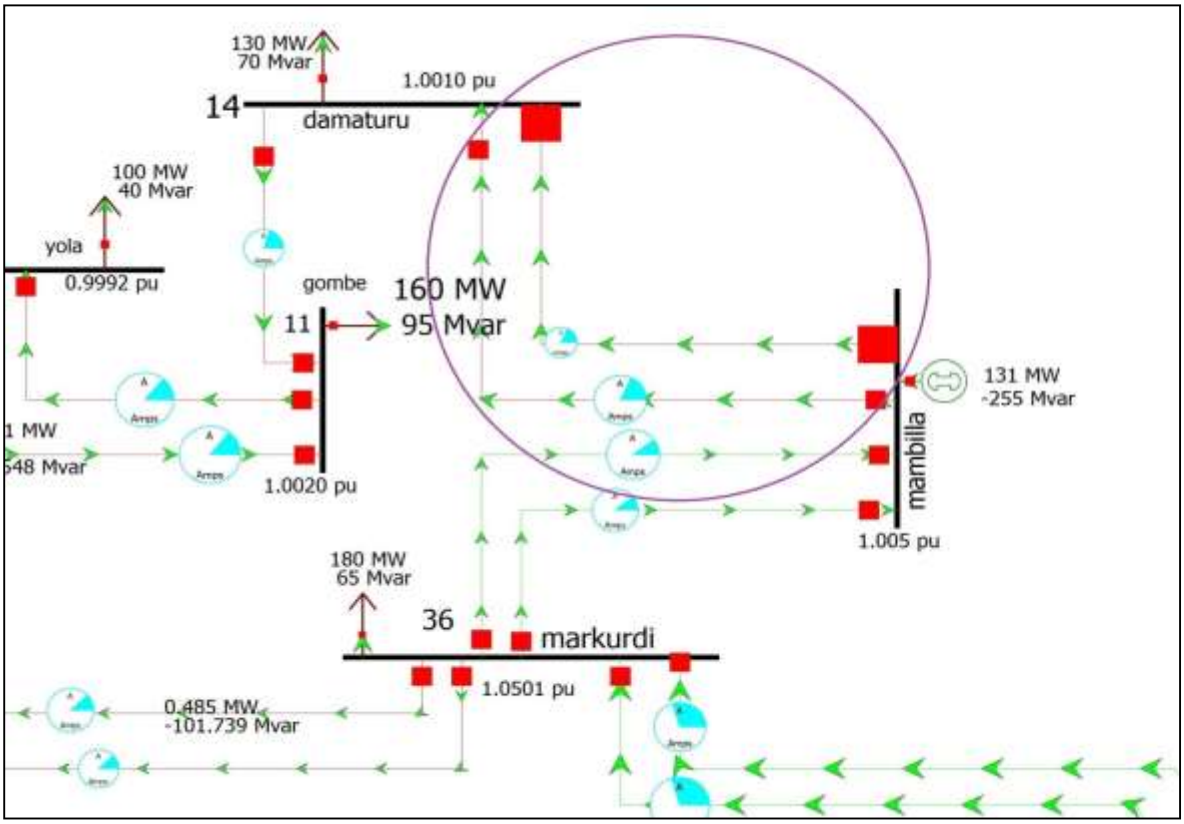

Figure 3. Fortified Damaturu-mambilla line

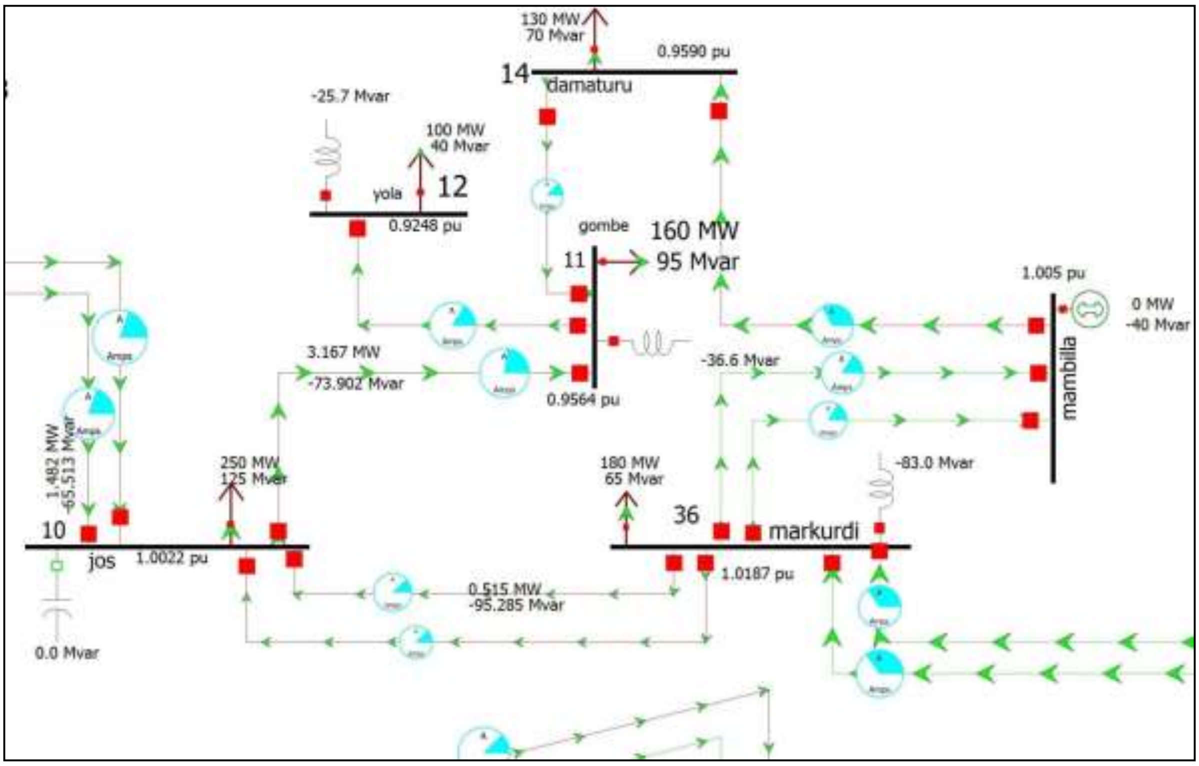

Figure 4. Post reform network with additional compensators at vulnerable buses

RESULTS AND DISCUSSION

Table 1 and figure 5 shows the violations at some buses during the outage of Jos-gombe line and Table 2 and figure 6 shows the violations at some buses during the outage of Damaturu-mambilla line. The per-unit voltage on these lines fall beyond the operating voltage which is 0.95p.u – 1.05p.u

Table 3 and figure 7 also outlines the violations during simulation with generator contingency at mambilla.

Provision of double circuit transmission lines to interconnect buses susceptible to voltage violations during contingencies will improve the voltage profile of these vulnerable buses.

In the case of the voltage violations at some buses due to the collapse of the generator at mambilla, shunt compensation can be used to stabilize the voltages at these buses.

It is known that in the power system network generally reactive power is the reason for the voltage problems. Hence in the case of low voltage problems, reactive power is supplied to the bus to increase the voltage profile at the bus. In the case of the high voltage, reactive power is absorbed at the buses to maintain the system normal voltage.

Figures 8, 9 and 10 shows the results on simulating the network during those contingencies after the fortifications were implemented. It can be seen that there were no violations at any of the buses.

