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Loadability Assessment of 330 kv Network for Contingency Expansion Planning for Improved Reliable Power Supply

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Abstract

The selections of line to be switched depends on system overload, this means that elimination of overloaded lines are key parameter for loadability assessment,. Load flow analysis shows that Nigeria power system classified and ranked as one of the unstable system. Since operating limit are based on certain criteria for voltage stability rating, transient stability rating, system voltage limit, power flow limit which must comply to statutory conditions in order to avoid system collapse. There are many ways in which system can be adjusted to compensate for an overloaded line. Previous researchers has shown that shift in generation or phase shifter adjustment can be calculated to correct an overload, these corrections are based on analytical solutions of the systems, however, many algorithms has been developed to use these techniques for load flow solutions. Evidently, effort has been made through PHEDC, PHCN, NERC, private and public practitioners and system planners and operators on the view to improve its reliability through co-existence expansion program.

This paper will adopt the application of Newton-Raphson load flow, impedance matrices techniques embedded in power world simulator software tool on the view to address contingency due to system loadability margin to access any form of violations that may result to system outages or failure. Single-line representation of the study case (Afam to Alaoji, Benin to Onitsha, Sapele to Benin and Onitsha to Alaoji) were characterized and represented .Selection of lines to be switched are proposed to be doubling the line overload for purpose of reinforcing for power quality and voltage profile. Essentially, the technique have the capacity to develop, identify overloaded lines to be removed in order to reduce the line overload in the power system, this means that line can be added or removed from the system on the view to cause a shift in the power flow in order to avoid network congestion.

Keywords: Transmission-line, contingency-analysis, power flow, expansion-planning.

1. Introduction

The assessment of electric power supply particularly Nigeria power system continually undergoing loadability evaluation as a result of constant increase in power demand margins and poor availability of electric power supply. Haven noted 330kv transmission network as super grid voltage, the grid network is an interconnection of the following dimensions 9.45km length of 330kv transmission lines consisting of twenty-two (22) generating stations, via a network flow of fifty-nine (59) buses and sixty-seven (67) transmission lines of dual or single circuit configuration with forty-eight (48) load buses been controlled centrally at Oshogbo with supporting center at (Benin, Shiroro and Egbin) respectively [1], [2].

Essentially, when system components fail, this may result into instability and outages in the network performance. This will invariably affects the reliability of power quality delivery to the end users. However, the activities of power flow processes are from generating station, been transmitted through high voltage transmission network to the distribution section up to the point of utilization. Following the exponential growing pattern of electricity consumption and system overload necessitates network expansions planning for contingency analysis on the view to create and facilitate alternative paths for maximum power transfer capability, for example a given power plant generation to the load center during emergency. This means that there should be strong need for expansion plan for contingency arrangements as soon as possible to avoid system collapse [3], [4]. Thus, the needs for transmission expansion through the addition of new lines (where? When? and What? new capacity needed to be installed over the planning period) thereby making provision for the network to meet optimal capacity, operational capacity, technical/reliable stability criteria for future power demand. Many researchers have engaged the application of optimal techniques through decomposition, sensitivity analysis and related algorithms, etc., on the view to determine where to locate new transmission lines capacity reinforcement to enhance better performance.

Consequently, it is a key necessity to obtain the optimal solutions for reliable power system operations for purpose of transmission expansion and planning which must be performed after generation expansion planning in order to secure optimal results independently. This technical paper will be achieved using contingency technique for transmission expansion planning [5].

2. Contingency Analysis Technique for Transmission Expansion Planning

Assessment and evaluation of system failures is an indication to develop ways to maintain system operation when network component fails. The tendency of power system to maintain and secure network condition for probable loss of one or more element in the network capacity in order to continue operation without network collapse is a necessary step for this analysis.

However, the contingency analyses tool have the veritable assessment properties to secure, identify any overloads and eventually plan for managing transmission expansion due to exponential loads growth, in order to avoid associated system violations. This tool have the capacity to show how system planner/operators will do in the events of probable changes for improved performance, in order to avoid the consequences of failure or outage. This will thus, provide the system planners and operators to have the best locations for new transmission lines to compensate for system overloads during emergency situation or circumstances [6], [7].

Removing a line from service can be simulated in the system model by adding the negative of the series impedance of the line between its two end buses. When considering line additions or removal from an existing system it is not always necessary to build a new Z_{bus} or to calculate new triangular factor of Y_{bus} matrix especially if the interest is to establish the impact of changes on the existing bus voltages and line flows. An alternative procedure is considered to the injection of compensating currents into existing system to account for the effect of the line changes [8], [9].

