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Power Losses and Bus Voltage in Transmission Lines of a 28 Bus System

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Abstract: *Inadequate supply of power is increasing day by day and causing a lot of problems and affecting various sectors of the country. This work involves the power analysis on the 28-bus network of the Nigeria 330kV integrated power system. The network consists of twenty-eight (28) buses, nine (9) generation stations, and fifty-two (52) transmission lines. Newton-Raphson (N-R) method of power flow analysis was carried out on the network using the relevant data. This analysis was carried out using PSS®E to determine bus voltages, real and reactive power losses of the integrated network. The work also involves carrying out line outages on various parts of the network to determine the effects on power losses and bus voltages. The results show that the following buses were not in line with the statutory limit of* $0.95 \leq V_i \leq 1.05$*: bus 13 (New-Heaven), bus 14 (Onitsha), bus 16 (Gombe), bus 19 (Jos), bus 22 (Kano). Bus 16 was observed to not satisfy the limit during the analysis going as low as 0.7602p.u. in one of the line outages (Makurdi-Mambila off). The total losses was also determined and the highest power loss was observed when Makurdi-Mambila line was taken out of service (142.54MW, 1072.16MVAR) and the lowest loss was observed when the double transmission line between Benin-Sapele were both taken out of service(105.0MW, 830.50MVAR). This result concludes that the Nigeria network still needs to undergo changes to ensure sustainable and reliable power system. Compensation is recommended on the above stated weak buses using Flexible Alternating Current Transmission System (FACTS).*

Keywords: *Transmission Lines, Bus Voltages, Power Losses, Compensation, Nodal Voltages.*

I. INTRODUCTION

The Nigeria Electricity Supply Industry needs more reliable, efficient and steady power but are faced with problems such as; inadequate power generation, insufficient funding of power stations, obsolete equipment, tools, safety facilities and operational techniques, insufficient electricity supply to consumers, inability to dispatch generated energy to meet load demand, large number of overloaded transformers etc. [1-4]. The aforementioned problems affect the power loss and voltage profile of the network. Moreover, in Nigeria there is an increasing demand in electricity. The demand for electricity is far more than the available energy for supply, this leads to the transmission system being loaded beyond its capacity and thereby stressing the system beyond its tolerable limit. This in turn affects the quality of power produced and the voltage profile of the network. A good voltage profile of a network is important and voltages of a network can be determined through power flow analysis. Power flow analysis is one of the most important aspects of power system planning and operation [3]. Power flow analysis is carried out to monitor voltages at various buses, real and reactive power flow between buses, to plan future expansion of existing systems etc.

As a result of the various problems faced by the Nigeria Electricity Supply Industry, there is a need to analyze the power losses and bus voltages to ensure adequate transmission and supply of electricity. The results obtained from the determination of power losses and bus voltages will provide a compiled profile of bus voltages and power losses. This will help in improving the Nigerian network and ensure a better performance of the entire system. It will further aid in identification of weak buses in the network and guide in recommendations for the weak buses compensation(s).

A power system network consists of generators, transformers, transmission lines, circuit breakers, etc., combined to supply electrical energy which is an essential source of electricity [5]. It could also be defined as a collection of buses interconnected through transmission lines [4]. Using Nigeria as a case study, most of its generating stations are situated afar from the load centers, with a partial longitudinal network, making it probable to experience low bus voltage, power loss at transmission lines, frequency fluctuations and poor systems damping in the network, resulting to instability of the network when exposed to certain fault conditions [3].

Power loss could be technical or non-technical. The losses which occur at the transmission lines are deemed technical; power may be lost through copper, dielectric or radiation/induction loss [6]. The non-technical aspect of power loss is due to theft, unpaid bills and any number of ways through which the power network is accessed illegally [7]. Bus voltage can be determined by identifying the weakest bus of the system using sensitivity indicator method [8].