Table 1. Violation summary when Jos – Gombe line was opened

Bus	Value	Limit	Percentage
Gombe	0.93	0.95	
Yola	0.92	0.95	
Damaturu	0.94	0.95	

Table 2. Violation summary when Damaturu – Mambilla line was opened

Bus	Value	Limit	Percentage
Jos	0.87	0.95	
Gombe	0.46	0.95	
Yola	0.40	0.95	
Damaturu	0.45	0.95	

Table 3. Violation summary when the generator at Mambilla was shutdown

Bus	Value	Limit	Percentage
jos	1.09	1.05	
gombe	1.13	1.05	
yola	1.14	1.05	
damaturu	1.14	1.05	
mambilla	1.17	1.05	
markurdi	1.12	1.05	

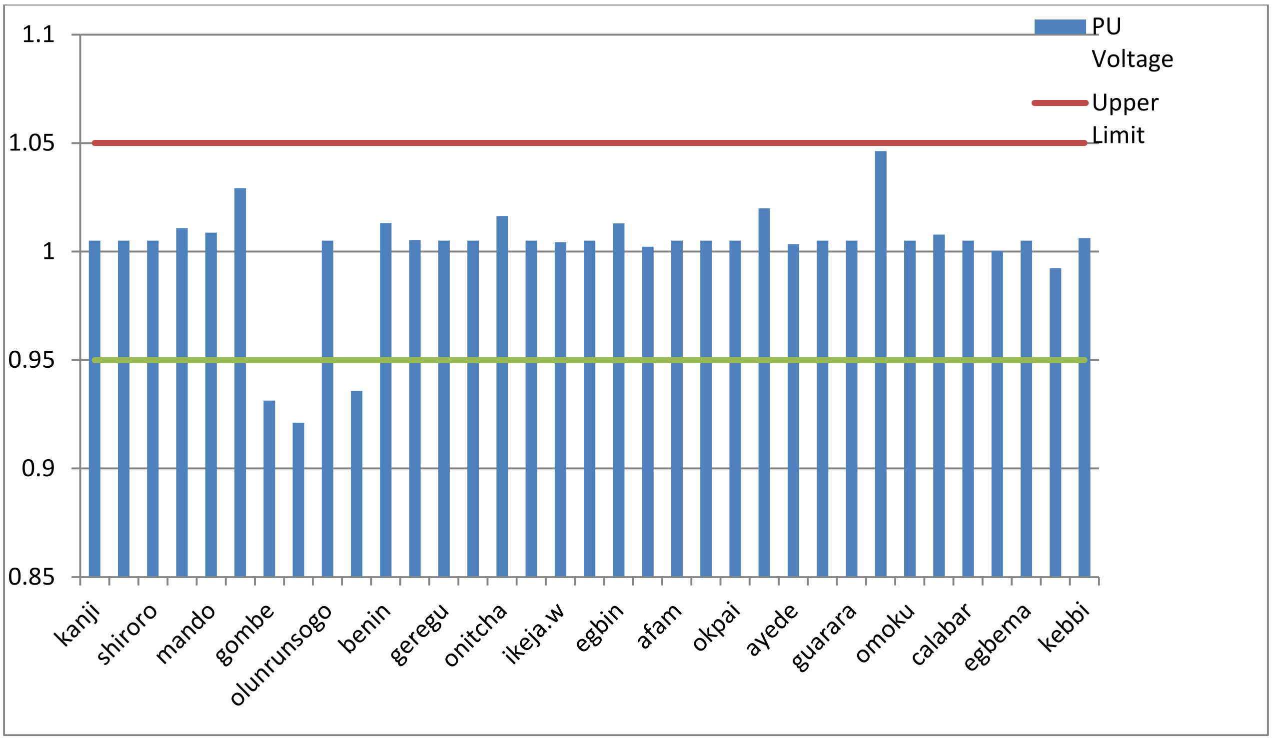

Fig 5. PU voltage When Jos – Gombe line was opened

