International Journal of Recent Engineering Research and Development (IJRERD)
Volume No. 02 – Issue No. 05, ISSN: 2455-8761
www.ijrerd.com, PP. 01-23

Comparative Power Flow Analysis of 28 and 52 Buses for 330KV Power Grid Networks in Nigeria Using Newton-Raphson Method

Akwukwuegbu I.O.[1], Nosiri O.C.[2], Agubor C.K.[3], Olubiwe M.[4]
[1.2.3.4]Department of Electrical and Electronic Engineering, Federal University of Technology, Owerri, Nigeria

Abstract: Newton-Raphson technique was formulated and used to evaluate the electrical performances of the existing 28-bus and improved 52-bus Nigerian 330kV power networks. The Jacobian matrix for both the existing 28-bus and the improved 52-bus Nigerian power system was derived using Newton-Raphson power flow solution method. The steady-state critical bus voltages, voltage and angle profiles at each bus, active and reactive power flows, transformer tap settings, component or circuit loading, generator exciter regulator voltage set points and system losses of these networks were determined to ascertain their effectiveness and proper network reconfiguration. The results obtained showed a better performance of the 52-Bus system in power quality, voltage and angle profiles over the conventional 28-bus system.

Keywords: Newton-Raphson, real power, Jacobian matrix, bus system

1. Introduction

The increasing demand for electricity in Nigeria is far more than what is available. This has resulted in the interconnected transmission systems being heavily loaded and stressed beyond their allowable tolerable limit, coupled with the fact that the generating stations are sometimes connected to load centers through very long, fragile and radial transmission lines. These constraints affect the quality of power delivered. To cub this challenge, an analytical method must be deployed to evaluate the electrical performance of Nigerian 330kV power network.

The existing 28-bus, 330kV Nigerian grid network is improved by incorporating many complex equipment such as transmission lines, transformer tapings, alternator, reactors, compensators, phase shifters, synchronous condensers, static capacitors, etc, which are required for data collection. The data obtained are for assessment of system status, operations, analysis by network designers and operators, and the need for changes in a prescribed manner [1]. This constitutes power flow problems, hence the necessity for power flow simulation to analyze the steady-state response for system stability and line reinforcement.

This work was therefore carried out to evaluate the network performance, effectiveness and alternative plans for network reconfiguration based on mathematical approach. Newton-Raphson method was deployed to solve the power flow problems of the existing 28-bus and the improved 52-bus Nigerian 330kV power networks at their present status and compare their performance characteristics. In the Newton-Raphson method, the n quadratic equations are first linearized by forming a Jacobian matrix. The power flow simulation of Nigeria power networks are analytical, as the solution and nature of the problem always call for refinement and necessary adjustment of the data and variables at the nodes. It is a solution of equations in equilibrium describing only the steady-state condition of the networks, and disturbance of a complex plant under specific loading conditions [2].

Successful power system operation under normal balanced three-phase steady –state conditions requires the following:

(a) Generation supplies the demand (load) plus losses.
(b) Bus voltage magnitudes remain close to rated values.
(c) Generators operate within specified real and reactive power limits.
(d) Transmission lines and transformers are not overloaded.

The power–flow computer program or load flow is the basic tool for investigating these requirements. This program computes the voltage magnitude (V) and angle (δ) at each bus in a power system under balanced three – phase steady state conditions. It also computes real(P) and reactive (Q) power flows for all equipment interconnecting the buses, as well as equipment losses. Both existing Nigeria 330kV transmission grid and the proposed transmission grid including new generation sites and new transmission line locations to meet the increasing population and load demand growth are of interest [3].

The power flow studies are conducted for the flowing purposes:

- Planning of new generation sites and new transmission line location to meet the load demand growth.

- Analyzing system performance under contingency, emergency operations such as the effects of temporary loss of generating system, transmission path, line on the system, power flow under emergency or fault conditions.
- Knowing the effect of reactive power compensation on bus voltages in order to create rooms for the placement of additional capacitive, inductive vars or Flexible ac Transmission Systems (FACTS) devices to the system.
- To determine the voltage profile (voltage magnitude and angle) in the system.
- To determine equipment losses and overloaded elements in the system.

Conventional nodal or loop analysis is not suitable for load flow studies because the input data for loads are normally given in terms of power, not impedance. Also, generators are considered as power sources, not voltage or current sources. The power–flow problem is therefore formulated as a set of nonlinear algebraic equations suitable for computer solution.

2. Methodology

In order to ascertain the impact of the integrated network on the existing network, a power or load flow analysis was carried out. A conventional Newton-Raphson power flow model was used to investigate voltage stability and derive the Jacobian power matrix. Implementation was carried out using MATLAB SIMULINK Power System Analysis Toolbox (PSAT).

The power–flow computer program or load flow is the basic tool for investigating the voltage stability of a network. This program computes active/real (P) power and reactive (Q) power flow in lines for all the equipment interconnecting the buses, transformer loads, power losses, voltage magnitudes (V) and angles (δ) at different buses for specified conditions under balanced three – phase steady - state conditions.

2.1 Mathematical Formation of Power Flow Problems

The power-flow problem can be stated as:

Given n – bus system, there exists $4n$ variables; $2n$ of which are known or specified and $2n$ power flow equations of the form:

$$f(x, y) = 0 \tag{1}$$

Where:

x = $2n$ unknown variables

y = $2n$ input data, known, controlled or fixed variables.

Consider a typical bus of a power system network shown in the figure 1 [4, 5, 6, 7].

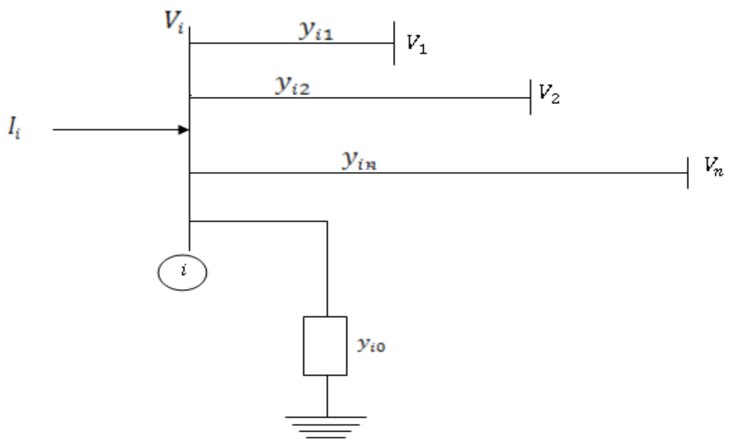

Fig. 1: A typical bus of a power system network.

The transmission lines are represented by their equivalent Pi – models, where impedances have been converted to per unit admittances on a common MVA base.

The general nodal current equation describing the performance of the power system network of figure 1 is given by:

$$I_{BUS} = Y_{BUS}V_{BUS} \tag{2}$$

From figure 1, the total nodal current entering the ith bus of n- bus system is given by:

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + \ldots + Y_{ii}V_i + \ldots + Y_{in}V_n = \sum_{i=1}^{n} Y_{ik}V_k \tag{3}$$

Where,

Y_{ik} = the admittance of the line between buses i and k

V_k = the voltage at bus k

In polar coordinates,

$V_i = |V_i| < \delta_i = |V_i|e^{j\delta_i}$

$V_k = |V_k| < \delta_K = |V_k|e^{j\delta_k}$

$Y_{ik} = |Y_{ik}| < \theta_{ik} = |Y_{ik}|e^{-j\delta_{ik}}$

δ_i = bus i voltage angle

θ_{ik} = bus admittance angle

The complex power injected into ith bus is

$$S_i = P_i + jQ_i = V_i I_i^* \tag{4a}$$

Taking the complex conjugate of Equation (4a) gives the complex conjugate power as:

$$S_i^* = P_i - jQ_i = V_i^* I_i \tag{4b}$$

Substituting the value of I_i from Eqtn. (3) intoEqtn. (4b) gives:

$$S_i^* = P_i - jQ_i = V_i^* \sum_{k=1}^{n} Y_{ik}V_k \tag{5}$$

Where: $i = 1, 2, \ . \ . \ ., n$

$V_i^* = |V_i| < -\delta_i = |V_i|e^{-j\delta_i}$

Therefore,

$$P_i - jQ_i = |V_i| \sum_{k=1}^{n} |Y_{ik}||V_k| e^{-j(\theta_{ik} + \delta_i - \delta_k)} \tag{6}$$

$$= \sum_{k=1}^{n} |V_i||Y_{ik}||V_k|[cos(\theta_{ik} + \delta_i - \delta_k) - jsin(\theta_{ik} + \delta_i - \delta_k)] \tag{7}$$

