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Expansion Planning for Nigeria's South East Electric Power Transmission Network

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ABSTRACT
Nigeria's power system rank one of the most unstable. That is why the federal government is making frantic effort to improve its reliability through massive expansion programme. In this paper, the south east grid network is singled out for study and analysis, with the view of making it very reliable. Power world simulator software was used for the study and analysis. At the end, some lines were recommended for doubling which are Afam-Alaoji, Benin-Onitsha, Sapele-Benin and Onitsha-Alaoji. The transmission lines were assumed to be single circuits for the analysis. The.

KEY WORDS: *Power system, line violation, contingency analysis, over-load, simulation. network shows that Sapele-Benin and Afam-Alaoji have been made double circuits; therefore, the remaining circuits to be doubled are Onitsha-Alaoji and Benin-Onitsha transmission lines. It is expected that the new lines will strengthen the grid robustness and also reduce the frequent incidents of avoidable system collapses*

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I. INTRODUCTION

The electric power system in Nigeria is continually undergoing changes as a result of consistent increase in power demand. In most cases, the system fails to retain its stability when there is a sudden outage of one of its component. This invariably affects the power quality delivered by the system.In a typical power system, the supply of electricity to load center is carried out by three main processes, generated power at the generating stations will be transferred to the distribution centers through the high voltage transmission network. At the distribution station, the electrical power is reduced to lower voltage level to serve low voltage consumers. Due to the growing electricity consumption and expected renewable energy integration, the transmission network expansion planning is required to facilitate alternative paths for power transfer from power plants to load centers during emergencies. This expansion need to be done urgently and properly. Therefore, the transmission network expansion planning is defined as the problem of determining where to locate new transmission lines, when and how much additional new capacity must be installed over the planning horizon so that the network meet optimal operational, economical, technical and reliability criteria of the future power demand. Different techniques have been adopted in solving transmission expansion planning, but none have given a satisfactory solution. Some of the techniques include branch and bound, sensitivity analysis, bender decomposition, simulated annealing, genetic algorithms, tabu search and greedy randomized adaptive search procedure (GRASP) [1-5]. Transmission expansion planning is usually performed after generation expansion planning since it is different to obtain the optimal solution for a realistic system considering both generators and transmission lines simultaneously. In this paper, a methodology is proposed for choosing the best transmission expansion planning using contingency criterion.

II. CONTINGENCY ANALYSIS OVERVIEW

Evaluation of power system security is necessary in order to develop ways to maintain system operation when one or more elements fail. A power system is "secured" when it can withstand the loss of one or more elements and still continue operation without major problems. Contingency analysis is one of the "security analysis" applications in a power utility control center. Its purpose is to analyse the power system in order to identify the overloads and problems that can occur due to "contingency"In network planning, contingency analysis is used to examine the performance of a power system and the need for new transmission expansion due to load growth or generation expansion. Contingency analysis provides tools For managing, creating, and reporting list of contingencies and associated violations. In general, the quality of a power system is determined by its ability to meet the expected demand under different contingency conditions.

Contingency analysis is used as a study tool for the off-line analysis of contingency events, and as a tool to show operators what would be the effects of any failure or outage. This will equip the system planners with the best location for new transmission lines to compensate for overloads during contingency situations. The under listed points were considered during this contingency analysis:

- Security is determined by the ability of the system to withstand equipment failure
- Weak elements are those that present overloads in the contingency conditions (congestion)
- Standard approach is to perform a single (N-1) analysis simulation
- A ranking method will be used to prioritize transmission planning

III. CLASSIFICATION OF CONTINGENCY

Contingency analysis is an abnormal condition in electrical network. Most times, power system are operated under stressed conditions and thus leading to transmission systems working closer to their limit.

Contingency can occur due to

- Sudden opening of transmission line
- Generator tripping
- Sudden change in generation
- Sudden change in load value

In this work, contingencies that may occur due to sudden opening of transmission line and generator tripping were considered, and overload/violations were also checked.

IV. EVALUATING TRANSMISSION NETWORK SECURITY IN NIGERIA.

The Nigeria power system is currently suffering from inadequate generation and transmission capacity. The demand is much higher than the generated power, and this has led to constant load shedding and erratic power supply. The transmission network is mostly radial and is not sufficient to transfer the additional power injected to the grid by the new power plants.Typical steady-state system security demands the following: (i)No loss of load, (ii) bus voltages within power quality bands, (iii) transmission flows within thermal limits and (iv) system operation at a safe margin from static voltage collapse. Long term design of system expansion is facilitated when there is high demand during a contingency. Contingency analysis enables the determination of quasi-optimal transmission topologies. National Electrical Regulatory Commission (NERC) requires that systems be designed and operated to withstand N-1 and certain critical N-2 or greater contingencies.