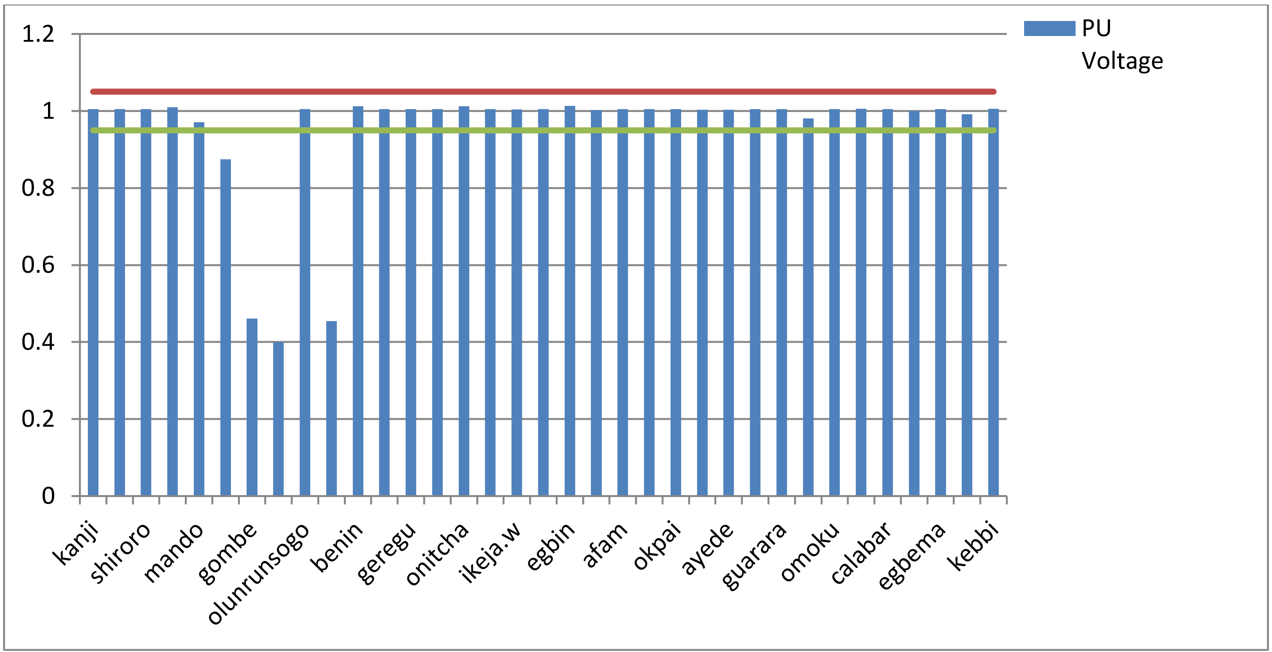

Fig 6. PU voltage When Damaturu – Mambilla line was opened

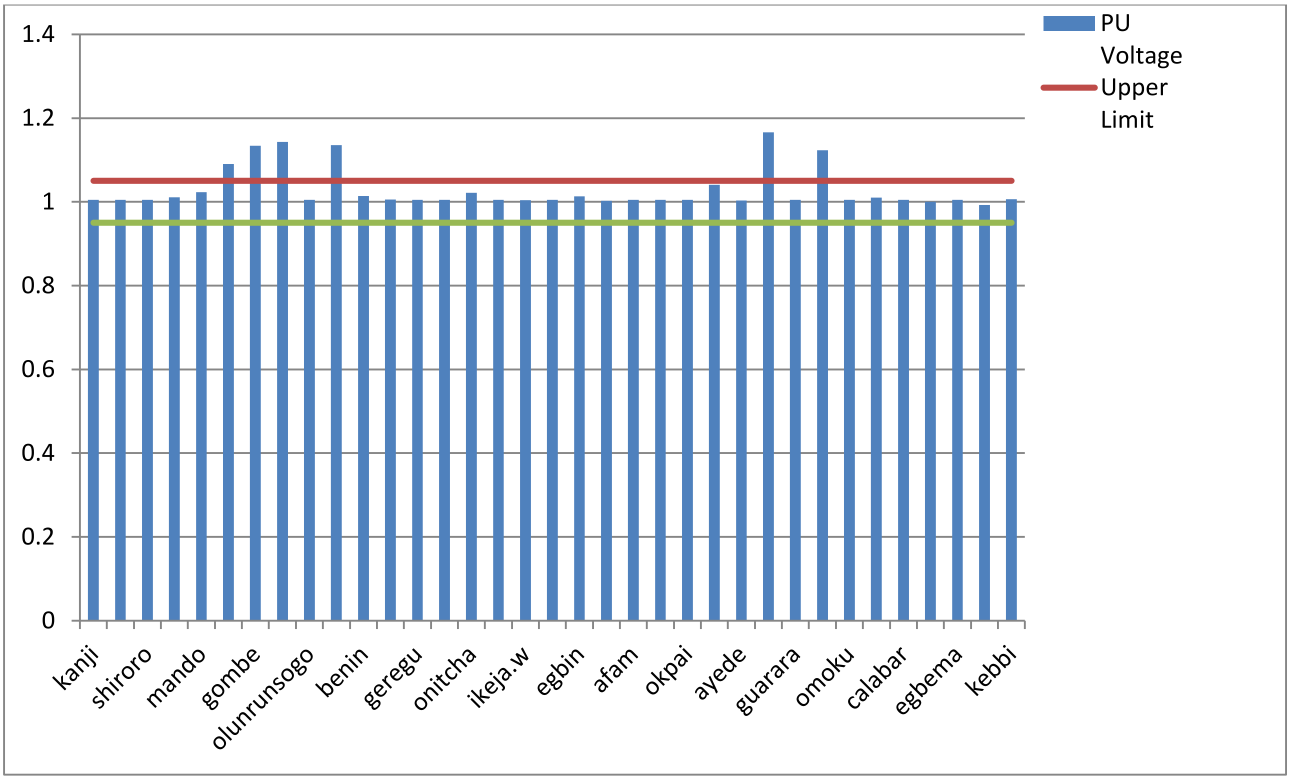

Fig 7. PU voltage When the generator at Mambilla was shutdown

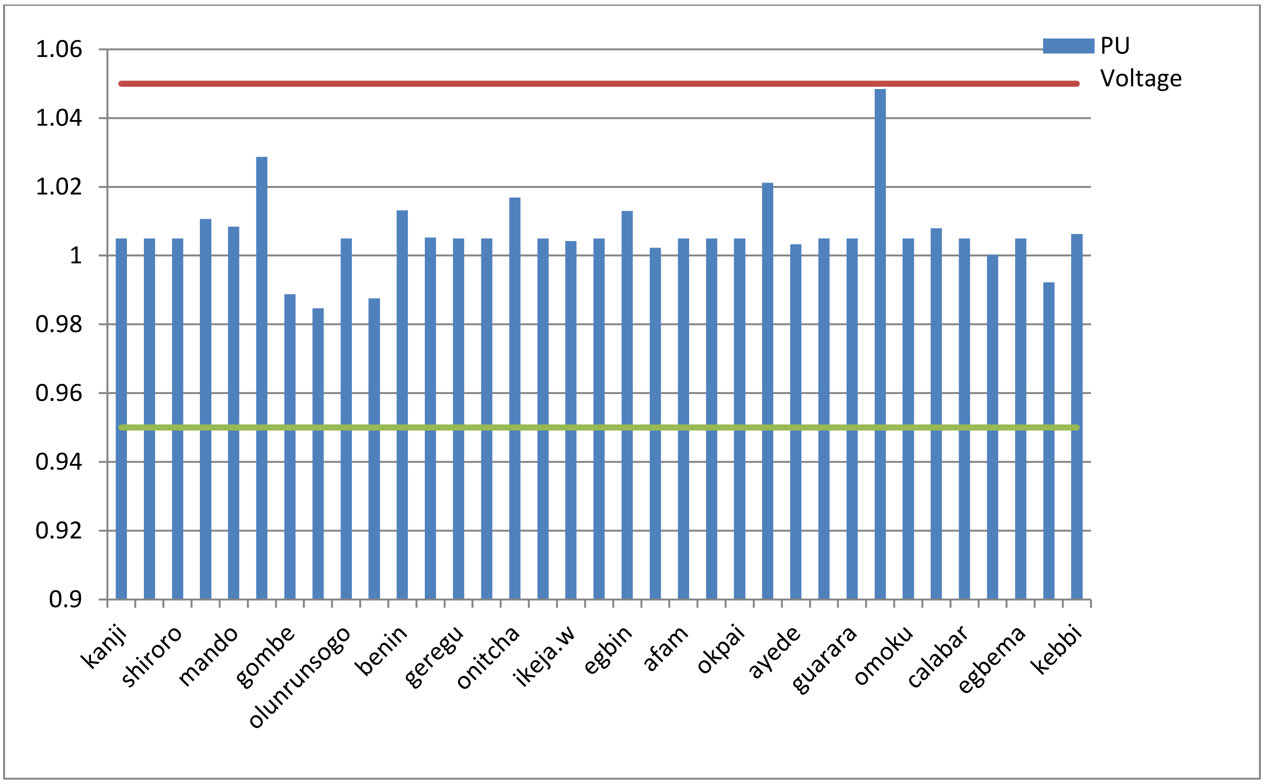

Fig 8. PU voltage: Fortified Jos – Gombe line (When a line was opened)