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Furthermore, a load analysis is performed using the Newton-Raphson (N-R) method, to pinpoint the major buses with load increases and take necessary action to return voltage stability.There is need to reduce power loss to minimize cost of production and the high cost of electricity bills. Capacitor banks connected to the system in star or delta form generating capacitor power which cancels out inductive reactance of the system,

Compensating for the line losses. This solution can be applied at substations along transmission lines for effective power supply [6]. Power losses can also be minimized by reducing current, reducing reactance and impedance as well as minimizing voltages [9].

Evidently, many methods abound which can be employed to stop power loss and voltage instability, but most of them have side effects detrimental to certain aspects of the integrated power system. A more viable use of a power electronics based technology, called FACTS (Flexible AC Transmission System) is used [10]. Of all the FACTS controllers, STATCOM (Static Synchronous Compensator) was used by most of the literature consulted. Apart from the use of STATCOM, proper maintenance of the constituents of an integrated power system will in turn ensure reliable voltage stability [11].

Electricity losses occur at each stage of the power distribution process, beginning with the step-up transformers that connect power plants to the transmission system, and ending with the customer wiring beyond the retail meter.

Losses occur in both transmission and distribution lines and in transformers, the fundamental components of the electricity distribution system or “the grid.” Some losses, called “core” or “no-load” losses, are incurred to energize transformers in substations and on the distribution system. A larger share is labeled “resistive” or “copper” losses; these losses reflect the resistance of the materials themselves to the flow of electricity. The system consists of several key components: step-up transformers, transmission lines, substations, primary voltage distribution lines, line or step-down transformers, and secondary lines that connect to individual homes and businesses. These components are described as:

i. **Step-Up Transformers:** These are the transformers located at generating facilities, which convert the power produced at generating plants to voltages suitable for transmission lines.
ii. **Transmission System Conductors:** Long-distance transmission lines bring power from generators to the service territory of the distribution utility. Although the conductors themselves have low resistance, the length of the lines and the sizing of the conductors affect losses.
iii. **Distributing Stations:** These stations receive power at high voltage (330 kV) and deliver that power to multiple distribution substations Transformer losses that occur in substations are incurred twice – first in transforming power from high-voltage transmission to an intermediate voltage, then again at the substations transforming it down to primary voltage. The principal losses in distributing stations are transformer losses.
iv. **Voltage Regulators:** These are transformers with multiple taps installed along distribution circuits to enable increasing or decreasing voltage at various points.
v. **Primary Distribution Lines:** Primary lines connect substations to circuits that bring power into business districts and neighborhoods.
vi. **Line Transformers:** They convert primary voltage distribution power to the voltages we use in our homes and businesses.
vii. **Secondary Distribution Lines.** They connect line transformers to individual homes and businesses. They are typically very short, in part because at these lower voltages, the amperage needed to move power is significant, which requires larger conductors. Losses can be quite high owing to the high current.

The major problem in the electricity sector is the high power losses. Losses result from technical and non-technical reasons. The non-technical losses result from theft, unpaid bills and any other illegal ways of accessing the network. Technical losses are the results of generation, transmission, distribution and operation systems [7].

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Core losses are typically 25 to 30 percent of total distribution losses, and do not increase (or decrease) with changes in load. They are largely influenced by the characteristics of the steel laminations used to manufacture the core of transformers. Resistive losses are analogous to friction losses in the lines and transformers. As loads increase, the wires (including those in the transformers) get hotter, the material becomes more resistive, and line losses increase. For this reason, resistive losses increase exponentially with the current on a line [12]. Core losses occur at low load levels while at peak electrical demand periods, resistive losses are experienced.

The increasing demand for electricity in Nigeria is far more than what is available, thus resulting in the interconnected transmission systems being heavily loaded and stressed beyond their allowable tolerable limit. It is faced with so many problems such as; Inability to effectively dispatch generated energy to meet the load demand, large number of uncompleted transmission line projects, reinforcement and expansion projects in the power industry [3]. The above problems are true but also it can be said that unbalanced load sharing, inadequate generation of electricity to mention a few also pose as a problem.

Some of the transmission lines are also Fragile and radial nature, which is prone to frequent system collapse. Poor network configuration in some regional work centers, controlling the transmission line parameters, large numbers of overloaded transformers in the grid system, frequent vandalism of 330kV transmission lines in various parts of the country and using the transmission lines beyond their limit [3].