V. MATERIALS AND METHODS

Power world was a major tool to achieve the solution of the power flow problem (power world co-operation, 2006)[7]. The 11 bus network of the south east network in Nigeria was modeled in the edit mode of power world simulator. The network has a total number of 11 buses (6 generator buses and 11 load buses)

VI. LOAD FLOW SOLUTION

The buses that were used in power world simulator were classified as load buses, generator buses and slack bus(Meier,2006)[8], which is similar to PV bus but take the slack in power flows so as to achieve convergent solution. Power flow problem starts with a single line diagram of the system, from which computer solutions can be achieved. Data for the simulation include bus data, transmission line data and generator data which are shown in appendix A. Computer simulation was used to obtain the solutions to network power flow based on the newton-raphson technique in power world run mode.

Load Flow Problem

The complex power injected by the source into the ith bus of a power system is

$$S_i = P_i + jQ_i = V_i I_i \quad (1)$$

i = 1,2, - - - -, n

Taking the complex conjugate of the above equation

$$P_i - jQ_i = V_i I_i \quad (2)$$

i = 1,2, - - - n

Substituting

$$I_i = \sum_{k=1}^{n} (Y_{ik} V_k)$$

from eq 1.0 in Eq 2.0 above, we have

$P_i - Q_i = V_i [\sum_{k=1}^{n} Y_{ik} V_k]$ wherei=1,2---n

Equating real and imaginary parts, we get

$$P_i (Real\ power) = Real \left[V_i \left(\sum_{k=1}^{n} Y_{ik} V_k \right) \right] \quad (3a)$$

$$Q_i (Reactive\ power) = -Imaginary \left[V_i \left(\sum_{k=1}^{n} Y_{ik} V_k \right) \right] \quad (3b)$$

$Let\ V_i = |V_i| e^{j\delta_i},\ V_k = |V_i| e^{j\delta_k},\ Y_{ik} = |Y_{ik}| e^{j\theta_{ik}}$; Then

$$P_i (Real\ Power) = |V_i| \sum_{k=1}^{n} |V_k| |Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i) \quad (4a)$$

$$Q_i (Reactive\ power) = -|V_i| \sum_{k=1}^{n} |V_k| |Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (4b)$$

Where (i = 1,2, - - - -n)
Equation 4.0a and 4.0b are called power flow equations.

VII .CONTINGENCY ANALYSIS

Contingency analysis is a method by which we can predict steady state bus voltages and line currents in a power system following switching on or off a line in the system [9]. The method does not require the exact values of voltages and currents, it rather assess the approximate values to check whether the system, components and buses will be overloaded or will face under/overvoltage following switching on or off the prescribed line. Contingency analysis frequently uses [Z_{Bus}] and loads are assumed to be treated as constant current injectors. Removing a line is treated as adding negative impedance. A generalized method of developing an algorithm for addition of line is given below [9].

ADDITION AND REMOVAL OF LINES IN POWER SYSTEM

Let
V_1, V_2, - - - - V_N = bus voltage in P.U in the network,
I_1, I_2, - - - -., I_N = known current (PU) injections at respective buses
Z_x and Z_y = P.U impedance of lines to be added in the system between buses i – j and k – l respectively
I_x and I_y = current (P.U) in branches Z_x and Z_y respectively
$[V^1_1, V^1_2, - - - -, V^1_N]^T$ = bus voltages in P.U in the same power network after addition of Z_x and Z_y in the network
Therefore [V] = [Z_{Bus}] [I] $[V] = [Z_{BUS}][I] \quad (5)$