Setting $Y_{ik} = G_{ik} - jB_{ik} = |Y_{ik}|e^{-j\theta_{ik}}$ (8)

$$V_i^* V_k = \left(|V_i|e^{-j\delta_i}\right)\left(|V_k|e^{j\delta_k}\right) = |V_i||V_k|e^{-j(\delta_i - \delta_k)}$$
$$= |V_i||V_k|[cos(\delta_i - \delta_k) + jsin(\delta_i - \delta_k)] \tag{9}$$

Therefore,

$$P_i - jQ_i = \sum_{k=1}^{n} |V_i||V_k|(G_{ik} - jB_{ik})e^{j(\delta_i - \delta_K)} \tag{10}$$

$$= \sum_{k=1}^{n} |V_i||V_k| (G_{ik} - jB_{ik}) [cos\ (\delta_i - \delta_k) + jsin(\delta_i - \delta_k)]$$

$$= \sum_{k=1}^{n} |V_i||V_k| [(G_{ik}\ \cos(\delta_i - \delta_k) + jG_{ik}\, sin(\delta_i - \delta_k)$$

$$-jB_{ik}\, cos(\delta_i - \delta_k) + B_{ik}\, sin(\delta_i - \delta_k)]$$

$$= \sum_{k=1}^{n} |V_i||V_k| [(G_{ik}\ \cos(\delta_i - \delta_k) + B_{ik}\, sin(\delta_i - \delta_k)$$

$$-jG_{ik}\, sin(\delta_i - \delta_k) - jB_{ik}\, cos(\delta_i - \delta_k)] \quad (11)$$

Where:

S_i^* = a complex conjugate apparent power at bus i.

P_i = the real power at bus i.

Q_i = the reactive power at bus i.

B_{ik} = the line susceptance between buses i and k

G_{ik} = the line conductance between buses i and k

Separating the real and imaginary parts at ith bus results in:

$$P_i = R_e \sum_{k=1}^{n} \left[|V_i||Y_{ik}||V_k| e^{-j(\theta_{ik} + \delta_i - \delta_k)}\right] \quad (12)$$

Or

$$P_i = R_e \sum_{k=1}^{n} [|V_i||Y_{ik}||V_k| cos(\theta_{ik} + \delta_i - \delta_k)] \quad (13)$$

Or

$$P_i = R_e \sum_{k=1}^{n} |V_i|V_k|[G_{ik} \cos(\delta_i - \delta_k) + B_{ik} \sin\ (\delta_i\ \delta_k)] \quad (14)$$

and

$$Q_i = I_i \sum_{k=1}^{n} \left[|V_i||Y_{ik}||V_k| e^{-j(\theta_{ik} + \delta_i - \delta_k)}\right] \quad (15)$$

Or

$$Q_i = - \sum_{k=1}^{n} [|V_i||Y_{ik}||V_k| sin(\theta_{ik} + \delta_i - \delta_k)] \quad (16)$$

Or

$$Q_i = \sum_{k=1}^{n} |V_i|V_k|[G_{ik}\sin(\delta_i - \delta_k) + B_{ik}\cos(\delta_i - \delta_k)] \quad (17)$$

Equations (14) and (17) are called the STATIC LOAD FLOW EQUATIONS (SLFE) and their solution is the load flow solution, which has the following physical constraints.

i. $|V_i|_{mm} < |V_i|_{max}$.
ii. $|\delta_i - \delta_k|_{mm} < |\delta_i - \delta_k|_{max}$ due to the physical limitation of the machines.
iii. $P_{Gkmin} < P_{Gk}^{k} < P_{Gk\,max}$ and $Q_{Gk\,min} \angle Q_{Gk} \angle Q_{Gk\,max}$.

$$P_{Gi} = \sum P_{Li} + P_{LOSS};\ Q_{Gi} = \sum Q_{Li} + Q_{LOSS} \quad (18)$$

where

$S_{Gi} = P_{Gi} + jQ_{Gi}$ = generated power at the bus (19)

$S_{LOSS} = P_{LOSS} + jQ_{LOSS}$ = total power loss (20)

The power-flow equations or static load flow equations are non-linear equations and, therefore, only a numerical solution is possible. The power – flow equations (5) and (17) are solved by iterative methods like Gauss – Seidel and Newton – Raphson.

Newton – Raphson Technique Formulation

In numerical analysis, Newton – Raphson method remains the best known method for finding successively better approximations to Zeros (or Roots) of real valued functions[4].

Newton – Raphson method solves the polar form of the power flow equations until the ΔP and ΔQ mismatches at all buses fall within specified tolerance. This method made use of real power (P_i) equations and reactive power (Q_i) equations, and voltage angle (δ_i) unknowns and voltage magnitude (V_i) unknowns are the two unknown variables to be solved for.

The bus voltages (V_i) and line admittances (Y_{iK}) are expressed in polar form.

$$V_i = e_i + jf_i = |V_i|e^{j\delta_i} = |V_i|(\cos\delta_i + j\sin\delta_i) \quad (21a)$$

$$V_i^* = e_i - jf_i = |V_i|e^{-j\delta_i} = |V_i|(\cos\delta_i - j\sin\delta_i) \quad (21b)$$

$$V_k = |V_i|e^{j\delta_k} \quad (22)$$

$$Y_{ik} = |Y_{ik}|e^{-j\theta_{ik}} \quad (23)$$

where

e and f = the real and reactive bus element

δ = the phase angle of the bus voltage

θ_{ik} = an admittance angle between buses i and k.

The nodal current entering the ith bus of n - bus system is given by:

$$I_i = \sum_{k=1}^{n} Y_i V \ , i = 1, 2, \ldots, n \quad (24)$$

At ith bus, complex conjugate power will be

$$S_i^* = P_i - jQ_i = V_i^* I_i = V_i^* \sum_{k=1}^{n} Y_{ik} V_k \tag{25}$$

Or

$$P_i - jQ_i = \sum_{k=1}^{n} \left[|V_i||Y_{ik}||V_k| e^{-j(\theta_{ik+} \delta_i - \delta_k)} \right] \tag{26}$$

$$= \sum_{k=1}^{n} |V_i||Y_{ik}||V_k| [\cos(\theta_{ik} + \delta_i - \delta_k) - j\sin(\theta_{ik+} \delta_i - \delta_k)] \tag{27}$$

The real power at ith bus will be

$$P_i = R_e \sum_{k=1}^{n} \left[|V_i||Y_{ik}||V_k| e^{-j(\theta_{ik+} \delta_i - \delta_k)} \right] \tag{28}$$

Or

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

$$= V_i V_i Y_{ii} cos\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i||Y_{ik}||V_k| \cos(\theta_{ik} + \delta_k - \delta_i)$$

$$= |V_i|^2 |Y_{ii}| cos\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i||Y_{ik}||V_k| \cos(\theta_{ik} + \delta_k - \delta_i)$$

$$= P_i(|V|, \delta) \tag{29}$$

The reactive power at ith bus will be

$$Q_i = \mathrm{I}_m \sum_{k=1}^{n} \left[|V_i||Y_{ik}||V_k| e^{-j(\theta_{ik} + \delta_i - \delta_k)} \right] \tag{30}$$

Or

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

$$= V_i V_i Y_{ii} sin\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i||Y_{ik}||V_k| \sin(\theta_{ik} + \delta_k - \delta_i)$$

$$= |V_i|^2 |Y_{ii}| sin\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i||Y_{ik}||V_k| \sin(\theta_{ik} + \delta_k - \delta_i)$$

$$= Q_i(|V|, \delta) \tag{31}$$

The Newton – Raphson load flow technique linearizes non-linear load flow equations using Taylor's Series expansion of real power and reactive power (or absolute voltage) about the initial estimate and, neglecting second and higher order terms. Taylor's Series expansion of power-flow equations (29) and (31) produces linearized equations presented in matrix form in equation. (32) for an n – bus system load buses and m generator buses (i.e., $1 + m = n$) [5, 6, 7, 8, 9, 10] .

$$
\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix}
=
\begin{array}{c}
\begin{array}{cc} J_1 & J_2 \end{array} \\
\left[\begin{array}{ccc|ccc}
\frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} & \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\
\vdots & & \vdots & \vdots & & \vdots \\
\frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n} & \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \\
\hline
\frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n} & \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\
\vdots & & \vdots & \vdots & & \vdots \\
\frac{\partial Q_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n} & \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|}
\end{array}\right] \\
\begin{array}{cc} J_3 & J_4 \end{array}
\end{array}
\begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix}
\tag{32}
$$

In a more compact form, the matrix form of equation (32), obtained from the linear equation in polar form is expressed as follows:

$$
\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \left[\begin{array}{c|c} J_1 & J_2 \\ \hline J_3 & J_4 \end{array}\right] \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \tag{33}
$$