The formulation of this technique is to examine the steady – state effects of adding lines to an existing system using the developed mathematical formulation. The concept of injecting compensating currents is introduced in order to allow the existing system Z_{bus} formulation.

3. Load Flow Solution

The system components are classified as load buses, generator buses and slack bus respectively, which is similar to PV bus but take the slack bus in power flow in order to achieve convergent solution. Power flow problem starts with a single line diagram of the system, from which computer software application tool are simulated. Computer simulation was used to obtain the solutions to the network of power flow based on the Newton-Raphson technique in power world simulator software either in edit mode or run mode [10], [11].

4. Load Flow Problem

The complex power injected by the source into the ith bus is a power system given as;

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

$$i = 1.2. - - -, n$$

Taking the complex conjugate of given equation as;

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

$$i = 1.2. - - -, n$$

Substituting, to obtain as:

$$I_i = \sum_{k=1}^{n} (Y_{ik} V_k) \qquad (3)$$

From equation (1) into equation (2) above, to obtain as;

$$P_i - Q_i = V_i [\sum_{k=1}^{n} (Y_{ik} V_k)] \qquad (4)$$

Where $i = 1, 2 \dots, n$

Equating real and imaginary parts, to obtain as;

$$P_i(Real\ power) = Real\ [V_i(\sum_{k=1}^{n} (Y_{ik} V_k))] \quad (5)$$

$$Q_i(Reactive\ power) = -Imaginary\ [V_i(\sum_{k=1}^{n} (Y_{ik} V_k))] \qquad (6)$$

Let $V_i = |V_i| e^{j\delta i}, V_k = |V_i| e^{j\delta k}, Y_i = |Y_{ik}| e^{j\theta ik}$,

Then

$P_i(Real\ power) = |V_i| \sum_{k=1}^{n} |V_k|\,|Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i)$ (7)

$Q_i(Reactive\ power) = -|V_i| \sum_{k=1}^{n} |V_k|\,|Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i)$ (8)

Where $(i = 1, 2, \ldots, n)$

Equation (5) and (6) are called the power flow equations.

5. Model Formulation for Calculation of Zbus Elements from Ybus, in a Five (5) Bus System.

When the final numerical elements of Z_{bus} is not explicitly required from an application then the calculated elements of Z_{bus} are needed for the upper and lower triangular factors of Y_{bus} which are available. To analyses how this can be done consider the post multiplying Z_{bus} by a vector with only one non-zero element L=1in row m and all other elements equal to zero, where Z_{bus} is N/N matrix this can be presented as:

$$\begin{matrix}1\\2\\\vdots\\m\\\vdots\\N\end{matrix}\underbrace{\begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1m} & \cdots & Z_{1N}\\ Z_{21} & Z_{22} & \cdots & Z_{2m} & \cdots & Z_{2N}\\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots\\ Z_{ml} & Z_{m2} & \ddots & Z_{mm} & \ddots & Z_{mV}\\ \vdots & \vdots & & \vdots & & \vdots\\ Z_{Nl} & Z_{N2} & \cdots & Z_{Nm} & \cdots & Z_{NN}\end{bmatrix}}_{Z_m}\begin{bmatrix}0\\0\\\vdots\\L_m\\\vdots\\0\end{bmatrix} = \begin{matrix}1\\2\\\vdots\\m\\\vdots\\N\end{matrix}\begin{bmatrix}Z_{1m}\\Z_{2m}\\\vdots\\Z_{mm}\\\vdots\\\underbrace{Z_{Nm}}_{Z_{bus}^{(m)}}\end{bmatrix} \quad (9)$$

Thus in post multiplying Z_{bus} by the vector shown in the mth column matrix operation which are called the vector $Z_{bus}^{(m)}$ that is;

$$Z_{bus}^{(m)} \triangleq \begin{bmatrix}Column\\ of\\ Z_{bus}\end{bmatrix} = \begin{matrix}1\\2\\\vdots\\m\\\vdots\\N\end{matrix}\begin{bmatrix}Z_{1m}\\Z_{2m}\\\vdots\\Z_{mm}\\\vdots\\Z_{Nm}\end{bmatrix} \quad (10)$$

Since the product of Y_{bus} and Z_{bus} are equals to unit matrix then it becomes given as;

$$Y_{bus}Z_{bus}\begin{bmatrix}0\\0\\\vdots\\I_m\\\vdots\\0\end{bmatrix} = Y_{bus}Z_{bus}^{(m)}\begin{bmatrix}0\\0\\\vdots\\I_m\\\vdots\\0\end{bmatrix} \quad (11)$$