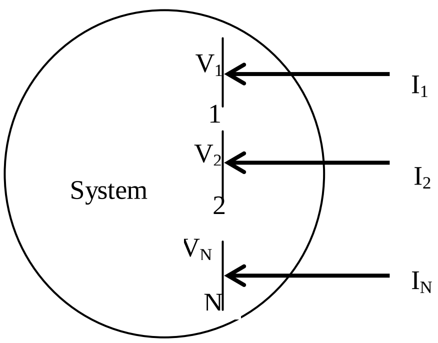


Fig 1.0a: Original System

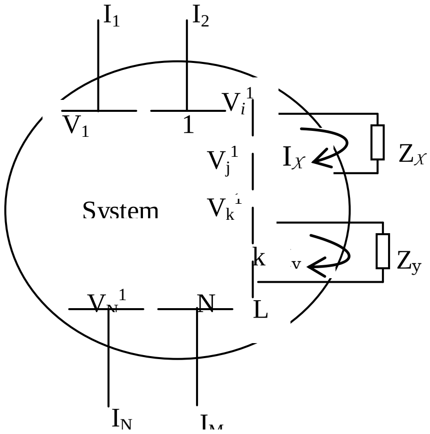


Fig 1.0b: Z_X and Z_y are added to the system

Fig 1.0a represents the original system while fig 1.0b represents the system after Z_X and Z_y were added at the designated buses.The equation below gives the general guideline for contingency analysis.

$$\left[\left\{\frac{(Z_{JI}-Z_{IJ})}{(Z_{KI}-Z_{KJ})}\;\frac{-(Z_{JI}-Z_{JJ})+Z_X}{-(Z_{LI}-Z_{LJ})}\;\middle|\;\frac{(Z_{JI}-Z_{IJ})}{(Z_{KK}-Z_{KL})}\;\frac{-(Z_{JK}-Z_{JL})}{-(Z_{LK}-Z_{IL})+Z_Y}\right\}\right]\begin{bmatrix}I_X\\ I_Y\end{bmatrix}$$

$$=\begin{bmatrix}V_I & -V_J\\ V_K & -V_L\end{bmatrix} \quad (6)$$

VIII RESULTS AND DISCUSSIONS

The following were considered in analyzing the state of the network

Bus voltages to check whether they were within the allowable voltage tolerance limits of $\pm$5% (0.95$\leq$ V_i 1$\leq$ 1.05PU).Percentage apparent power (MVA) loading of the transmission lines with a view to determine the lines that are underutilized or congested in the system.

IX CASE STUDY WITH AN 11 BUS IN SOUTH EAST 330KV NETWORK.

Here an 11 bus, 330kv network in the south eastern Nigeria was created and run in power world simulator. The eleven bus system was selected to demonstrate the use of contingency screening method using load flow to check the behaviour of the line with single line and single generator contingencies in order to determine the best plan for new transmission lines. The system consist of 11 buses, 5 of them are generator buses and 6 transmission lines buses. The A.C load flow using Newton–Raphson method was used in the analysis. The data for the study is from PHCN daily operational report of 09/08/2012 which is shown in appendix A.Load flow was run on the network to ascertain the behavior of the network at base case. The load flow results show that there was no violation in the bus voltage and the transmission line MVA rating. The results were within the limits of operation.

Figure 2 shows the network at run mode in power world simulator

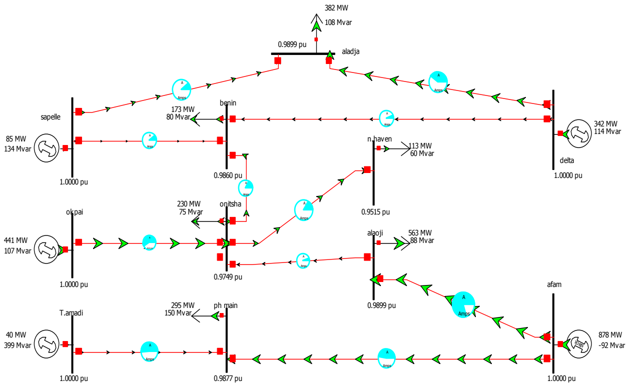


Fig 2.0: The network at run mode

(a) SINGLE TRANSMISSION LINE CONTINGENCY TEST

After running the network at base case, a contingency was inserted into the network to check the performance during outage/failure of the components (generators and transmission line). The first contingency that was inserted was the single line contingency test and the effect on the network is given in table1.

Table 1.0: Single transmission line contingency test in the network.