Considering the fact that most of the existing Nigeria generating stations are located far from the load centers with partial longitudinal network, there is possibility of experiencing low bus voltages, lines overload, frequency fluctuations and poor system damping in the network, thus making the stability of the network to be weak when subjected to fault conditions. Line losses can be linked to a number of factors, such as:

i. Quality of the connections at each end of the conductors.
ii. Size of the conductor relative to the amperage it carries.
iii. voltage at which the conductors operate

The losses in any system would, however, depend on the pattern of energy use, intensity of load demand, load density, and capability and configuration of the transmission and distribution system that vary for various system elements [12].

Bus bar is a term used for a conductor carrying an electric current to which many connections may be made. The term bus is derived from the word omnibus, meaning collector of things. Thus electrical bus bar is the collector of electrical energy at one location. Bus bars are merely convenient means of connecting switches with other equipment into various arrangements. The bus bars in substations are usually bare rectangular x-section bars but they can be of other shapes also, as round tubes, round solid bars or square tubes. The bus bars are usually made of aluminum; this is because as an electric conductor it has quite a number of advantages over copper, which include lower cost for equal current carrying capacity, excellent corrosion resistance and ease of formability [13]. A bus is a node at which one or many lines of one/many loads and generators are connected. It is indicated by a vertical line at which several components are connected. Buses are associated with some electrical quantities which depending on the type of bus, one or two of such quantities are meant to be determined. These quantities include:

- Voltage $|V|$
- Phase Angle $|\delta|$
- Active Power $|P|$
- Reactive Power $|Q|$

Buses are further classified based on the stated quantities. They include:

a. Generation Bus (Voltage-controlled Bus): It's also known as the P-V bus. Here, the magnitude of the voltage V corresponds to the generator voltage and the active power as given by the ratings of the device. The voltage is maintained at a specific value while the reactive power Q varies. The unknown quantities to be determined here are the Reactive Power Q and the Phase Angle δ.

b. Load Bus (P-Q Bus): The total injected power, both reactive and active power is specified in this type of bus. Magnitude and phase angle of the voltage is to be obtained. P and Q as that of a load bus voltage are allowed to vary within permissible values i.e. 5%.

c. Slack Bus (Reference or Swing Bus): In power system, there can be various generation buses and one is chosen as a slack /swing bus. At this bus, the magnitude and phase voltage are stated, the phase angle is assumed to be zero. The slack bus provides or absorbs active and reactive power to and from the transmission line to provide for losses, since these variables are unknown until the final solution is established. The system reference phase angle is defined as slack bus.

The active and reactive power is to be determined. Slack buses are due to I^2R losses and are not precisely known in advance and therefore total power injected cannot be specified for every bus. Cases where the slack bus is specified, generator bus with maximum active power is chosen as reference bus. Difference between expected and solved output (MW) gives the error in the estimate of the system I^2R losses. In swing bus, the active power is normally assumed to be unknown. In carrying out load flow studies, slack buses tend to balance the active load and reactive power and they also provide for load losses by absorbing/ emitting of active and (or) reactive power to and from a system [13].

Table I: Various buses and parameters

	P	Q	V	δ
P-Q bus	Known	Known	Unknown	unknown
P-V bus	Known	unknown	Known	Unknown
Slack bus	Unknown	unknown	Known	Known

A. Bus-Bars protection

The most commonly used schemes for bus zone protection are [9]: Backup protection, Frame leakage protection and Differential Over current Protection which includes Circulating current protection and Voltage Overvoltage Protection.

1) Backup protection for Bus-Bars

It is the simplest of all to protect the buses with the aid of backup protections of the connected, supplying element which should respond to any fault appearing on the buses. Bus backup protection may also mean that in case the breaker fails to operate for a fault on the outgoing feeder, it must be regarded as a fault. It should then open all breakers on that bus. Such a backup protection can be provided with an appropriate time delay through a timer

2) Frame Leakage or Fault-Bus Protection

This is the simplest form of protection. This method consist of insulating the bus-supporting structure and its switchgear from the ground, interconnecting all the framework, circuit breakers tanks, etc. and provided a single ground tank connection through a CT that feeds an over current relay. The over current relay controls a multi-contact auxiliary relay that trips the breakers of all circuits connected to the bus.