Similarly, if the lower-triangular matrix 'L' and the upper-triangular matrix 'U' of Y_{bus} are available, then equation (12) can be written as;

$$LUZ_{bus}^{(m)}\begin{bmatrix}0\\0\\\vdots\\I_m\\\vdots\\0\end{bmatrix} \quad (12)$$

It is important to note that the elements in the column $Z_{bus}^{(m)}$ can be found in equation (12) by forward elimination and back substitution operation, if only some of the elements of $Z_{bus}^{(m)}$ are required then the calculations can then be reduced accordingly, suppose it is required to generate Z_{33} and Z_{43} of Z_{bus} for a four-bus system, while using convenient notation for the elements of L and U given as;

$$\begin{bmatrix}L_{11} & . & . & .\\ L_{21} & L_{22} & . & .\\ L_{31} & L_{32} & L_{33} & .\\ L_{41} & L_{42} & L_{43} & L_{44}\end{bmatrix}\begin{bmatrix}L & U_{12} & U_{13} & U_{14}\\ . & L & U_{23} & U_{24}\\ . & . & L & U_{34}\\ . & . & . & L\end{bmatrix}\begin{bmatrix}Z_{13}\\Z_{23}\\Z_{33}\\\underbrace{Z_{43}}_{Z_{bus}^{(3)}}\end{bmatrix} = \begin{bmatrix}0\\0\\1\\0\end{bmatrix} \quad (13)$$

Evidently, it can be solve using this equation for $Z_{bus}^{(m)}$ in two steps as follows:

$$\begin{bmatrix}L_{11} & . & . & .\\ L_{21} & L_{22} & . & .\\ L_{31} & L_{32} & L_{33} & .\\ L_{41} & L_{42} & L_{43} & L_{44}\end{bmatrix}\begin{bmatrix}x_1\\x_2\\x_3\\x_4\end{bmatrix} = \begin{bmatrix}0\\0\\1\\0\end{bmatrix}$$

or

where; $$\begin{bmatrix}L & U_{12} & U_{13} & U_{14}\\ . & L & U_{23} & U_{24}\\ . & . & L & U_{34}\\ . & . & . & L\end{bmatrix}\begin{bmatrix}Z_{13}\\Z_{23}\\Z_{33}\\\underbrace{Z_{43}}_{Z_{bus}^{(3)}}\end{bmatrix} = \begin{bmatrix}x_1\\x_2\\x_3\\x_4\end{bmatrix} \quad (14)$$

by forward substitution equation (14) yields as;

$$\times_1 = 0,\ \times_1 = 0,\ \times_3 = \frac{1}{1_{33}},\ \times_4 = \frac{-L_{43}}{LL_{44}L_{33}} \quad (15)$$

By back substitution of this results into equation (15) in order to find the required elements of column 3 and Z_{bus}

$Z_{43} = \times_4$

$Z_{33} = \times_4 - u_{34}Z_{43}$ (16)

That is, if all element of $Z_{bus}^{(m)}$ are required , then the operations can be continued following the calculation process as;

$Z_{43} = \times_2 - u_{23}Z_{33} - u_{24}Z_{43}$

$$Z_{13} = \times_1 - u_{12}Z_{23} - u_{13}Z_{33} - u_{14}Z_{43} \qquad (17)$$

The computational effort in generating the required elements can be reduced by choosing the numbers.

However it is necessary to evaluate the terms $(Z_{im} - Z_{in})$ involving difference between column (m) and (n) of Z_{bus}. If the elements of Z_{bus} are not explicit, then it is possible to calculate the required differences by solving system of equations given as;

$$LUZ_{bus}^{(m)} \begin{bmatrix} 0 \\ \vdots \\ I_m \\ \vdots \\ -I_n \\ \vdots \\ 0 \end{bmatrix} \qquad (18)$$

Where; $Z_{bus}^{(m-n)} = Z_{bus}^{(m)} - Z_{bus}^{(n)}$ is the vector formed by subtracting column (n) from column (m) Z_{bus} of I_m and I_m = L in row m and $-I_n$ = −1 in row n of the vector column.

6. Adding and Removing Multiple Lines Consideration

Considering line additions or removals from an existing system it is not always necessary to build a new Z_{bus} to calculate new triangular factors for instance if the only interest is to establish the impact of the changes on the existing bus voltages and load flows then an alternative procedure is to consider the injection of compensating currents into the existing system to account for the effect of the line changes. To express this mathematically the basic concepts can be considered by adding to the lines of impedances Z_a and Z_b to an existing system with known Z_{bus}. This means that it is necessary to consider three or more lines addition [12], [13].