Label	Skip	Processed	Solved	Violations
L_000001sapelle-000005beninC1	NO	YES	YES	1
L_000011aladja-000001sapelleC1	NO	YES	YES	0
L_000002okpai-000006onitshaC1	NO	YES	YES	3
L_00003T.amadi-00007phmainC1	NO	YES	YES	1
L_000007phmain-000004afamC1	NO	YES	YES	0
L_000009alaoji-000004afamC1	NO	YES	YES	3
L_000005benin-000006onitshaC1	NO	YES	YES	1
L_000005benin-000010deltaC1	NO	YES	YES	0
L_00006onitsha-00008n.havenC1	NO	YES	YES	0
L_000006onitsha-000009alaojiC1	NO	YES	YES	1
L_000011aladja-000010deltaC1	NO	YES	YES	0

From the table, it shows that a total of **11** contingency tests were performed, giving rise to **9** violations.**1** violation was recorded on the transmission line with high % MVA limit, while **8** violations were recorded on the buses with low limit voltage. The use of contingency selection/screening now helped in singling out those conditions that led to violations.

(b) SINGLE GENERATOR CONTINGENCY TEST

Having selected the contingencies that led to violations in the single line contingency test, we now insert the single generator contingency to also screen out the conditions that would lead to violation. Table2 shows the network violations when single generator contingency was inserted
.

Table 2.0: single generator contingency test on the network

Label	Skip	Processed	Solved	Violations
G_000001sapelleU1	NO	YES	YES	1
G_000002okpaiU1	NO	YES	YES	4
G_000003T.amadiU1	NO	YES	YES	2
G_000004afamU1	NO	YES	YES	6
G_000010deltaU1	NO	YES	YES	2

From Table3, it shows that a total of **5** contingencies were inserted, giving rise to **15** violations. **5** violations were recorded on the MVA loading of the transmission lines, while **10** violations were recorded as the bus voltage limit violation. The entire generator contingency led to violations which can be bus voltage limit, transmission line overload violations or both at a time. No contingency selection was done in this case, since the entire single generator contingency led to different violations.

VII. DISCUSSIONS

Having seen the effects of these contingencies on the network, we now start planning on how to alleviate these overloaded lines in contingency situations. Table 3 gives the summary of the results obtained during the contingency test carried out on the transmission line and generators.

Table 3.0: summary of results obtained during contingency.

S/N	Contingency considered	Overloaded line	%MVA loading	Bus violated	Bus voltage in p.u
1	Sapelle-benin	-	-	8(New heaven)	0.94687
2	Okpai-Onitsha	Alaoji-Afam	141	6(Onitsha) 8(new heaven)	0.9234 0.8985
3	Trans-amadi-P.H main	-	-	7(P.H main)	0.93458
4	Alaoji-Afam	-	-	6(Onitsha) 8(New heaven) 9(Alaoji)	0.90066 0.8751 0.75858
5	Benin-Onitsha	-	-	8(New heaven)	0.94825
6	Onitsha-Alaoji	-	-	8(New heaven)	0.94698
7	Shut down generator at sapelle	-	-	8(New heaven)	0.94684
8	Shut down generator at okapi	Alaoji-Afam	135.3	2(okapi) 6(Onitsha) 8(New heaven)	0.92705 0.92704 0.90229
9	Shut down generator at Trans-amadi	-	-	3(Trans-amadi) 7(P.H. main)	0.93459 0.92459
10	Shut down generator at Afam	Sapelle-benin Benin-onitsha Onitsha-	113.2 117.6 124	6(Onitsha) 8(New heaven) 9(Alaoji)	0.91132 0.88609 0.93664

		Alaoji			
11	Shut down generator at delta	Alaoji-Afam	121	8(New heaven)	0.94028

The summary of the contingency analysis given in table3 indicates that **4** transmission lines were overloaded during the contingency test. The affected lines were Alaoji-Afam, Sapelle-Benin, Onitsha-Benin and Onitsha-Alaoji. The most overloaded line was Alaoji-Afam, followed by Onitsha-Alaoji, Benin-Onitsha and Sapele-Benin.

Fig3 shows the maximum percentage loading of the line before adding new lines during a contingency test on the selected components (generators and transmission line)