3) Differential over Current Protection

a) Current Differential Protection

The protection schemes are based on the simple circulating current principle that under normal operating or external fault condition the sum of current entering into a bus-bar will be equal to the sum of current leaving the bus-bar.

If the sum of current is not zero, then it is because of short circuit current. Hence this type of scheme applies to both types of faults, i.e., phase-to-phase fault as well as ground fault.

b) **Voltage Differential Protection Relay**

In these schemes, CTs without iron cores, known as linear couplers is employed so that they have a much larger number of secondary turns that a core iron CT.
The secondary relay of CTs is connected in series and the differential relay coil connected across them. Under Normal operating condition or external fault conditions the sum of voltage induces in the secondary windings is zero in the event of an internal fault on the bus bar, the voltage of the CTs in all source circuits adds to cause the flow of current through the secondary windings and the differential relay operating coil.

There different types of bus protection which includes: Over current, Communication-Based Schemes, High-Impedance Current Differential, Distance, Linear Couple, Low-Impedance Current Differential, Arc Flash Detection, etc. But this paper is limited to protecting the transmission line. Losses which occur in transmission lines may be any of these three types: Copper, Dielectric and Radiation or Induction Losses.

II. METHODOLOGY

The following steps will be followed to determine the power losses and bus voltage on the 28 bus integrated power system:

a. Run Newton-Raphson load flow of the network.
b. Determine the power losses on the network with the results obtained from the load flow.
c. Determine the bus voltages of the network with the results of the Newton-Raphson load flow analysis.
d. Check the effect of line outage plans on power losses and bus voltages the existing geo-political zones of Nigeria.

The data used were modeled and simulated using PSSE using Newton-Raphson power flow algorithm as shown in Figure 1.

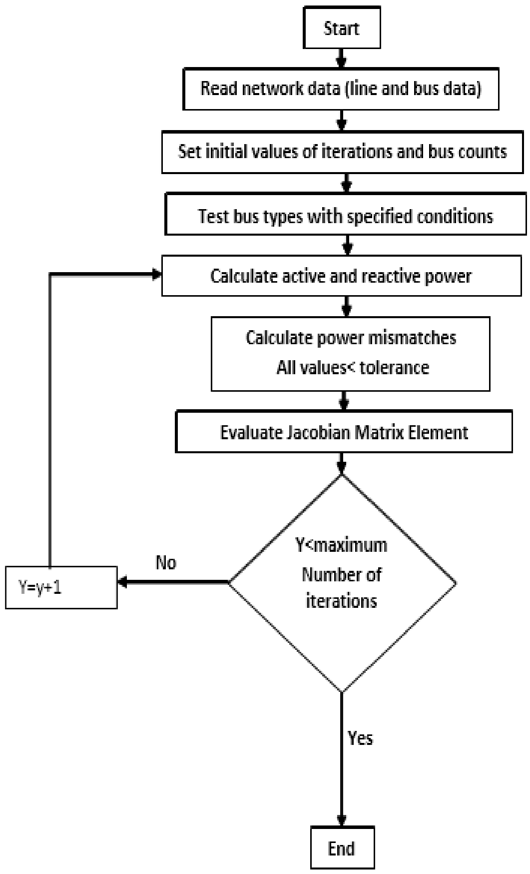

Fig. 1: Flowchart for Newton-Raphson Load Flow Algorithm

Step 1: Enter the Nigeria 330kV system data i.e. line data, bus data
Step 2: Set initial values of iterations and bus counts.

$$V_i = |V_{i.5p}| < 0^0 \; (at\ all\ PV\ buses) \qquad (1)$$

$$V_i = 1 < 0^0 \; (at\ all\ PQ\ buses) \qquad (2)$$

Step 3: Test bus, and then specify type using specified data
Step 4: Set the tolerance limit (convergence criterion)
Step 5: Form Y-Bus matrix
Step 6: Compute the active and reactive power of the network using equations respectively.