Suppose the impedance Z_a and Z_b are to be added between buses m-n and p-q respectively, as referred to figure 1 then assume that the bus voltages V_1, V_2 …, V_N are produced in the original system (without Z_a and Z_b) by the current injections I_1, I_2…, I_n which are known and this injection are fixed value and therefore are unaffected by the addition of Z_a and Z_b on a phase basis that bus impedance equations for the original system are then given as;

$V =$

$$\begin{bmatrix} V_1 \\ \vdots \\ V_m \\ V_n \\ V_p \\ V_q \\ \vdots \\ V_N \end{bmatrix} \begin{matrix} \\ 1 \\ 2 \\ \\ m \\ \\ N \\ \\ \end{matrix} \begin{bmatrix} Z_{11} & \cdots & Z_{lm} & Z_{ln} & Z_{iq} & \cdots & Z_{lm} \\ \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ Z_{ml} & \cdots & Z_{mm} & Z_{mn} & Z_{mq} & \cdots & Z_{mN} \\ Z_{nl} & \cdots & Z_{nm} & Z_{nn} & Z_{nq} & \cdots & Z_{nN} \\ Z_{pl} & \cdots & Z_{pm} & Z_{pn} & Z_{pq} & \cdots & Z_{qN} \\ V_{ql} & \cdots & Z_{qm} & Z_{qn} & Z_{qq} & \cdots & Z_{qq} \\ \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ Z_{Nl} & \cdots & Z_{Nm} & Z_{Nn} & Z_{Nq} & \cdots & Z_{NN} \end{bmatrix} \begin{bmatrix} I_i \\ \vdots \\ I_m \\ I_n \\ I_p \\ I_p \\ \vdots \\ I_n \end{bmatrix} \qquad (19)$$

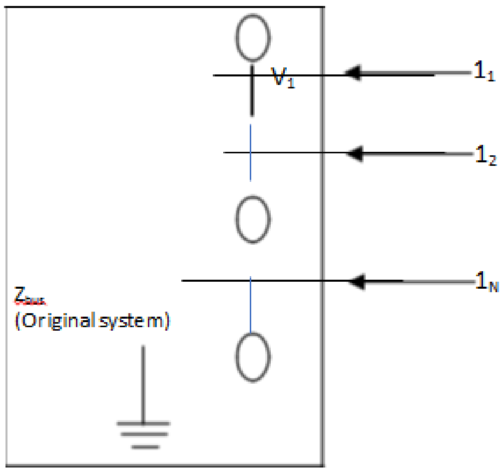

Fig. 1: System with voltages V_1, V_2…, V_N due to the current injections I_1, I_2,…I_N

Now in order to determine the changes in the bus voltage due to adding of two new line impedance. Let $V = (V_1, V_2, \dots, V_N)^T$ denoted as the vector of bus voltages which apply after Z_a and Z_b are been added. The voltage change at a typical bus (K) is then given as:

$$\Delta V_k = V_k^1 - V_k \qquad (20)$$

The currents I_a and I_b in the added branch impedance Z_a and Z_b are related to the new bus voltages by the equations given as;

$$Z_a I_a = V_m^1 - V_n^1, \text{ and } Z_b I_b = V_p^1 - V_q^1 \qquad (21)$$

Following vector matrix formation:

$$\begin{bmatrix} Z_a & 0 \\ 0 & Z_b \end{bmatrix} \begin{bmatrix} I_a \\ I_b \end{bmatrix} =$$

$$\begin{matrix} a \\ b \end{matrix} \begin{bmatrix} 0 & \dots & 1 & -1 & 0 & 0 & \cdots & 0 \\ 0 & \dots & 0 & 0 & 1 & -1 & \cdots & 0 \end{bmatrix} \begin{bmatrix} V_i^1 \\ \vdots \\ V_m^1 \\ V_n^1 \\ V_q^1 \\ \vdots \\ V_N^1 \end{bmatrix} = A_c V^1 \qquad (22)$$

Where A_c is the branch to node incidence matrix, which shows that the incidence of two new branches to the nodes of the system then the new branch currents I_a and I_b have the same effect on the voltages of the original system as two sets of injected currents $-I_a$ at bus (p), I_b at bus (q). This equivalent current injections combine with the actual current injections into the original system to produce the bus voltages $V_1, V_2 \dots, V_N$ the same as if the branch impedances Z_a and Z_b had been actually added to the network. In other words currents I_a and I_b are to compensate for not modifying Z_{bus} of the original system to include Z_a and Z_b on this account, are called compensating currents.