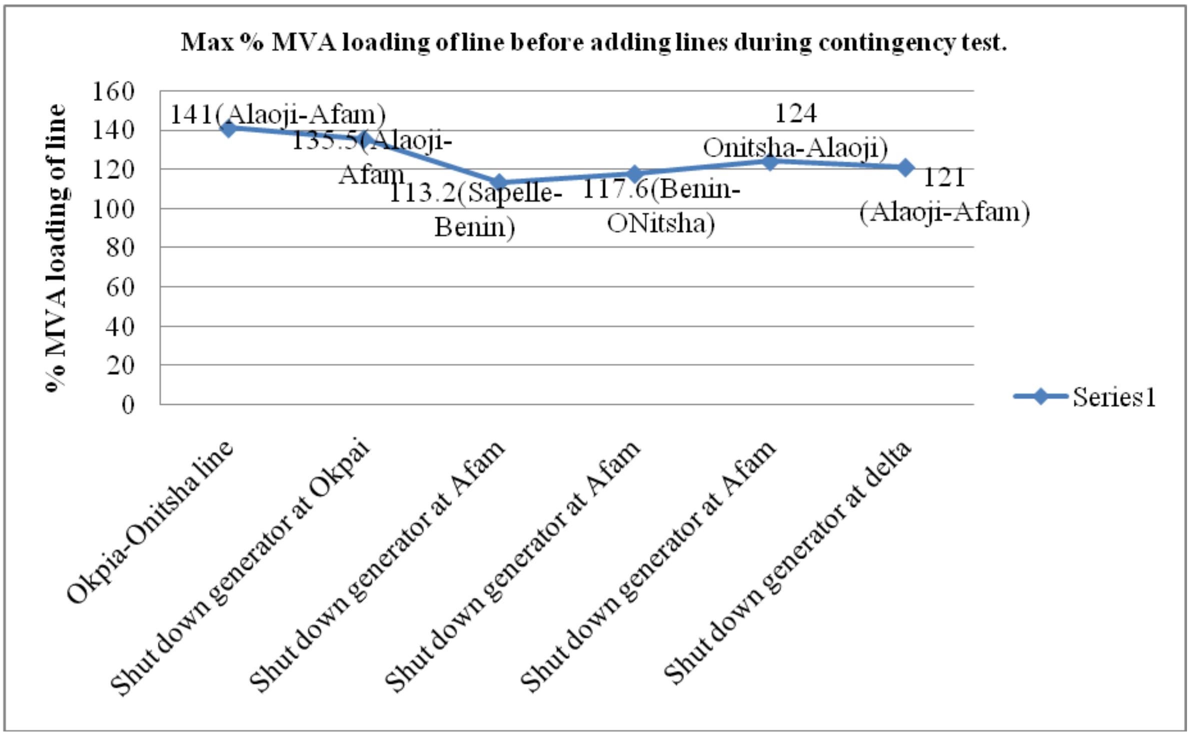


Fig 3.0: Max % MVA loading of line before adding new lines during contingency test

REMEDIAL ACTIONS-TRANSMISSION EXPANSION PLAN

T achieve reliability, four new lines have to be added to the network in the order of priority given in table4..

Table 4.0: New lines to be added to the network to alleviate the overloaded lines

Priority of adding lines	1	2	3	4
List of new lines considered	Alaoji-afam	Onitsha-Alaoji	Benin-Onitsha	Sapelle-Benin

The line data in appendix **A** show that, the lines between **Alaoji-Afam** and **Sapelle-Benin** has been made double line circuits. Therefore, the remaining lines to be doubled are the **Onitsha-Alaoji** and **Benin-Onitsha** circuits, since they are still single line circuits. The **Benin-Onitsha** second transmission line is nearing completion. The new transmission lines were added one after another in their order of priority to alleviate the overloaded lines during contingency. Contingency test was also carried out after addition of the lines to see the effect on the network. The addition of the new transmission lines recorded no overload when the system was subjected to single transmission line and single generator contingency. Also the low voltage limits experienced in the buses were corrected and the voltages were within the tolerance limit of 0.95pu. Table4shows the contingency selection results when single transmission line and single generator contingency were inserted into the network after adding the new transmission lines.

Table 5.0: Single line transmission contingency inserted into the network after adding the new lines

Contingency Selection Records

Label	Skip	Processed	Solved	Violations
L_000001sapelle-000005beninC1	NO	YES	YES	0
L_000001sapelle-000005beninC2	NO	YES	YES	0
L_000002okpai-000006onitshaC1	NO	YES	YES	0
L_000003T.amadi-000007phmainC1	NO	YES	YES	0
L_000005benin-000006onitshaC1	NO	YES	YES	0
L_000005benin-000010deltaC1	NO	YES	YES	0
L_000006onitsha-000005beninC2	NO	YES	YES	0
L_000006onitsha-000008n.havenC1	NO	YES	YES	0
L_000006onitsha-000009alaojiC1	NO	YES	YES	0
L_000006onitsha-000009alaojiC2	NO	YES	YES	0
L_000007phmain-000004afamC1	NO	YES	YES	0
L_000009alaoji-000004afamC1	NO	YES	YES	0
L_000009alaoji-000004afamC2	NO	YES	YES	0
L_000011aladja-000001sapelleC1	NO	YES	YES	0
L_000011aladja-000010deltaC1	NO	YES	YES	0

Table 6.0: Single generator contingency inserted into the network after adding new lines.