$$P_{i\,Cal} = P_i = G_{ii}|V_i|^2 + \sum_{k=i}^{k=1} |V_i||V_k|\left(G_{ik}\cos u_{ik} + B_{ik}\sin u_{ik}\right) \qquad (3)$$

$$Q_{i\,Cal} = Q_i = -B_{ii}|V_i|^2 + \sum_{k=i}^{k=1} |V_i||V_k|\left(G_{ik}\sin u_{ik} + B_{ik}\cos u_{ik}\right) \qquad (4)$$

Step 7: Evaluate the Jacobian matrix and solve the linearized equation

$$\begin{bmatrix} \Delta U^{(r)} \\ \Delta U^{(r)} \\ |V| \end{bmatrix} = \left[J^{(r)}\right]^{-1} \begin{bmatrix} \Delta P^{(r)} \\ \Delta Q^{(r)} \end{bmatrix} \qquad (5)$$

Step 8: Compute power mismatches using equations.

$$\Delta P_i^{(r)} = P_{i.5p} - P_{i\,Cal}^{(r+1)}\ (at\ PV\ and\ PQ\ buses) \quad (6)$$

$$\Delta Q_i^{(r)} = Q_{i.5p} - Q_{i\,Cal}^{(r+1)}\ (at\ PQ\ buses) \quad (7)$$

Step 9: Update nodal voltages using Figure 2.

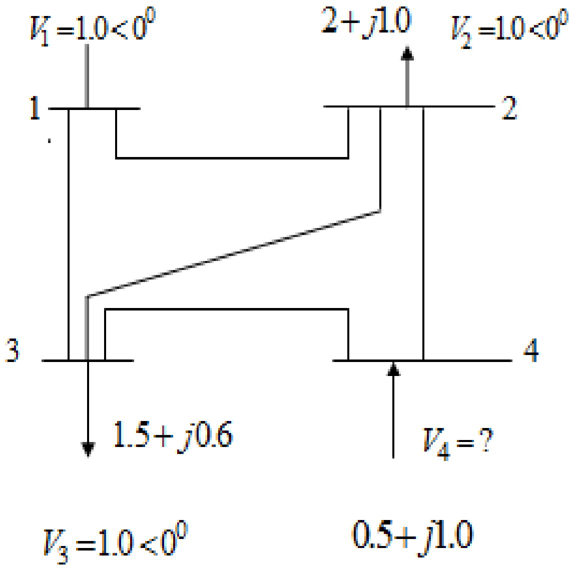

Fig. 2: Nodal voltages

$$Y_{12} = \frac{1}{0.05 + j0.25} = 0.77 - j3.85 p.u.$$

$$Y_{23} = \frac{1}{0.15 + j0.50} = 0.55 - j1.85 p.u.$$

$$Y_{13} = \frac{1}{0.10 + j0.50} = 1.0 - j3.0 p.u.$$

$$Y_{34} = \frac{1}{0.15 + j0.50} = 2.0 - j6.0 p.u.$$

$$Y_{24} = \frac{1}{0.10 + j0.30} = 1.0 - j3.0 p.u.$$

$$Y_{Buj} = \begin{bmatrix} (Y_{12}+Y_{13}) & -Y_{12} & -Y_{13} & 0 \\ -Y_{12} & (Y_{12}+Y_{23}) & -Y_{23} & -Y_{24} \\ -Y_{12} & -Y_{32} & (Y_{13}+Y_{23}+Y_{34}) & -Y_{34} \\ 0 & -Y_{24} & -Y_{34} & (Y_{24}+Y_{34}) \end{bmatrix} \quad (8)$$

$$Y_{Buj} = \begin{bmatrix} (7.07\angle -75.0) & 3.93\angle 106.4 & 3.16\angle 106.4 & 0 \\ 3.93\angle 106.4 & (8.96\angle -75.0) & 1.91\angle 106.4 & 3.16\angle 106.4 \\ 3.16\angle 106.4 & 1.91\angle 106.4 & (11.4\angle -75.0) & 6.32\angle 106.4 \\ 0 & 3.16\angle 106.4 & 6.32\angle 106.4 & (9.49\angle -75.0) \end{bmatrix} \quad (9)$$