It can also be expressed using compensating currents in vector-matrix form as follows:

$$I_{comp} = \begin{matrix} 1 \\ \\ m \\ n \\ p \\ q \\ \\ N \end{matrix} \begin{bmatrix} 0 \\ \vdots \\ -I_a \\ I_a \\ -I_b \\ I_b \\ \vdots \\ 0 \end{bmatrix} = \begin{matrix} 1 \\ \\ m \\ n \\ p \\ q \\ \\ N \end{matrix} \begin{bmatrix} 0 & 0 \\ \vdots & \vdots \\ -1 & 0 \\ I & 0 \\ 0 & -I \\ 0 & I \\ \vdots & \vdots \\ 0 & 0 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \end{bmatrix} = A_C^T \begin{bmatrix} I_a \\ I_b \end{bmatrix} \quad (23)$$

The changes in the bus voltages from $V_1, V_2 \dots, V_N$ to $V_1^1 \dots, V_N^1$ can be calculated by multiplying the original system Z_{bus} by the vector I_{comp} (of compensating current). Adding $Z_{bus}\, I_{comp}$ to the vector V of existing bus voltages yields.

$$V^1 = V + Z_{bus}\, I_{comp} = V - Z_{bus}\, A_C^T \begin{bmatrix} I_a \\ I_b \end{bmatrix} \quad (24)$$

The equation shows that the changes at the buses of the original system due to the addition of the branch impedance Z_a and Z_b between the buses (m) – (n) and (p) – (q) respectively are given as:

$$\Delta V = V^1 - Z_{bus}\, A_C^T \begin{bmatrix} I_a \\ I_b \end{bmatrix} \quad (25)$$

Where I_a and I_b are the compensating currents, it is useful to check the dimensions of each term in equation (25) from which the voltage changes $\Delta V = V^1 - V$ can be calculated directly once the values for the currents I_a and I_b are determined. Thus this show how this can be determined. We now show how this determination can be made by pre-multiplying equ. (24) by A_c and then substituting for $A_c V^1$ from equ. (22), to obtain as;

$$\begin{bmatrix} Z_a & 0 \\ 0 & Z_b \end{bmatrix} \begin{bmatrix} I_a \\ I_b \end{bmatrix} = A_c V - A_c Z_{bus}\, A_c^T \begin{bmatrix} I_a \\ I_b \end{bmatrix} \quad (26)$$

Collecting terms which involve I_a and I_b which gives as:

$$\underbrace{\left(\begin{bmatrix} Z_a & 0 \\ 0 & Z_b \end{bmatrix} + A_c Z_{bus} A_C^T \right)}_{z} \begin{bmatrix} I_a \\ I_b \end{bmatrix} = A_c V = \begin{bmatrix} V_m & V_n \\ V_p & V_q \end{bmatrix} \quad (27)$$

When Z is a loop impedance matrix which can be formed directly from the original bus impedance matrix of the system, then solve equation (27) for I_a and I_b to find that;

$$\begin{bmatrix} I_a \\ I_b \end{bmatrix} = Z - 1 A_c V = Z_{-1} \begin{bmatrix} V_m & -V_n \\ V_p & -V_q \end{bmatrix} \quad (28)$$

That is $V_m - V_n$ and $V_p - V_q$ are open-circuit voltage drops between buses (m) – (n) and (p) – (q) in the original network, that is with branch impedances Z_a and Z_b open. These open-circuit voltages are either known or can be easily calculated from equation (19). The definition of matrix Z in equ. includes the term $A_c Z_{bus} A_C^T$ which can be determined as follows;

$$A_c Z_{bus} A_C^T = \begin{matrix} a \\ b \end{matrix} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \end{bmatrix} \begin{matrix} m \\ n \\ p \\ q \end{matrix} \begin{bmatrix} Z_{mm} & Z_{mn} & Z_{mp} & Z_{mq} \\ Z_{nm} & Z_{nm} & Z_{np} & Z_{nq} \\ Z_{pm} & Z_{pn} & Z_{pn} & Z_{pd} \\ Z_{qm} & Z_{qn} & Z_{qp} & Z_{qq} \end{bmatrix} \begin{matrix} m \\ n \\ p \\ q \end{matrix} \begin{bmatrix} 1 & 0 \\ -1 & -0 \\ 0 & 1 \\ 0 & -1 \end{bmatrix} \quad (29)$$