Where:
$[\Delta P]$ =real power mismatch, calculated from equation (36)
$[\Delta Q]$ =reactive power mismatch, calculated from equation (37)
$[\Delta V]$ = voltage mismatch, calculated from equation (38)
$[\ J\ ]$ = is the Jacobian matrix, determined from power flow equations (30) and (32) as follows:
The off – diagonal $(K \neq i)$ and diagonal $(K = i)$ elements of $\mathrm{J}_1, \mathrm{J}_2, \mathrm{J}_3,$ and J_4 are computed as follows:

For $K \neq i$,

$$J_{1ik} = \frac{\partial P_i}{\partial \delta_k} = |V_i||V_k||Y_{ik}|\sin(\theta_{ik} + \delta_i - \delta_k) \tag{34a}$$

$$J_{2ik} = \frac{\partial P_i}{k} = |V_i||Y_{ik}|\cos(\theta_{ik} + \delta_i - \delta_k) \tag{34b}$$

$$J_{3ik} = \frac{\partial Q_i}{\partial \delta_k} = -|V_i||V_k||Y_{ik}|\cos(\theta_{ik} + \delta_i - \delta_k) \tag{34c}$$

$$J_{4ik} = \frac{\partial Q_i}{\partial V_k} = |V_i||Y_{ik}|\sin(\theta_{ik} + \delta_i - \delta_k) \tag{34d}$$

For $k = i$,

$$J_{1ii} = \frac{\partial P_i}{\partial \delta_i} = - \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i||V_k||Y_{ik}|\sin(\theta_{ik} + \delta_i - \delta_k) \tag{34e}$$

$$J_{2ii} = \frac{\partial P_i}{\partial V_i} = 2|V_i||Y_{ii}|\cos\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_k||Y_{ik}|\cos(\theta_{ik} + \delta_i - \delta_k) \tag{34f}$$

$$J_{3ii} = \frac{\partial Q_i}{\partial \delta_i} = \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i||V_k||Y_{ik}|\cos(\theta_{ik} + \delta_i - \delta_k) \tag{34g}$$

$$J_{4ii} = \frac{\partial Q_i}{\partial V_i} = 2|V_i||Y_{ii}|\sin + \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_k||Y_{ik}|\sin(\theta_{ik} + \delta_i - \delta_k) \tag{34h}$$

Gauss elimination and back substitution are used to solve equation (33). The real and reactive powers, and voltage residuals consisting of $\Delta P_i, \Delta Q_i$, and $|\Delta V_i|^2$ are calculated as follows:

$$\Delta P_i^{(k)} = P_i^{SP} - P_i^{(k)} \tag{35}$$

$$\Delta Q_i^{(k)} = Q_i^{SP} - Q_i^{(k)} \tag{36}$$

$$\Delta \left|V_i^{(k)}\right|^2 = \left|V_i^{SP}\right|^2 - \left|V_i^{(k)}\right|^2 \tag{37}$$

Where:

P_i^{SP} = known or specified value of real power.

$P_i^{(k)}$ = calculated value of real power.

$Q_i^{(SP)}$ = known or specified value of reactive power.

$Q_i^{(k)}$ = calculated value of reactive power.

$\left|V_i^{SP}\right|$ = known or specified value of voltage magnitude

$\left|V_i^{(k)}\right|$ = calculated value of voltage magnitude

Equations (35), (36) and (37) present the difference between the known or specified and calculated values of real and reactive powers, and voltage magnitude.

The new better estimates for bus voltage angles (δ_i) and bus voltages (V_i) are updated or augmented by:

$$\delta_i^{(k-1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{38a}$$

$$\left|V_i^{(k-1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \tag{38b}$$

Equations (38a) and (38b) calculate the new voltage magnitudes and phase angles of the voltage. The basis of the Newton –Raphson technique is to solve the polar form of load flow equations until the $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ mismatches at all buses are reduced to a pre-specified tolerance. That is, the $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ mismatches at all buses must fall within specified tolerance. That is;

$$\left|\Delta P_i^{(k)}\right| \leq \varepsilon \qquad (39)$$
$$\left|\Delta Q_i^{(k)}\right| \leq \varepsilon$$

Solution procedures for Newton–Raphson techniques are explained as follows (flow chart in Fig 2):

1. At all load buses (or PQ buses), P_i^{SP} and Q_i^{SP} are specified, known or input data; while the voltage magnitudes $|V_i|$ and phase angles (δ_i) at these PQ buses are set equal to the slack bus values. That is, $\left|V_i^{(o)}\right| \angle\delta_i^{(o)} = 1.0\angle 0^o$ per unit is input data.

   At all generated, voltage controlled or PV buses, P_i^{SP} and $|V_i|$ are specified, known or input data, while phase angle of the voltage (δ_i) at these PV buses are equal to slack bus angle or zero.

2. $P_i^{(k)}$ and $Q_i^{(k)}$ for all PQ buses are calculated from equations (29) and (31); whereas $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are computed from equations (35) and (36).

3. For all PV buses, $P_i^{(k)}$ and $\Delta P_i^{(k)}$ are calculated from equations (29) and (35).
4. The voltage residue $\left(\Delta\left|V_i^{(k)}\right|\right)$ is computed from equation (37).
5. The elements of Jacobian, J_1, J_2, J_3 and J_4 are calculated from equations (34a-h).
6. Gauss elimination and back substitution are used to solve the linear equation (33).
7. The values of new voltage magnitudes $\left(\left|V_i^{(k+1)}\right|\right)$ and phase angles $(\delta_i^{(k+1)})$ for all PQ buses are computed from equations (38a and b).
8. The values of new phase angles $(\delta_i^{(k+1)})$ for all PV buses are computed from equation (38a).
9. For all PV buses, $Q_i^{(k)}$ is computed from equation (31) and $Q_{i\,mm}^{(k)} < Q_i < Q_{i\,max}$ is used to check the value of $Q_i^{(k)}$.
10. The process is continued until residuals ΔP_i^k and ΔQ_i^k at all PQ buses and $\Delta P_i^{(k)}$ at all PV buses are less than the specified accuracy. That is, $\left|\Delta P_i^{(k)}\right| \leq \varepsilon$ and $\left|\Delta Q_i^{(k)}\right| \leq \varepsilon$