1st Iteration

$$P_4^{\,0} = |V_4^{\,0}||V_2^{\,0}||Y_{24}|Cos(\theta_{24} - \delta_2^{\,0} + \delta_4^{\,0})$$
$$+ |V_3^{\,0}||V_4^{\,0}||Y_{34}|Cos(\theta_{34} - \delta_2^{\,0} + \delta_4^{\,0}) + (V_4^{\,0})^2|Y_{44}^{\,0}|Cos(\theta_{44})$$
$$= (1)(1)(1.91)Cos(106.4) + (1)(1)(6.32)Cos(106.4)$$
$$+ (1)^2(9.49)Cos(-75) = 0.13 p.u$$

$$P_3^{\,0} = |V_3^{\,0}||V_1^{\,0}||Y_{13}|Cos(\theta_{31} - \delta_1^{\,0} + \delta_3^{\,0})$$
$$+ |V_3^{\,0}||V_4^{\,0}||Y_{34}|Cos(\theta_{34} - \delta_3^{\,0} + \delta_4^{\,0}) + (V_3^{\,0})^2|Y_{33}^{\,0}|Cos(\theta_{33})$$
$$= (1)(1)(3.16)Cos(106.4) + (1)(1)(6.32)Cos(106.4)$$
$$+ (1)^2(11.4)Cos(-75) = 0.27 p.u$$

$$Q_4^{\,0} = -|V_4^{\,0}||V_2^{\,0}||Y_{24}|Sin(\theta_{24} - \delta_2^{\,0} + \delta_4^{\,0})$$
$$- |V_3^{\,0}||V_4^{\,0}||Y_{34}|Sin(\theta_{34} - \delta_3^{\,0} + \delta_4^{\,0}) - (V_4^{\,0})^2|Y_{44}^{\,0}|Sin(\theta_{44})$$
$$= -(1)(1)(1.91)Sin(106.4) - (1)(1)(6.32)Sin(106.4)$$
$$- (1)^2(9.49)Sin(-75) = 1.27 p.u$$

$$\Delta P_4^{\,0} = P_Y^{\,sch} - P_4^{\,0} = 0..5 - 0.13 = 0.30 p.u$$
$$\Delta P_3^{\,0} = P_3^{\,sch} - P_3^{\,0} = -1.5 - 0.27 = -1.77 p.u$$
$$\Delta Q_4^{\,0} = Q_Y^{\,sch} - Q_4^{\,0} = 1 - 1.27 = -0.27 p.u$$

$$\begin{bmatrix} \Delta P_{4^0} \\ \Delta P_{3^0} \\ \Delta Q_{4^0} \end{bmatrix} = J^{-1} \begin{bmatrix} \Delta \delta_{4^0} \\ \Delta \delta_{3^0} \\ \Delta V_{4^0} \end{bmatrix}$$

$$J = \begin{bmatrix} \frac{\Delta P_{4^0}}{\Delta \delta_{4^0}} & \frac{\Delta P_{4^0}}{\Delta \delta_{3^0}} & \frac{\Delta P_{4^0}}{\Delta |V_{4^0}|} \\ \frac{\Delta P_{3^0}}{\Delta \delta_{4^0}} & \frac{\Delta P_{3^0}}{\Delta \delta_{3^0}} & \frac{\Delta P_{3^0}}{\Delta |V_{4^0}|} \\ \frac{\Delta Q_{4^0}}{\Delta \delta_{4^0}} & \frac{\Delta Q_{4^0}}{\Delta \delta_{3^0}} & \frac{\Delta Q_{4^0}}{\Delta |V_{4^0}|} \end{bmatrix}$$

$$\frac{\Delta P_{4^0}}{\Delta \delta_{4^0}} = |V_{4^0}||V_{2^0}||Y_{42}| \sin(\theta_{42} - \delta_4)$$
$$+ |V_{4^0}||V_{3^0}||Y_{46}| \sin(\theta_{43} - \delta_3 + \delta_4)$$