This equation shown only those elements of A_c and Z_{bus} which substitute to the calculations. Since all other elements of A_c are zeros. It is now necessary to display the full Z_{bus}. The indicated multiplication yield.

$$A_c Z_{bus} A_c^T = \begin{matrix} a \\ b \end{matrix} \begin{bmatrix} (Z_{mm}-Z_{nm})-(Z_{nm}-Z_{nn}) | (Z_m - Z_{mq}) - (Z_{np}-Z_{nq}) \\ (Z_{pm}-Z_{pn})-(Z_{qm}-Z_{qn}) | (Z_{pp}-Z_{pq})-(Z_{qp}-Z_{qq}) \end{bmatrix} \quad (30)$$

The diagonal element in the equation can be rearranged using Thevenin impedance Z_{thmn} and Z_{thpq} when looking into the original system between buses (m) – (n) and (p) – (q) respectively. This is,

$$Z_{thmn} = Z_{mn} + Z_{nn} - Z_{mn} - Z_{nm} \quad (31)$$

$$Z_{thpq} = Z_{pp} + Z_{qq} - Z_{pq} - Z_{qp} \quad (32)$$

Substituting from equation (30) into equation (27), we obtain as:

$$\begin{matrix} a \\ b \end{matrix} \left[\underbrace{\begin{matrix} (Z_{mm}-Z_{nm})-(Z_{nm}-Z_{nn}) | (Z_m - Z_{mq}) - (Z_{np}-Z_{nq}) \\ (Z_{pm}-Z_{pn})-(Z_{qm}-Z_{qn}) | (Z_{pp}-Z_{pq})-(Z_{qp}-Z_{qq}) \end{matrix}}_{z} \right]$$

or

$$X \begin{bmatrix} I_a \\ I_b \end{bmatrix} = \begin{bmatrix} V_m & -V_n \\ V_p & -V_q \end{bmatrix} \quad (33)$$

Which shows that the compensating currents I_a and I_b can be calculated by using the known bus voltage V_m, V_n, V_p and V_q of the original network and the elements of its Z_{bus}. Thus, equation (33) and (25) can be considered using two-step procedure for the closed-form solution of the voltages changes at the buses of the original system due to simultaneous addition of branch impedance Z_a and Z_b under the assumption of constant externally injected currents into the original system, first calculate the compensating currents using equation (33) and then substitute for these currents in equation (25) to find the new bus voltages which result from adding the new branches. The removal of branch impedances Z_a and Z_b from the original system can be analyzed in a similar manner simply by treating the removals as additions of the negative impedances $-Z_a$ and $-Z_b$. The elements in the 2 x 2 matrix of equation (30) can be calculated by using the appropriate elements of columns m, n, p, and q of Z_{bus}, or they can be generated from the triangular factors L and U of Y_{bus}.

7. Contingency Analysis Technique for Expansion Planning

Contingency analysis is a method by which system can predict steady-state bus voltages and line currents in a power system following switching on or off a line in the system. 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 within the set time or will face under/overvoltage following switching on or off the prescribed line. Contingency analysis uses [Z_{bus}] and loads are considered to assumed constant current injectors. Removing a line is treated as adding negative impedance. A generalized method of developing an algorithm for addition of line are given.

8. Addition and Removal of Lines in Power System Analysis

Let $V_1, V_2, \dots V_N$: bus voltage in P.U in the network.

$I_1, I_2, \dots I_N$: known current in (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 the branches Z_x *and* Z_y respectively.

$[V_1^1, V_2^1, \dots, V_N^1]^T$: bus voltages in P.U in the same power network after addition of Z_x *and* Z_y in the network.

Therefore,

$$[V] = [Z_{Bus}][I] \quad (34)$$

The equation below gives the general guideline for contingency analysis.

$$\left[\begin{Bmatrix} \frac{(Z_{Ji}-Z_{Ij})-(Z_{Ji}-Z_{Jj})+Z_x}{(Z_{KI}-Z_{KJ})-(Z_{LI}-Z_{LJ})} & \frac{(Z_{JI}-Z_{IJ})-(Z_{JK}-Z_{JL})}{(Z_{KI}-Z_{KJ})-(Z_{LI}-Z_{LJ})+Z_y} \end{Bmatrix}\right]\begin{bmatrix} I_X \\ I_Y \end{bmatrix} = \begin{bmatrix} V_I & -V_J \\ V_K & -V_L \end{bmatrix} \quad (35)$$

9. Case Study with South East Nigeria 330kv Network

The study case consist of 11 buses, 5 generators and 6 load buses was created for contingency analysis study to be simulated and run in power world simulator environment. The system under review was analyzed using load flow study (Newton-Raphson) to check the behavior of the line in order to determine the best plan for the transmission line for purpose emergency. The data set for the study case is obtained from PHCN database. The load flow study shows many violations in the bus voltage and transmission line apparent power (MVA) rating loadability in order to access the result within the acceptable limit of operation [7].