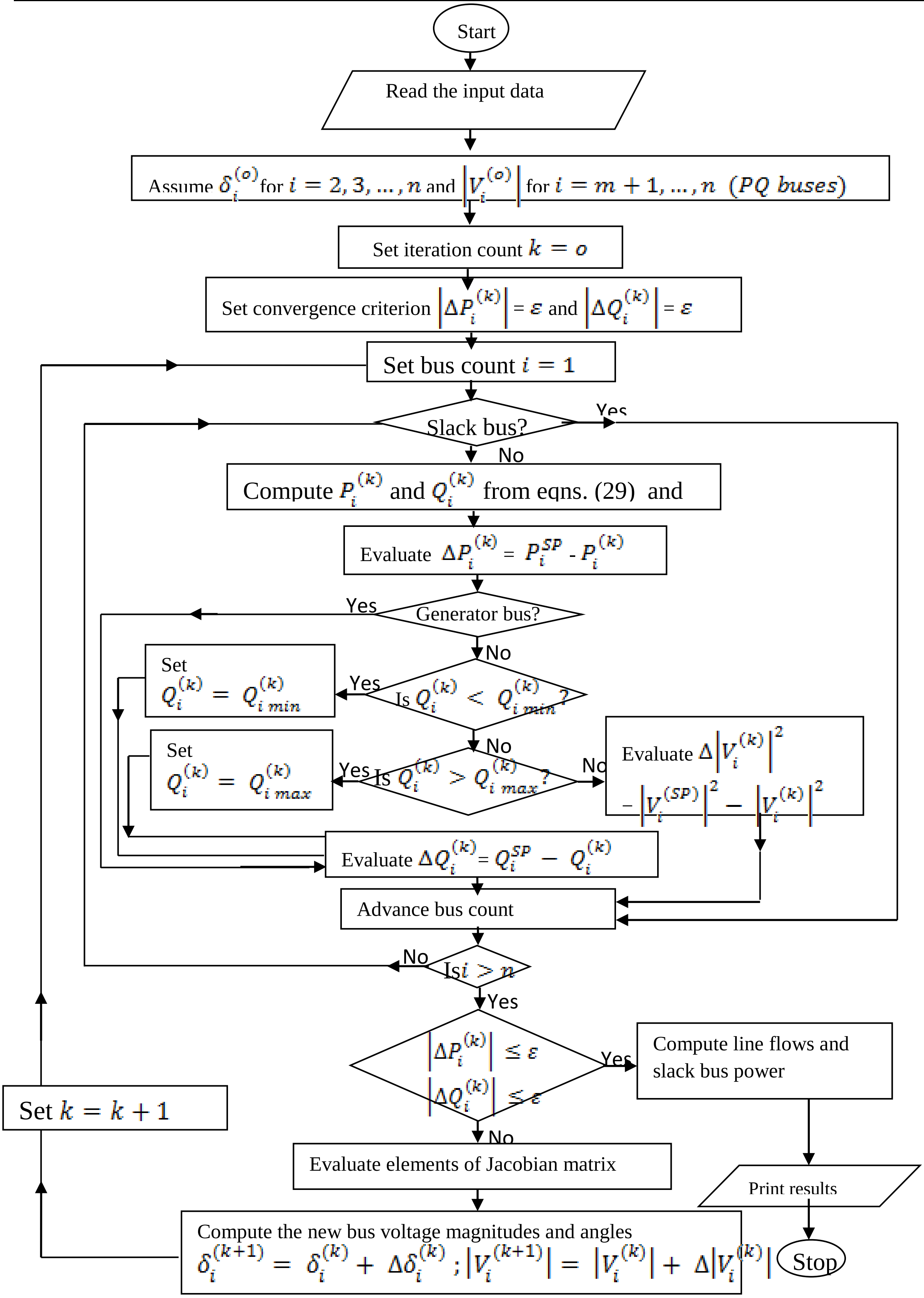

Fig. 2: Flowchart for the Newton-Raphson power flow Algorithm.

Newton-Raphson power flow technique was formulated, developed and coded in Matlab/SIMULINK Power Analysis Toolbox (PSAT) for the power flow analysis of the 28-bus and the improved 52-bus Nigerian 330kV power networks. The procedure was described in the flow chart of figure 2. System admittance matrix and Jacobian matrix were formed. At the next approach, Jacobian matrix and the mismatched power flow equations were modified. The bus voltages are updated at each iteration. Convergence is checked and if not achieved, the process continues until convergence is achieved and power flow results are displayed. The Nigerian 330kV power networks for this study consist of 28 buses/nodes, 10 generators, 18 load(PQ) buses, 16 transformers, 32 transmission lines and 11,000Km grid transmission lines for the 28-bus network and 52 buses/nodes, 17 generators, 35 load(PQ) buses, 28 transformer, 64 transmission lines and 8,985.28Km grid transmission lines for improved 52-bus network as shown in figures 3 and 4 respectively.

The 28-bus power network has a total load of 20.96753pu(2,096753MW) and 19.7995pu (1,97995Mvar),whereas, 52-bus power network has a total load of 30.0pu(9,000MW) and 22.5pu(6,750Mvar) as shown in tables 1 to 6. The system bus 1 is slack bus and bus 2 to bus 10 are PV buses. 11 to 28 are PQ(load) buses for the 28-bus power network. For the 52-bus power network, bus1 is slack bus, and 2 to 17 are PV buses while 18 to 52 are PQ(load) buses as shown in tables 1 to 6 and figures 3 to 6. The existing 28-bus and improved 52-bus 330kV Nigerian transmission networks of figures 3 and 4 were modeled using SIMULINK library and are shown in figures 5 and 6 respectively.

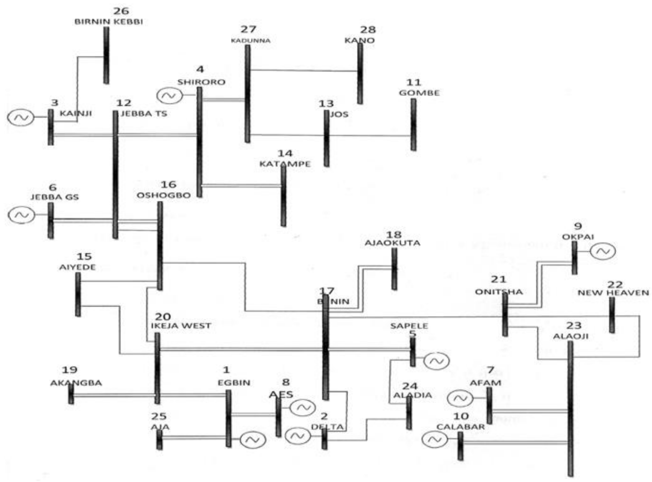

Fig. 3: One-line diagram of the existing 28 bus 330kV Nigerian transmission grid.

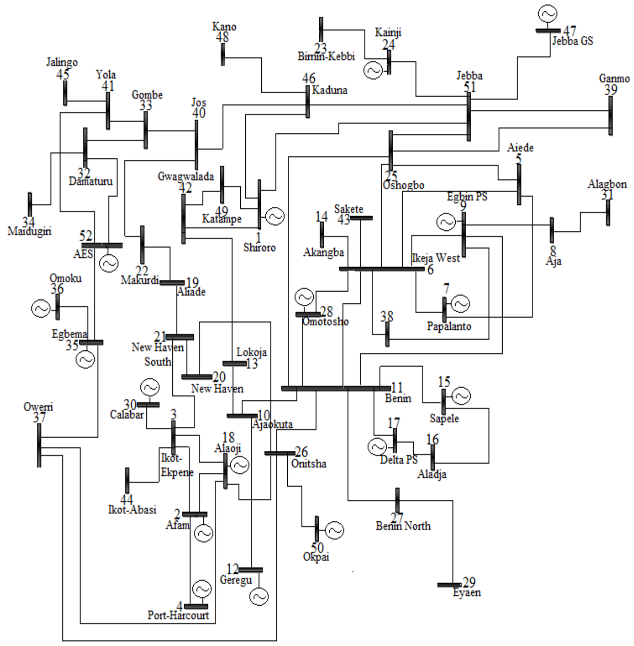

Fig. 4: One-line diagram of the improved 52-bus 330kV Nigerian transmission network

3.1 System Data Field Collection and Preparation

Systemdata for the existing 28-bus and 52-bus Nigeria 330kV power networks are obtained from Power Holding Company of Nigeria (PHCN), processed and arranged as Bus data file and line data file, and tabulated in tables 1 to 4 [11, 12, 13]. Other information collected are one – line diagrams of the existing Nigeria 330kV 28-bus and improved 52-bus transmission grid networks as shown in figures 3 to 4. These input data provide the values of series impedances, admittances of the transmission lines, transformer ratings and impedances required for the power/load flow study. These parameters were modeled and simulated in MATLAB/SIMULINK power system analysis TOOLBOX (PSAT) program environment using Newton-Raphs on power flow algorithm.

Bus Data File: The format for the bus entry was chosen to facilitate the required data for each bus in a single row. The information required must be included in matrix called bus data as shown in tables 1 to 2.
Column 1 of bus data is the bus number, whereas column 2 of bus data contains the bus code. Column 3 and 4 of bus data are the voltage magnitude in per unit and phase angle in degrees. Column 5 and 6 of bus data are load MW and MVar. Columns 7 to 10 of bus data respectively are MW, MVar, minimum MVar (Q_{min}) and maximum MVar (Q_{max}) of generation, in that order. The bus code in column 2 of bus data is used for identifying swing bus / slack bus, generator bus / voltage – controlled bus / PQ bus as outlined below:

Code 1: This code is used for the slack bus / swing bus / reference bus. This bus is numbered bus 1 as shown in tables 1 to 2, where the magnitude and phase angle of the voltage are known or specified. That is, the swing bus is a reference bus for $V_1\angle\delta_1$, typical 1.0 $\angle$ 0^o per unit, is input data. The power flow program computes P_1 and Q_1.
Code 2: This code is used for the generator bus / voltage – controlled bus / PV bus. This bus is numbered bus 2 as shown in tables 1 to 2. At this bus, the real power (P_i) and voltage magnitude (V_i) are known or specified. P_i and V_i are input data. The power flow program computes reactive power (Q_i) and phase angle of the voltage or voltage angle (δ_i). Examples are buses to which generators, switched shunt capacitors, or static var systems are connected. The maximum reactive power (Q_{Gmax}) and minimum reactive power (Q_{Gmin}) limits that equipment can supply are specified or known and are used as input data. Another example is a bus to which a tap – changing transformer is connected; the power flow program computes the tap setting.

Code 3: This code is used for the load bus / PQ bus. This bus is numbered bus 3 as shown in tables 1 to 2. At this bus, the active power (P_i) and reactive power (Q_i) are known or specified. P_i and Q_i are input data. The power flow program computes voltage magnitude (V_i) and phase angle (δ_i). A pure load bus (no generating facility at the bus, that is, $P_{Gi} = Q_{Gi} = 0$) is a PQ bus.

The bus bar data relates to individual bus bars and provides the following information for the power flow and continuation power flow methods: the bus name, identifying number and type (load, generator or voltage controlled, swing or slack); initial bus voltage magnitude (V) and phase angle (δ); the generated power; the load power; and the upper and lower limits of reactive power or MVars generation.