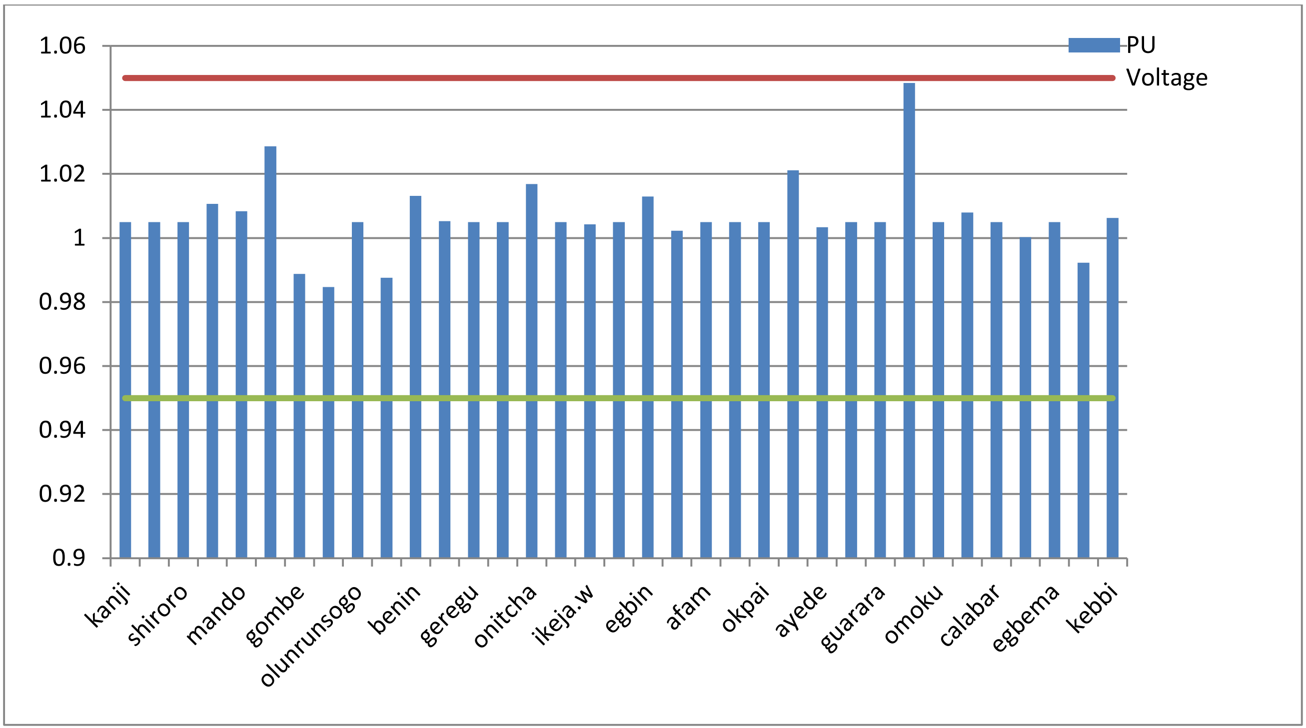

Fig 9. PU voltage: Fortified Damaturu – Mambilla line (When a line was opened)