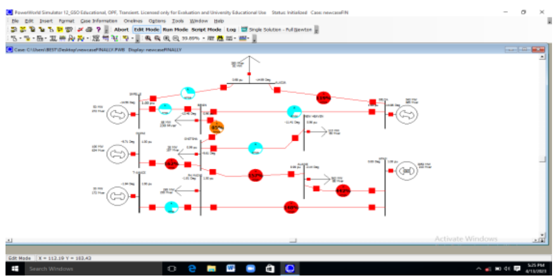

Fig. 2: Single representation of 11bus Nigeria South East 330kV network, using power world simulator

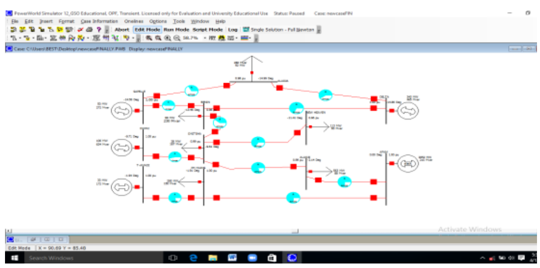

Fig. 3: Single-line representation simulated on run mode of 11bus Nigeria South East 330kV network, using power world simulator

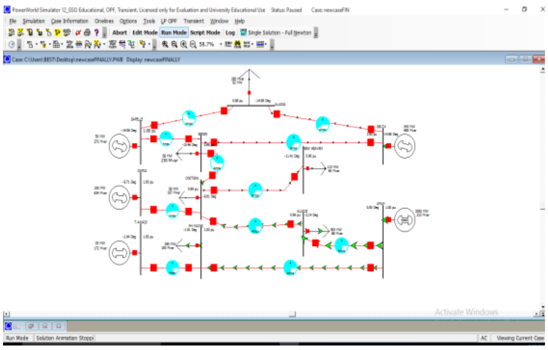

Fig. 4: Single-line representation simulated on edit mode of 11bus Nigeria South East 330kV network, using power world simulator

Table 1: Single-Line Representation for transmission line contingency investigation for system violation (reduced violation trend for transmission line insertion test)

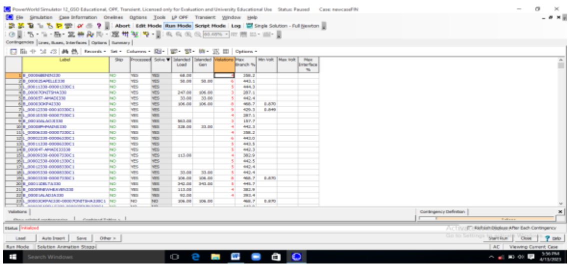

Table 2: Single-Line Representation for transmission line contingency investigation for system violation (reduced violation trend for transmission line insertion test), existing system parameters

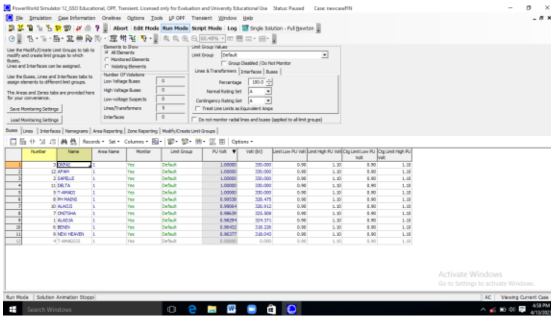

Table 3: Single-Line Representation for transmission line contingency investigation for system violation (reduced violation trend for transmission line insertion test), system showing degree of violations in the line overload

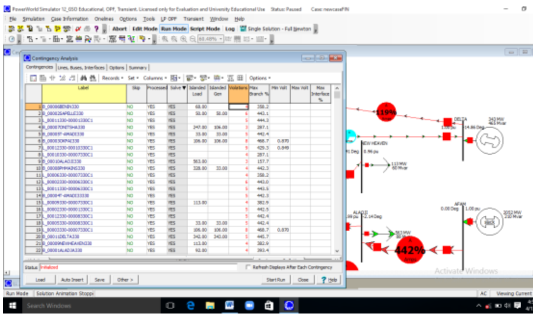

Table 4: Transmission Line Parameters for the South East 330kV Network in Nigeria.