Line Data File: the transmission lines or branch data relates to information on the branches of the transmission lines, reactors and transformers. The transmission lines or branch data provides the following necessary information for the power flow and continuation power flow methods: code to identify branch such as line, reactor or transformer; identifying number of each of the two buses to which the branch is connected; the branch resistance (R_{pu}) and reactance (X_{pu}); tap settings where applicable and MVA base.

Lines are identified by the mode – pair method. The information required must be identified in a matrix called line data as shown in tables 3 to 4. Columns 1 and 2 of line data are the line bus numbers. Columns 3 to 5 of line data respectively contain the line resistance, reactance, and one – half of the total line charging susceptance in per unit on the specified MVA base. The last column is for the transformer tap setting; for lines, 1 must be entered in this column. The lines may be entered in any sequence or order with the only restriction being that if the entry is a transformer, the left bus number is assumed to be the tap side of the transformer.

Table 1: Bus data of the 28-bus networks used as input for the Simulation.

Bus No.	Bus Code	Bus voltage (V_{sp})	Phase Voltage (θ^o)	Load		Generation				Tap Setting
				P_{Li}	Q_{Li}	P_{Gi}	Q_{Gi}	Q_{min}	Q_{max}	
1	1	1	0	150	105.62	0	0	-200	200	1
2	2	1	0	200	300	882	0	-300	320	1
3	2	1	0	0	0	760	0	-210	222	1
4	2	1	0	0	0	600	0	-120	140	1
5	2	1	0	0	0	1020	0	-250	260	1
6	2	1	0	0	0	578	0	-200	210	1
7	2	1	0	0	0	931.6	0	-290	300	1
8	2	1	0	0	0	302	0	-100	110	1
9	2	1	0	0	0	480	0	-200	210	1
10	2	1	0	0	0	600	0	-120	140	1
11	3	1	0	0	0	0	0	0	0	1
12	3	1	0	130	80	0	0	0	0	1
13	3	1	0	220	154.8	0	0	0	0	1
14	3	1	0	114	90	0	0	0	0	1
15	3	1	0	110	80	0	0	0	0	1
16	3	1	0	104	70	0	0	0	0	1
17	3	1	0	36	25	0	0	0	0	1
18	3	1	0	72	45	0	0	0	0	1
19	3	1	0	136	84	0	0	0	0	1
20	3	1	0	72	45	0	0	0	0	1
21	3	1	0	39	27.8	0	0	0	0	1
22	3	1	0	84	50	0	0	0	0	1
23	3	1	0	146	84.5	0	0	0	0	1
24	3	1	0	32	17.8	0	0	0	0	1
25	3	1	0	110	80	0	0	0	0	1
26	3	1	0	100	58.4	0	0	0	0	1
27	3	1	0	80	49.6	0	0	0	0	1
28	3	1	0	26	15.3	0	0	0	0	1

Table 2: Bus data of the 52-bus networks used as input for the Simulation.

Bus No.	Bus Code	Bus voltage (V_{sp})	Phase Voltage (θ^o)	Load		Generation				Tap Setting
				P_{Li}	Q_{Li}	P_{Gi}	Q_{Gi}	Q_{min}	Q_{max}	
1	1	1	0	0	0	0	0	-200	200	1
2	2	1	0	315	157.5	760	428	-210	222	1
3	2	1	0	321	160.5	578	207	-200	210	1
4	2	1	0	316	158	600	298	-120	140	1
5	2	1	0	70.5	35.11	414	207	-100	110	1
6	2	1	0	60.5	30.11	335	167.5	-90	100	1
7	2	1	0	700	350	1020	510	-250	260	1
8	2	1	0	300	150	882	441	-150	160	1
9	2	1	0	110	55	252	126	-200	210	1
10	2	1	0	230	115	480	240	-200	210	1

11	2	1	0	360	80	931.6	465.8	-290	300	1
12	2	1	0	75.1	37.5	300	150	-80	100	1
13	2	1	0	300	150	500	250	-200	210	1
14	2	1	0	200	100	253	126.5	-70	80	1
15	2	1	0	179	89.5	600	298.8	-180	200	1
16	2	1	0	315	157.5	730	365	-279	280	1
17	2	1	0	107.4	53.49	500	250	-100	120	1
18	3	1	0	65	33	0	0	0	0	1
19	3	1	0	136	84	0	0	0	0	1
20	3	1	0	72	45	0	0	0	0	1
21	3	1	0	39	27.8	0	0	0	0	1
22	3	1	0	84	50	0	0	0	0	1
23	3	1	0	146	84.5	0	0	0	0	1
24	3	1	0	32	17.8	0	0	0	0	1
25	3	1	0	110	80	0	0	0	0	1
26	3	1	0	100	58.4	0	0	0	0	1
27	3	1	0	80	49.6	0	0	0	0	1
28	3	1	0	26	15.3	0	0	0	0	1
29	3	1	0	440	220	0	0	0	0	1
30	3	1	0	400	200	0	0	0	0	1
31	3	1	0	400	200	0	0	0	0	1
32	3	1	0	450	225	0	0	0	0	1
33	3	1	0	400	200	0	0	0	0	1
34	3	1	0	440	220	0	0	0	0	1
35	3	1	0	400	200	0	0	0	0	1
36	3	1	0	450	225	0	0	0	0	1
37	3	1	0	400	200	0	0	0	0	1
38	3	1	0	440	220	0	0	0	0	1
39	3	1	0	400	200	0	0	0	0	1
40	3	1	0	450	225	0	0	0	0	1
41	3	1	0	440	220	0	0	0	0	1
42	3	1	0	400	200	0	0	0	0	1
43	3	1	0	450	225	0	0	0	0	1
44	3	1	0	430	215	0	0	0	0	1
45	3	1	0	450	225	0	0	0	0	1
46	3	1	0	460	230	0	0	0	0	1
47	3	1	0	450	225	0	0	0	0	1
48	3	1	0	460	230	0	0	0	0	1
49	3	1	0	480	240	0	0	0	0	1
50	3	1	0	400	200	0	0	0	0	1
51	3	1	0	450	225	0	0	0	0	1
52	3	1	0	440	220	0	0	0	0	1

Table 3: Line Data of the 28-bus networks used as input for the Simulation.

S/N	Transmission line		Line Impedance		B/2 (pu)
	From Bus	To Bus	R (pu)	X (pu)	
1	1	8	0.0001	0.0004	0.0996
2	1	20	0.0004	0.0029	0.0771
3	1	25	0.0007	0.0057	0.0771
4	3	17	0.0008	0.0063	0.3585
5	2	24	0.0008	0.0063	0.3585
6	3	26	0.0041	0.0304	1.8135

7	3	12	0.001	0.0082	0924
8	4	27	0.0011	0.0097	0.546
9	4	12	0.0022	0.0234	1.3905
10	4	14	0.009	0.0067	1.7933
11	5	17	0.0002	0.0015	0.936
12	5	24	0.0008	0.0063	0.3585
13	6	12	0.0001	0.0004	0.0996
14	7	23	0.0015	0.0012	0.312
15	9	21	0.0008	0.0063	0.3585
16	10	23	0.0163	0.014	0.786
17	11	13	0.0032	0.0027	1.515
18	12	16	0.0019	0.0159	0.8955
19	13	27	0.0027	0.0202	1.2114
20	15	16	0.0013	0.01	0.5999
21	15	20	0.0016	0.0134	0.8057
22	16	17	0.003	0.0254	1.431
23	16	20	0.0033	0.0227	1.4819
24	17	18	0.0023	0.0198	1.1117
25	17	20	0.0034	0.0016	1.7015
26	17	21	0.0016	0.0139	0.781
27	19	20	0.0007	0.0057	0.3855
28	21	22	0.0011	0.0097	0.5475
29	21	23	0.0163	0.014	0.786
30	22	23	0.0023	0.0171	1.3905
31	27	28	0.0027	0.0202	1.2114

Table 4: Line data of the 52-bus networks used as input for the Simulation.