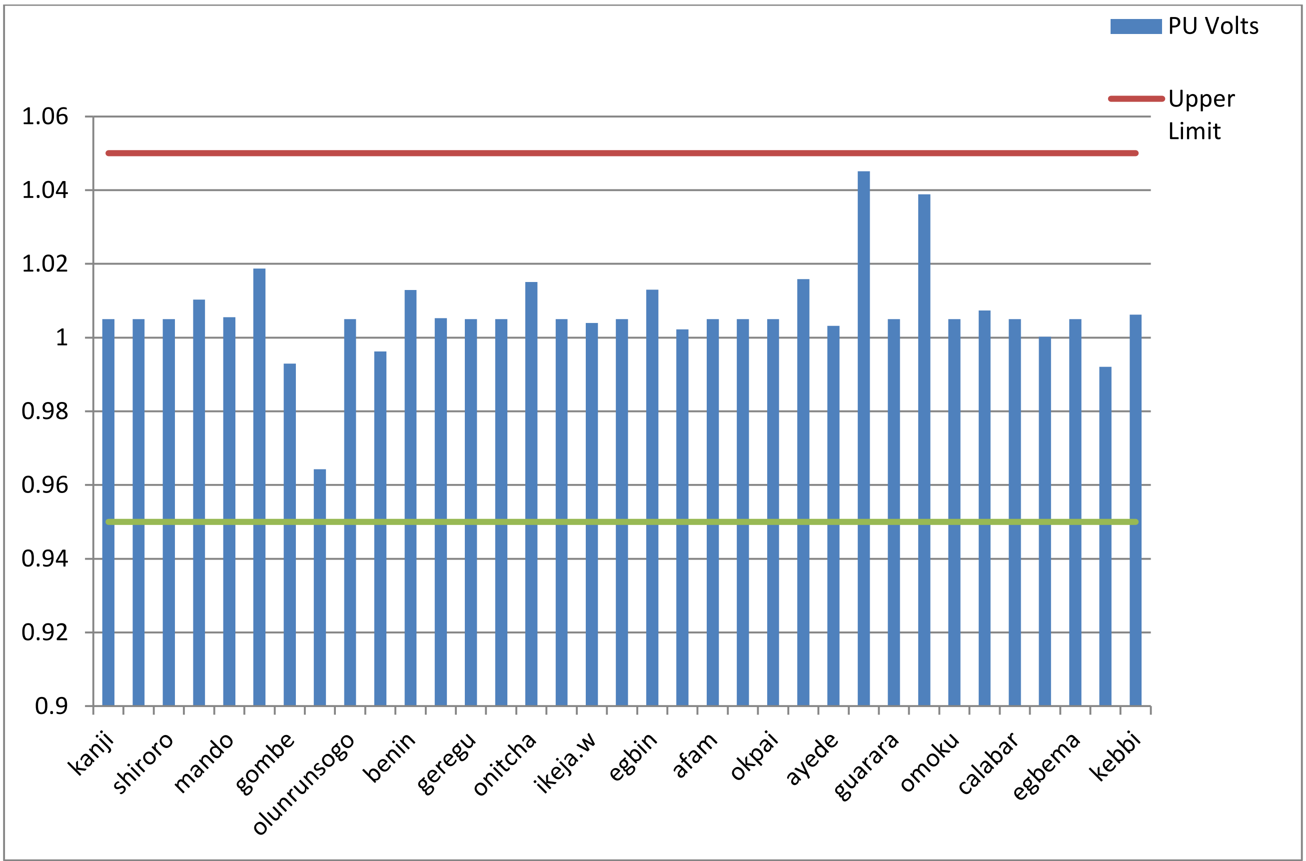

Fig 10. PU voltage When generator at mambilla was shut down, with addition of shunt reactors at vulnerable buses.

INFERENCE TO RESEARCH AND PRACTICE

Two major types of failure events that affect the power system mostly are transmission line outage and generation unit failures. Transmission line failures cause changes in the flows and voltages on the transmission equipment remaining connected to the system. Therefore, these analyses of transmission failures predict these flows and voltages to determine if they are within their respective limits. Generator failures can also cause power flow and voltages to change in the transmission system, with the addition of dynamic problems involving system frequency and operator output. So the research aims at improving the performance of the electric power system operations by adopting modern technology to aid in contingency analysis based on optimization on computation time and appropriate decision making. Also to minimize cost of maintenance, loss in revenue and prevention of large part or the entire power system from blackout by proffering suggestions on required infrastructure that can improve the reliability of the network operation based on these results obtained.

The importance of this analysis also includes:

- **Improving system reliability:** In a developing country like Nigeria, we are already facing huge amount of load shedding. There have been a number of reforms in the power sector in Nigeria. But currently, government reforms have failed to bring desired improvements in the power sector. On the other hand, we are losing transformers and generators from security violation or from some overload problems, or a bus voltage outside the limit. It means that if we are not able to maintain our existing generators or network properly it might be a great loss of our valuable property. With the help of contingency analysis we will be able to know the ranking, which helps us to know the amount of losses for any fault in bus, generator, transformer and transmission line. So we must have to be aware to solve the problem before they arise.

- **For future planning and expansion:** If fault occurs in any transmission line then the load flows through the rest of the lines in the system and this process will increase pressure on those lines. From this analysis such problems can be avoided by designing parallel lines. Thus contingency analysis helps us during transmission lines expansion and improves future power system performance.