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
Sapele	Benin	Double	50	0.0009	0,0070
Okapai	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

Sapele	Aladja	Single	63	0.0025	0.0186
Delta	Aladja	Single	30	0.0009	0.0072

Table 5: Existing Power Stations

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

The five (5) governing equations in line stability analysis with power flow equations are stated as;

Analysis 1: Fast voltage stability index (FVSI) given as;

$$FVSI_{ij} = \frac{4Z_j^2 Q_j}{V_i^2 (x_{ij})} \quad (36)$$

This analysis tool is considered for stable operation of the system that is the value of FVSI should maintained less than one (1) numerically.

Where,

Z_{ij}: Impedance between bus *i* and *j*

V_i: Voltage at sending-end

Q_{ij} Reactance at bus *i* and *j* respectively

Analysis 2: Line Stability Index (lmn)

According to Moghavemmi *et al.* (2019) proposes lmn based on power flow this is a single line representation of two-bus system, mathematically given as;

$$lmn = \frac{4X_{ij}Q_j}{V_i \sin(\theta_{ij} - \delta)} \quad (37)$$

That is the values of lmn close to one indicates that the system is losing its stability leading to voltage collapse.

Analysis 3: Line stability factor (LQP)

Essentially, according to Mohamed *et al* (2019) formulated LQP based on the same concept of power flow equations given as;

$$LQP = 4\left(\frac{X_{ij}}{V_i^2}\right)\left(Q_j \frac{P_i^2 X_{ij}}{V_i^2}\right) \quad (38)$$

That is for stable operation, LQP <1

Analysis 4: Voltage stability Index (Ld)

The index is also developed to determine voltage stability conditions, this is stated mathematically as;

$$Ld = \frac{\sqrt[4]{(P_i^2 + Q_i^2)(R_{ij}^2 + X_{ij}^2)}}{V_i^2} \quad (39)$$

Analysis 5: Novel Line Stability Index (NLSI)

The NLSI are developed to describe the stability behavior of system conditions, for purpose of avoiding voltage state. This is mathematically as;

$$NLSI = \frac{P_j + R_{ij} + Q_j X_{ij}}{0.25 V_i^2} \quad (40)$$

10. Result And Discussion

Essentially, selections of lines to be switched (addition or removal) rely strongly on the modelling and simulating of the existing base case in order to adjust to compensate for an overloaded line. The single line representation of the base case are modelled in power world simulator tool presented in figure 2, 3 and 4 respectively showing the violations and improved cases.

The operating voltage and system flow are contained and declared by statutory conditions whether they are within the allowable voltage tolerance limits of ±5% (0.95pu ≤ VI ≤ 1.05pu).

This means that the percentage apparent power (MVA) loading of the transmission lines are requested to fall within the acceptable range with a view to determine the lines that are underutilized or over utilized in the system.

Single-line transmission insertions were introduced to measure outages or failure of lines are thereby added or removed from the system in order to cause a shift in power flow in order to eliminate overload line in the system.

11. Conclusion

Transmission network expansion planning technique has the capacity to determine and identify selection of lines to the switch to probably eliminate overloaded lines in order to improve power quality and reliable power supply.

Evidently, contingency analysis tool are embedded in power world simulator in order to evaluate transmission component that needs to be added or removed from the system thereby providing plans for system security. The expansion plan following the base case study was simulated to provide the degree of overload for purpose of system configuration. This means that best locations for additional line or removal may probably reduce system overload for purpose of reinforcing the network. The security assessment is continuously repeated until no further overload occur in the system in order to achieve optimal decision plan.

The initial result of the study case shows Afam to PH mains overload, Onitsha to Okpai overload, Onitsha to Alaoji overload, Afam to Alaoji overload, Delta to Aladja overload respectively. The contingency analysis was run on the base study case which identify overloaded lines or elements with different degree of violations. The degree of overload lines is ranked according to their percentages.

Evidently, this paper proposes new lines as addition that need to be introduced at the proper locations in order to strengthen the grid capacity, in order to reduce frequent system collapse.

Recommendations

- Integration of grids decentralization strategy into Geopolitical zones are necessary to alleviate system over loads.
- Incorporation of Artificial neural network Algorithm architecture (ANN) into grids network are utmost important to consider system parameter correlations, performance, validation, in order to Avoid system mismatches or collapse.
- Consideration of power electronic controller for the injection of reactive power must be considered in order to improve system performance.

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