Contingency Records

Label	Skip	Processed	Solved	Violations
G_000001sapelleU1	NO	YES	YES	0
G_000002okpaiU1	NO	YES	YES	0
G_000003T.amadiU1	NO	YES	YES	0
G_000004afamU1	NO	YES	YES	0
G_000010deltaU1	NO	YES	YES	0

Fig4 shows the maximum percentage loading of the line after adding new lines during a contingency test on the selected components (generators and transmission line)

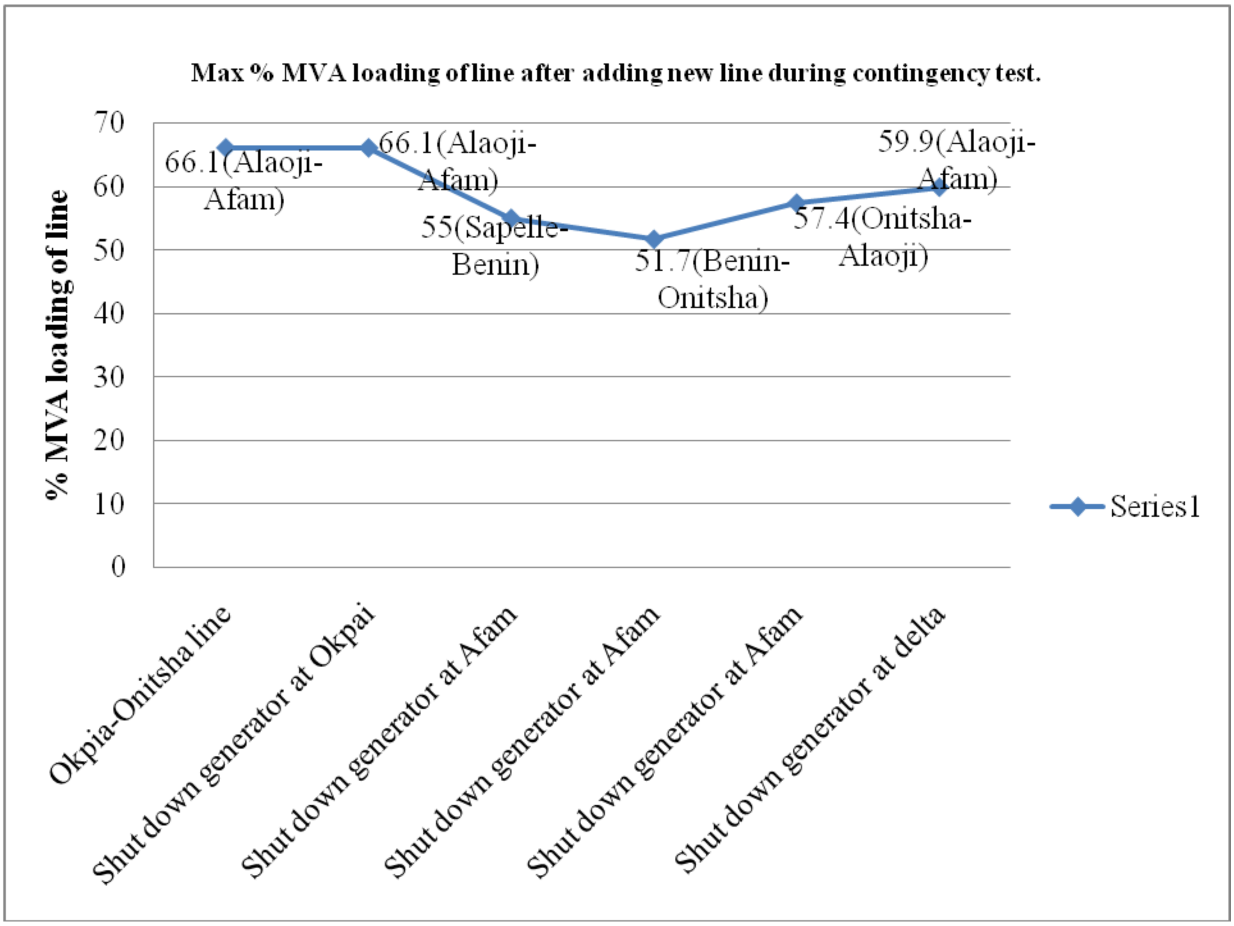


Fig 4.0: Max % MVA loading of line after adding new lines during a contingency test.