CONCLUSION

A security analysis study which is run in an operations centre must be executed very quickly in order to be of any use to the operators. The problem of studying thousands of possible outages becomes very difficult to solve if it is desired to present the results quickly. So it is very important to have a system which can detect the possible future outages and prioritize among them to determine the most critical cases for detailed analysis. This is done by Contingency Analysis which allows operators to be better prepared to react to outages by using pre-planned recovery scenarios.

From the network and from the results obtained, it is noted that, though the post-reform Nigeria 330kv grid system is more complex and difficult to analyse, there are fewer violations in the system during contingencies when compared to previous works done on the pre-reform grid. This is as a result of the availability of more than one transmission link between most stations (buses) in the system.

It is also noted that though parameter changes were always observed on lines and buses during contingencies, most severe violations were noted in areas with single circuit transmission line between the buses.

With these observations, direct corrective actions were planned and recommended for the power system network.

FUTURE RESEARCH

Contingency analysis of double components and above, in the transmission grid can be taken up for further studies and analysis.

On evaluating the country's power system, majority of the large outages which are very frequent in all parts of the country are caused by more than single line (N-1) outage contingencies. For example, the incidents in the following reports:

"Power Transmission Towers destroyed by Tanker Fire in Delta" Information Nigeria online newspaper, Tuesday 11th March, 2014.

"150MVA, 330/132/33kV power transformer at Oshogbo transmission station gutted by fire" Information Nigeria online newspaper, 9th March 2014.

Also at the same period, most Power generators to the grid were shut. Therefore a research on this type of contingencies is necessary.

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