S/N	Transmission line		Line Impedance		B (pu)
	From Bus	To Bus	R (pu)	X (pu)	
1	49	1	0.0029	0.0205	0.308
2	3	18	0.009	0.007	0.104
3	3	3	0.0155	0.0172	0.104
4	3	4	0.006	0.007	0.104
5	19	25	0.0291	0.0349	0.437
6	19	6	0.0341	0.0416	0.521
7	19	7	0.0291	0.0349	0.437
8	8	9	0.0155	0.0172	0.257
9	8	31	0.006	0.007	0.257
10	10	11	0.0126	0.0139	0.208
11	10	12	0.0155	0.0172	0.257
12	10	13	0.0155	0.0172	0.257
13	14	6	0.0155	0.0172	0.065
14	16	15	0.016	0.019	0.239
15	18	37	0.006	0.007	0.308
16	16	17	0.016	0.019	0.239
17	16	26	0.035	0.0419	0.524
18	16	3	0.0155	0.0172	0.257
19	19	21	0.006	0.0007	0.308
20	19	22	0.0205	0.0246	0.308
21	23	24	0.0786	0.0942	1.178
22	11	6	0.0705	0.0779	1.162
23	11	15	0.0126	0.0139	0.208

24	11	17	0.016	0.019	0.239
25	11	25	0.0636	0.0763	0.954
26	11	26	0.0347	0.0416	0.521
27	11	27	0.049	0.056	0.208
28	11	9	0.016	0.019	0.239
29	11	28	0.016	0.019	0.365
30	27	29	0.0126	0.0139	0.208
31	30	3	0.0126	0.0139	0.208
32	32	33	0.0786	0.0942	1.178
33	32	34	0.0786	0.0942	1.178
34	35	36	0.0126	0.0139	0.208
35	35	37	0.0126	0.0139	0.208
36	9	6	0.0155	0.0172	0.257
37	9	38	0.016	0.019	0.239
38	38	6	0.016	0.019	0.239
39	33	25	0.016	0.019	0.239
40	33	51	0.0341	0.0416	0.239
41	33	40	0.067	0.081	1.01
42	33	41	0.0245	0.0292	1.01
43	42	13	0.0156	0.0172	0.257
44	42	1	0.0155	0.0172	0.257
45	6	25	0.0341	0.0416	0.521
46	6	28	0.024	0.0292	0.365
47	6	7	0.0398	0.0477	0.597
48	6	43	0.0398	0.0477	0.521
49	44	3	0.0155	0.0172	0.257
50	51	25	0.0398	0.0477	0.597
51	45	41	0.0126	0.0139	0.208
52	51	47	0.002	0.0022	0.033
53	51	24	0.0205	0.0246	0.308
54	51	1	0.062	0.0702	0.927
55	40	46	0.049	0.0599	0.927
56	40	22	0.002	0.0022	0.308
57	46	48	0.058	0.0699	0.874
58	46	1	0.0249	0.0292	0.364
59	46	1	0.0205	0.0246	0.308
60	20	26	0.024	0.0292	0.365
61	20	21	0.0205	0.0246	0.308
62	50	26	0.006	0.007	0.104
63	26	37	0.006	0.007	0.104
64	3	21	0.0205	0.0246	0.257

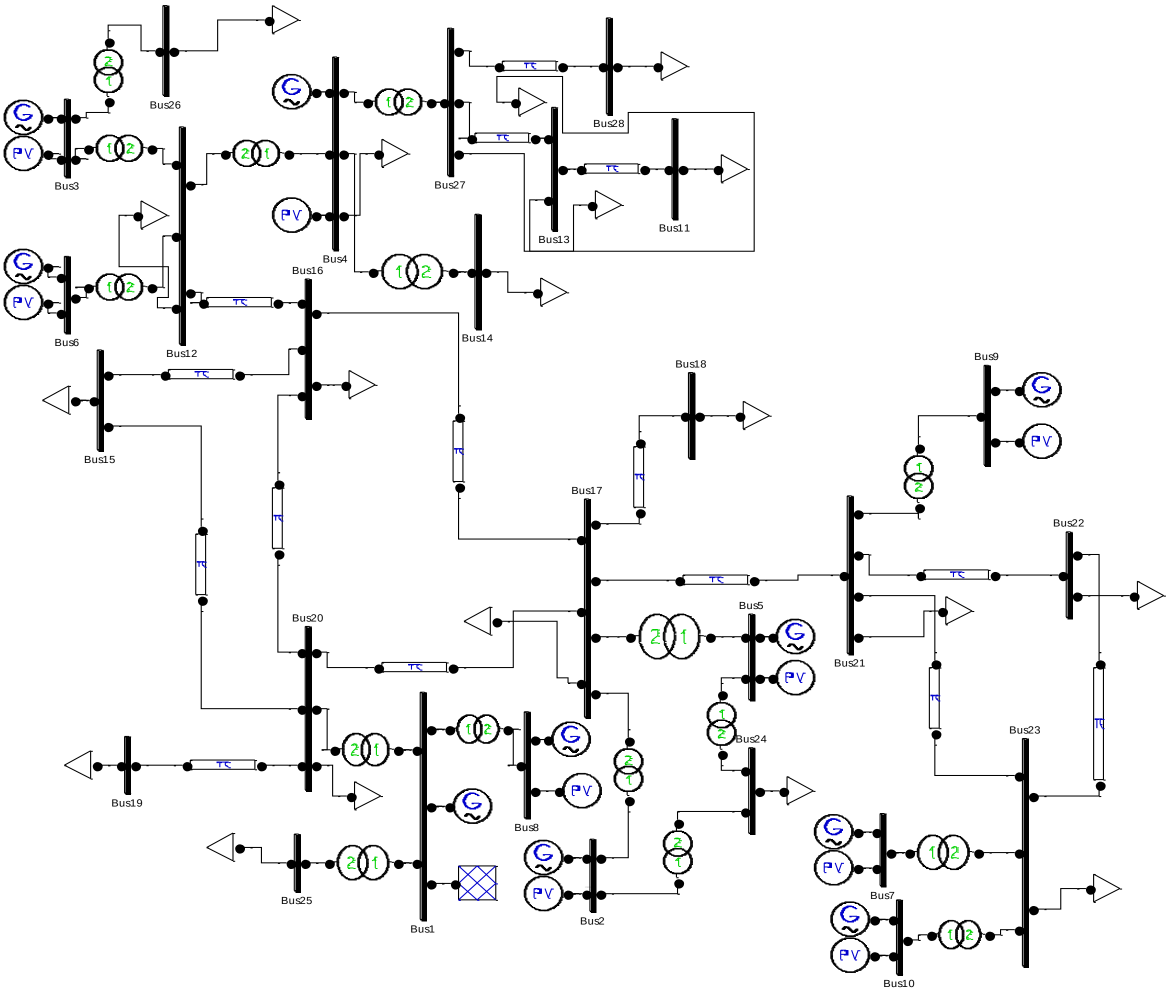

Fig. 5: SIMULINK model / run mode for power flow solution of 28 – bus power network.