Finally, we compare the transmission line MVA of the overloaded lines before and after adding new lines during the contingency tests.

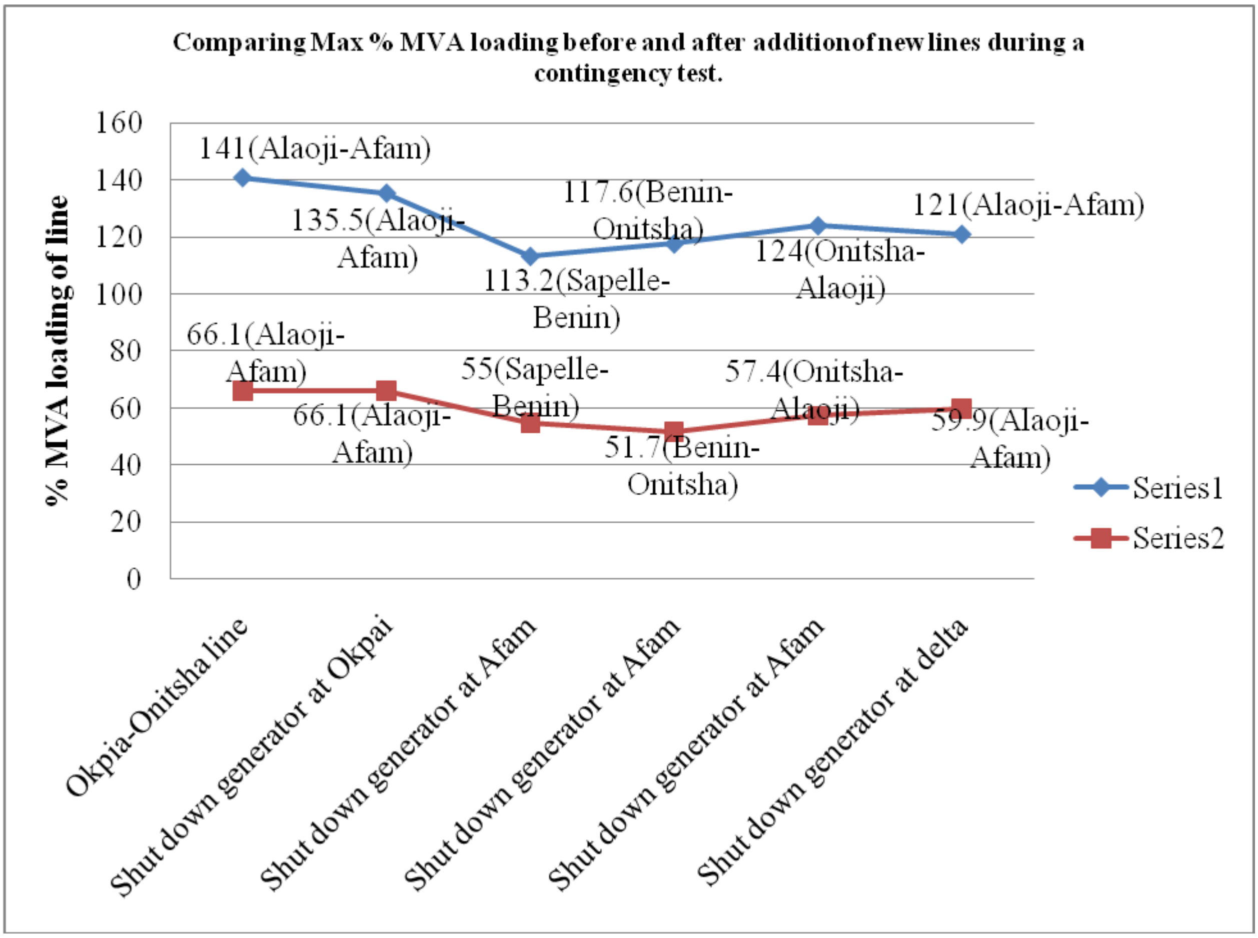
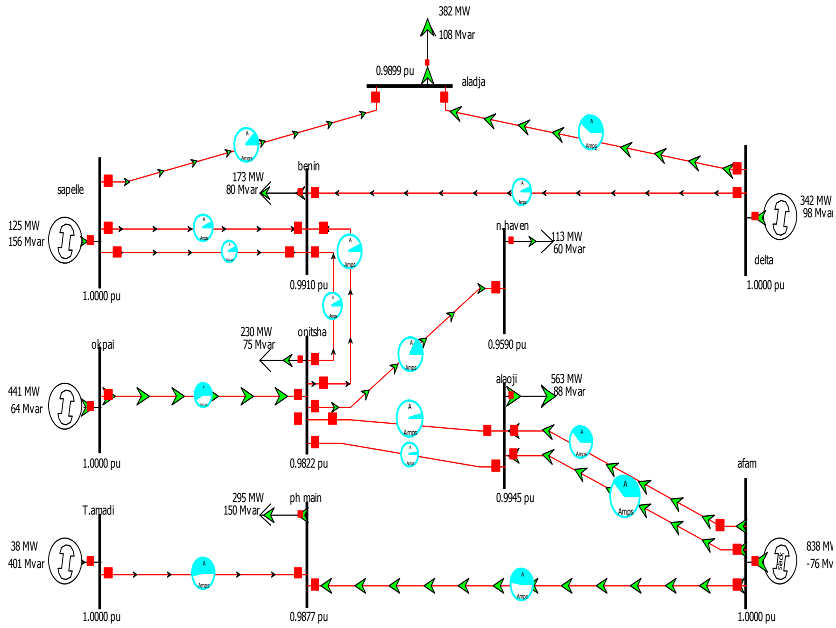