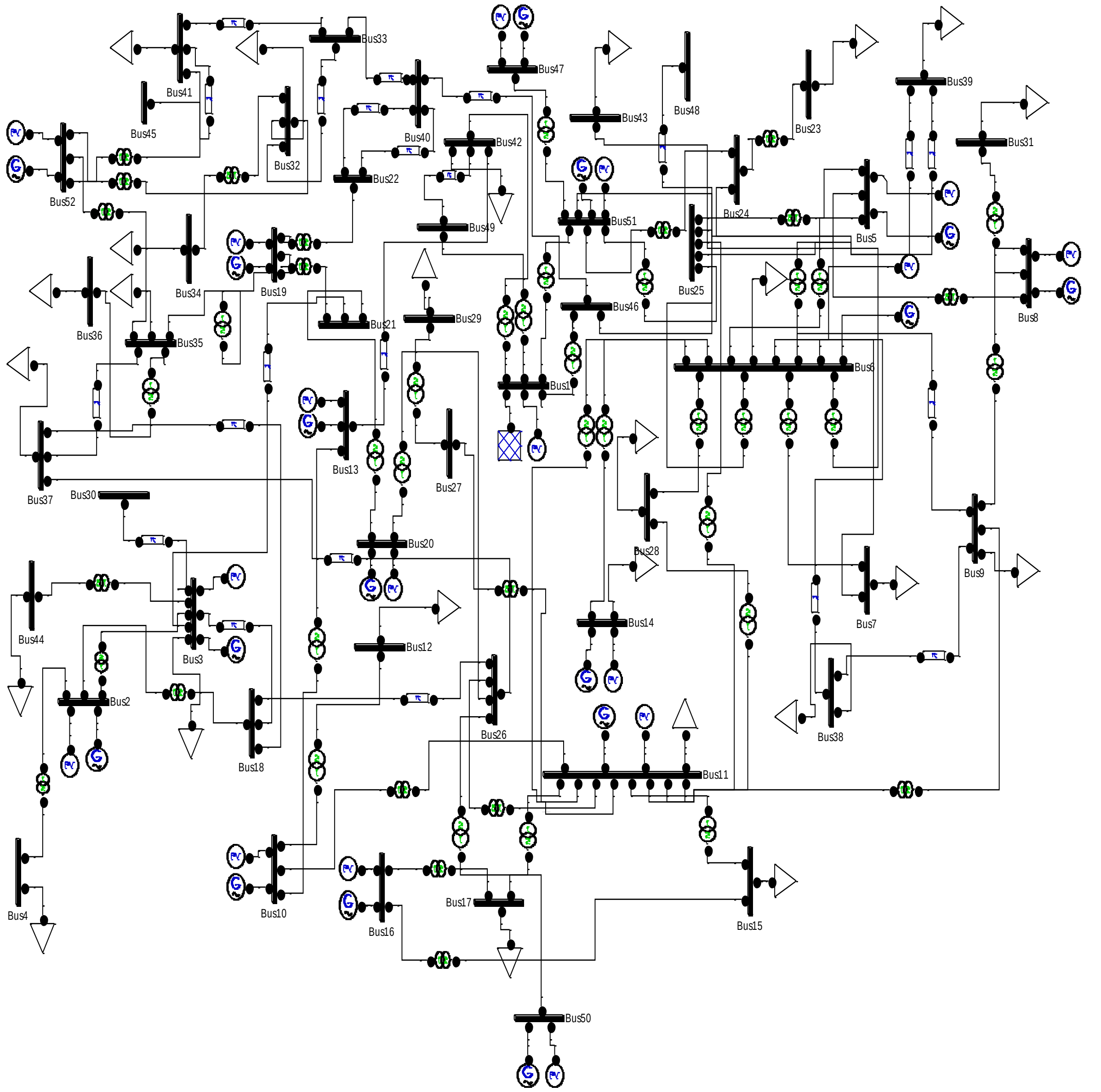

Fig. 6: SIMULINK model / run mode for power flow solution of 52– bus power network.

4.0 Results and Discussion

Newton-Raphson power flow simulation method was applied to 28-bus and 52-bus systems to derive the reduced Jacobian matrix, which produced the voltage profile of all the buses as presented in tables 5 and 6, figures 7 and 8 respectively. Tables 5 and 6 showed the bus voltage outputs in per unit, phase angles in radians, generation profile and power loading points respectively.

4.1 Load/ Power Flow solution for 28-bus network

The power flow solution result of the 28-bus system is shown in table 5 and the corresponding voltage profile of the system is presented in figure 7. The angle profile plot for 28-bus power network is shown in figure 8.

Table 5: Power flow solution result for 28-bus power network.

Bus No	V [pu]	phase [rad]	P gen [pu]	Q gen [pu]	P load [pu]	Q load [pu]
1	0.74977	0	-3.6852	4.3495	0	0
2	0.86715	0.21181	4.0233	1.0335	0	0
3	0.43687	-0.25855	0	0	3.7713	2.8285
4	0.69127	0.06161	0	0	0	0
5	0.4811	-0.25096	0	0	0	0
6	0.65627	0.0292	0	0	0	0
7	0.67094	-0.07429	0	0	3.7713	2.8285
8	0.66152	-0.05879	0	0	3.7713	2.8285
9	0.77577	0.02509	0	0	0	0
10	0.68183	-0.10528	0	0	3.7713	2.8285
11	0.71925	-0.03597	0	0	3.7713	2.8285
12	0.77843	0.02995	4.0211	2.3207	0	0
13	0.74504	0.00059	0	0	0	0
14	0.78359	0.11086	0	0	0	0
15	0.78555	0.11221	0	0	3.7713	2.8285
16	0.85218	0.20313	0	0	0	0
17	0.77737	0.02849	0	0	0	0
18	0.74977	0	0	0	0	0
19	0.69886	0.0715	0	0	0	0
20	0.63648	0.00061	0	0	0	0
21	0.60515	-0.00463	0	0	3.7713	2.8285
22	0.69886	0.0715	4.0169	3.5129	0	0
23	0.65627	0.0292	4.0268	1.827	0	0
24	0.77632	0.02704	4.0304	0.40897	0	0
25	0.69886	0.0715	4.0169	3.5129	0	0
26	0.85353	0.20392	4.024	0.87026	0	0
27	0.75013	0.00037	4.0188	3.1318	0	0
28	0	0	0	0	0	0
TOTAL			**28.493**	**31.8375**	**20.96753**	**19.7995**

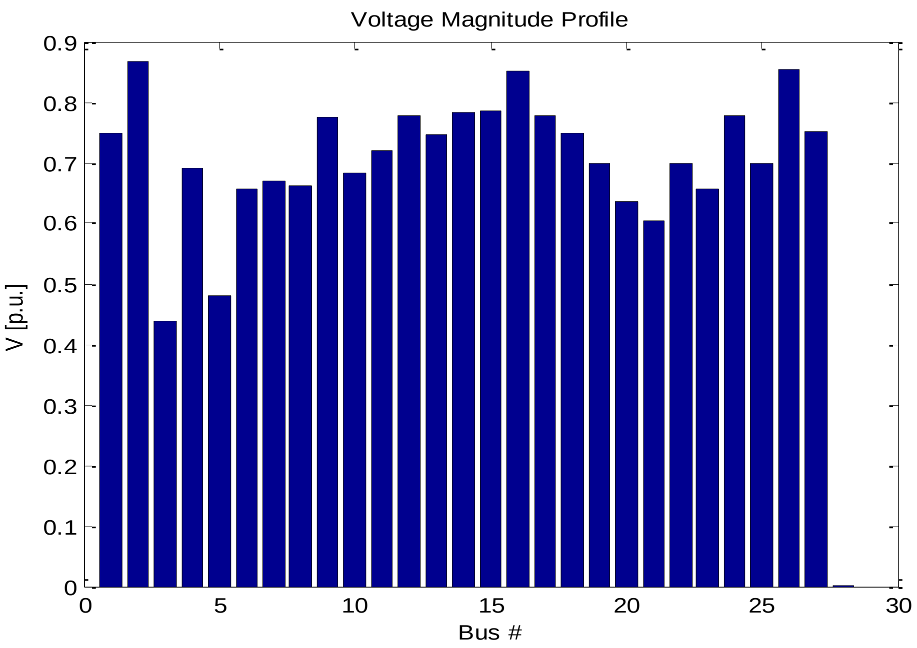

Fig 7: voltage profiles of 28 bus power network.

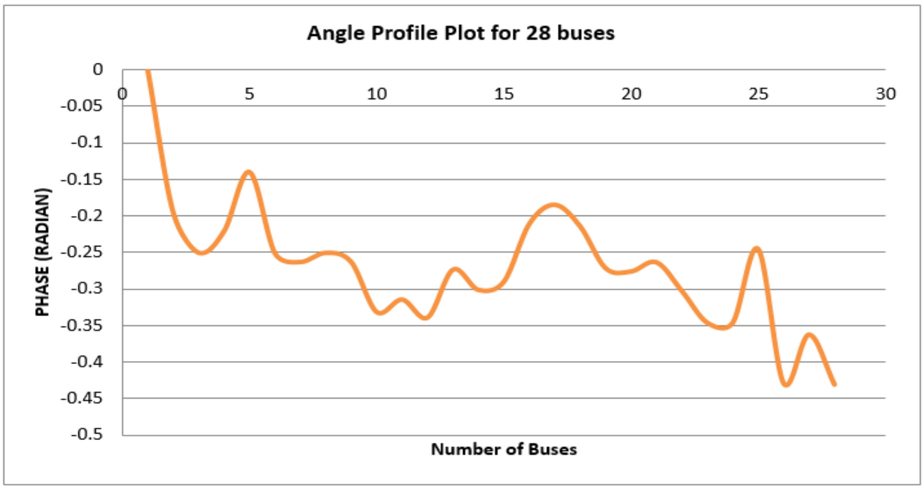

Fig. 8: Angle profile plot for 28-bus power network.

4.2 Load/ Power Flow Solution for 52-bus Power Network

The power flow solution result of the 52-bus system is shown in Table 6 and the corresponding voltage profile is presented in figure 9. The angle profile plot for the improved stable 52-bus power network is shown in figure 10.

Table 6: Power flow solution Result for the 52-bus power network.