Fig 5.0: comparison of % MVA loading of line before and after adding of new lines

Also the figure below show network at run mode after the addition of the new lines.



A transmission network expansion planning methodology for choosing the best transmission expansion plan using contingency analysis is used to evaluate potential transmission system and helps in selecting the best plan for overall system security. The expansion plan obtained from the base case study may contain insecure configurations. To ensure the system reliability, the expansion plan is assessed by a list of credible single line outages, i.e the "N-I" criteria, using a base case A.C load flow. Should overload happen in any transmission line, best location from the list of possibilities are selected to reinforce the network. The security assessment is repeated until no overloading occurs in the system and the optimal plan is finalized. Three steps of the security assessment involve contingency screening, N-I checking, and selection of extra lines for reinforcement. Finally the best lines to enhance security and reliability are selected from the rest of the possible lines.There is a lot of savings in the cost of transmission network expansion due to the planning strategy adopted in this work. Contingency analysis method is the best way to select the location of new transmission lines. The results obtained during these tests were found to be good and, thus provide remedial actions.. Contingency analysis, which is run on the base case network, identifies the overloaded lines or elements with violations. From the series of contingency tests carried out, the overloaded lines were singled out in their order of severity of violations. Therefore new lines can now be introduced comfortably at the right locations. It is expected that the new lines will strengthen the grid robustness and also reduce the frequent incidents of avoidable system collapses.

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APPENDIX A

Table A1: Transmission line parameters for the south east 330kv network in Nigeria.

Line between buses and the number of circuits			Length of line(km)	Line impedance	
from	To	Circuit type		R(p.u)	X(p.u)
Onitsha	Alaoji	Single	138	0.0054	0.0408
Onitsha	New-heaven	Single	96	0.0038	0.0284
Benin	Onitsha	Single	137	0.0054	0.0405
delta	Benin	Single	107	0.0042	0.0316
Sapelle	Benin	Double	50	0.0009	0.0070
Okapi	Onitsha	Double	56	0.0005	0.0042
Afam	Alaoji	Double	25	0.0006	0.0043
Afam	P.h main	Single	38	0.0015	0.0112
P.H main	Trans-amadi	Single	10	0.0004	0.003
Sapelle	Aladja	Single	63	0.0025	0.0186
Delta	Aladja	Single	30	0.0009	0.0072

Table A2 **Existing power stations**

S/N	Name	Gen. MW	Gen. MVR
1	Delta PS	342.95	112.82
2	Okpai	441.57	104.84
3	Sapele PS	125.17	-61
4	Afam PS	457.12	148
5	Trans-Amadi	32.63	18