Bus	V (pu)	Phase (rad)	P_{Gen}(p.u)	Q_{Gen}(p.u)	P_{load}(p.u)	Q_{load}(p.u)
1	1	0	11.1069	1.1529	0	0
2	1	-0.19497	1.2	1.0925	0	0
3	1	-0.25022	1.2	4.5426	1.2	0.9
4	0.97842	-0.22054	0	0	1.2	0.9
5	1	- 0.1395	1.2	0.36107	0	0

6	1	- 0.25084	1.2	0.9	1.2	0.9
7	0.98941	- 0.26288	0	0	1.2	0.9
8	1	- 0.25025	1.2	0.92494	0	0
9	0.98941	- 0.26288	0	0	1.2	0.9
10	0.99278	- 0.33133	0	0	0	0
11	1	- 0.3143	1.2	1.6596	0	0
12	1	- 0.33895	1.2	1.287	0	0
13	1	- 0.2733	1.2	0.13845	0	0
14	0.99997	- 0.30108	0	0	0	0
15	0.99045	- 0.2899	0	0	0	0
16	0.96593	- 0.21064	0	0	1.2	0.9
17	0.98779	- 0.18442	0	0	0	0
18	0.99579	- 0.21394	0	0	0	0
19	0.99612	- 0.27135	0	0	0	0
20	0.97721	- 0.27582	0	0	0	0
21	0.98941	- 0.26317	0	0	1.2	0.9
22	0.95509	- 0.30263	0	0	1.2	0.9
23	1	- 0.3461	1.2	2.0784	1.2	0.9
24	1.0001	- 0.3461	0	0	0	0
25	0.97842	- 0.24503	0	0	1.2	0.9
26	0.95747	- 0.42907	0	0	1.2	0.9
27	0.96731	- 0.36225	0	0	0	0
28	0.95613	- 0.43075	0	0	1.2	0.9
29	0.97484	- 0.37787	0	0	1.2	0.9
30	0.95266	- 0.40481	0	0	1.2	0.9
31	0.96315	- 0.35244	0	0	1.2	0.9
32	0.95713	- 0.29091	0	0	1.2	0.9
33	0.96083	- 0.20799	0	0	1.2	0.9
34	0.97842	- 0.36452	0	0	1.2	0.9
35	0.97858	- 0.2501	0	0	0	0
36	0.97508	- 0.409	0	0	1.2	0.9
37	0.98555	- 0.04476	0	0	1.2	0.9
38	0.97842	- 0.27641	0	0	1.2	0.9
39	0.97842	- 0.37167	0	0	1.2	0.9
40	0.97513	- 0.40901	0	0	0	0
41	0.99138	- 0.06023	0	0	0	0
42	1	- 0.11712	1.2	-0.0553	0	0
43	0.99143	- 0.06023	0	0	0	0
44	0.99671	- 0.01096	0	0	0	0
45	1	- 0.23095	1.2	0.65279	0	0
46	1	- 0.2454	1.2	0.13482	0	0
47	1	- 0.12494	1.2	1.9093	0	0
48	1	- 0.39782	1.2	4.2497	0	0
49	1	- 0.25084	1.2	3.9472	1.2	0.9
50	0.98936	- 0.25354	0	0	1.2	0.9
51	1	- 0.21946	1.2	2.1818	0	0
52	0.98672	- 0.25313	0	0	1.2	0.9
TOTAL			**30.3069**	**27.1577**	**30.00**	**22.50**

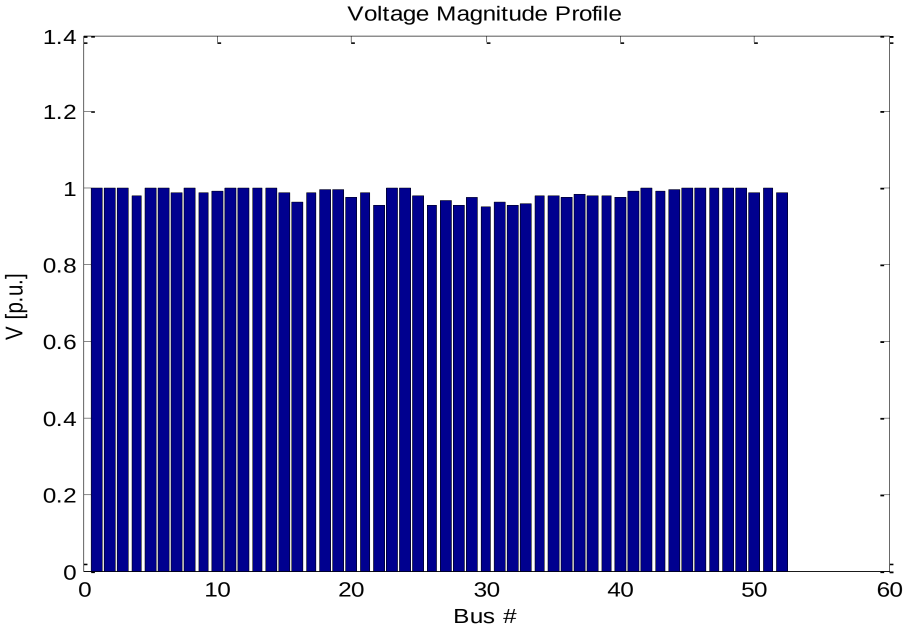

Fig. 9: Voltage profile for 52-bus power network.

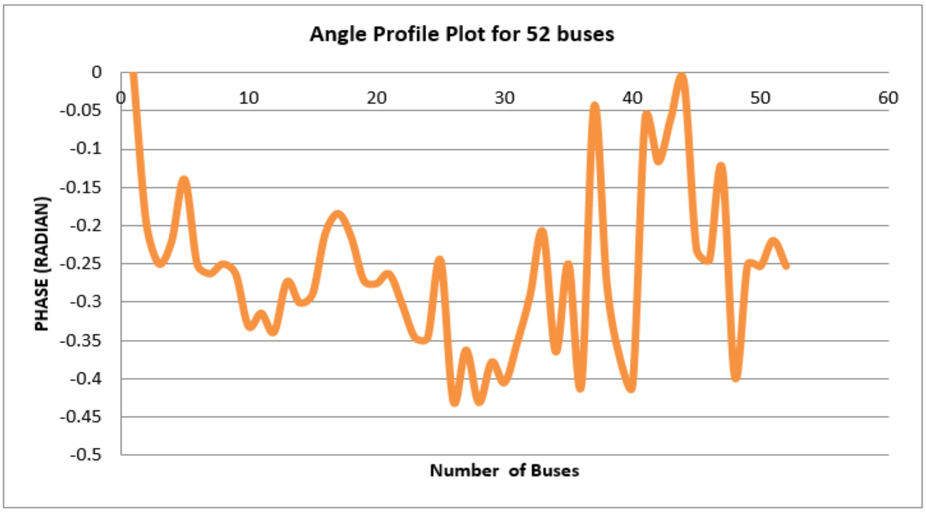

Fig. 10: Angle profile plot for the stable improved 52-bus power network.

4.3 Discussion

All the bus voltages of the 28-bus power network fall outside the acceptable voltage level limit of ±5% of the rated value of 0.95pu (313.5kV) to 1.05pu (346.5kV) as shown in table 5 and figure 7. In a stable improved 52-bus power network, all critical bus voltages met the acceptable range of ±5 of the rated value as shown in table 6 and figure 9. The weak buses recorded in the 28-bus power network are bus3 (Kainji GS), bus5 (Sapele PS) and bus21 (Onitsha TS) with voltage profiles of 0.43687pu (144.16kV), 0.4811pu (158.76kV) and 0.60515pu (199.70kV) as shown in table 5 and figure 7 respectively. Maximum active (P) and reactive (Q) load powers at different loading points are obtained as 32.2pu (3,220MW) and 24.3pu (2,430Mvar) for 28-bus, and 30.0pu (9,000MW) and 22.5pu (6,750Mvar) for the improved 52-bus power network as shown in tables 5 to 6 respectively. It can be observed that generation of reactive power decreases as the active power loading increases on both power networks. All the angle profiles for 28-bus and an improved 52-bus power networks showed acceptable phase angle/ power factor range from 0.99 to 1 as shown in tables 5 to 6 and figures 8 and 10 respectively. The improved 52-bus 330kV power network presented better power quality and improved voltage profile as shown in table 6 and figure 9.

5.1 Conclusion

To ensure continuity of power supply, effective power system operation planning, improvement and expansion of Nigerian power system network, a steady-state solution of the power system network, otherwise called power flow study was carried out on the existing Nigerian 330kV 28-bus and the improved 52-bus power system networks. The real power P, reactive power Q, critical bus voltage magnitude V, and voltage angle θ, associated with each bus of the present Nigerian 330kV 28-bus and improved interconnected 52-bus power networks were determined and displayed in tabulated forms. The power flow result showed that the 28-bus power network is confronted with overloaded bus bars, high voltage drop at all the transmission lines, a progressive congestion in the network and hence, unstable power network. These congestion in the network, overloaded lines and critical bus voltage problems were solved by adding new generating stations, new transformers and injecting reactive power into the present 28-bus power network, that gave rise to an improved stable 52-bus power network. From the results obtained for both 28-bus and 52-bus, it is recommended that the Nigerian 330kV power network be upgraded to run as an improved interconnected 52-bus power system network. This interconnected 52-bus power network comprising 52 buses and 17 generators will definitely improve electrical performance and stabilize the network.

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