Substituting values,

$$\frac{\Delta P_{4^0}}{\Delta \delta_{4^0}} = -(1)(1)(3.16)\sin(106.4)$$
$$+ (1)(1)(6.32)\sin(106.4) = 9.09 p.u.$$

$$\frac{\Delta P_{3^0}}{\Delta \delta_{3^0}} = -|V_{4^0}||V_{3^0}||Y_{43}|\sin(\theta_{34}-\delta_3+\delta_4)$$
$$= -(1)(1)(6.32)\sin(106.4) = 6.06\,p.u.$$

$$\frac{\Delta P_{4^0}}{\Delta |V_{4^0}|} = 2|V_{4^0}||Y_{44}|\cos(\theta_{44}) + |V_{4^0}||Y_{42}|\cos(\theta_{42}-\delta_3+\delta_4)$$
$$+ |V_{4^0}||Y\Delta||V_{4^0}|\cos(\theta_{43}-\delta_3+\delta_4)$$

Substituting values,

$$\frac{\Delta P_{4^0}}{\Delta |V_{4^0}|} = 2(1)(9.49)\cos(-75) + (1)(9.49)\cos(106.4)$$
$$+ (1)(9.49)\cos(106.4) = 2.24\,p.u.$$

$$\frac{\Delta P_{3^0}}{\Delta \delta_{4^0}} = \frac{\Delta P_{4^0}}{\Delta \delta_{3^0}} = -6.06\,p.u.$$

$$\frac{\Delta P_{3^0}}{\Delta \delta_{3^0}} = |V_{3^0}||V_{1^0}||Y_{31}|\sin(\theta_{42}-\delta_3+\delta_4)$$
$$+ |V_{4^0}||V_{3^0}||Y_{34}|\sin(\theta_{34}-\delta_3+\delta_4)$$

$$\frac{\Delta P_{3^0}}{\Delta \delta_{3^0}} = (1)(1)(3.16)\sin(106.4)$$
$$+ (1)(1)(6.32)\sin(106.4) = 9.09\,p.u.$$

$$\frac{\Delta P_{3^0}}{\Delta |V_{4^0}|} = |V_{3^0}||Y_{34}|\cos(\theta_{34}-\delta_3+\delta_4)$$
$$= (1)(6.32)\cos(106.4) = 1.78\,p.u.$$

$$\frac{\Delta Q_{3^0}}{\Delta \delta_{4^0}} = |V_{4^0}||V_{2^0}||Y_{42}|\cos(\theta_{42}-\delta_3+\delta_4)$$
$$+ |V_{4^0}||V_{3^0}||Y_{34}|\cos(\theta_{34}-\delta_3+\delta_4)$$

$$\frac{\Delta Q_{3^0}}{\Delta \delta_{4^0}} = (1)(1)(3.16)\cos(106.4)$$
$$+ (1)(1)(6.32)\cos(106.4) = -2.68\,p.u.$$

$$\frac{\Delta Q_{3^0}}{\Delta \delta_{4^0}} = -|V_{4^0}||V_{3^0}||Y_{42}|\cos(\theta_{43}-\delta_3+\delta_4)$$
$$= -(1)(1)(6.32)\cos(106.4) = 1.78\,p.u.$$

$$\frac{\Delta P_{3^0}}{\Delta |V_{4^0}|} = -2|V_{4^0}||Y_{44}|\sin(\theta_{44}) - |V_{4^0}||Y_{42}|\sin(\theta_{42}-\delta_2+\delta_4)$$
$$- |V_{4^0}||Y_{42}|\sin(\theta_{42}-\delta_2+\delta_4)$$

$$\frac{\Delta P_{3^0}}{\Delta |V_{4^0}|} = -2(1)(9.49)\sin(-75) - (1)(3.16)\sin(106.4)$$
$$- (1)(6.32)\sin(106.4) = 9.24\,p.u.$$

Putting the gotten values into J matrix,

$$J^{-1} = \begin{bmatrix} 9.09 & -6.06 & 2.24 \\ 6.06 & 9.09 & -1.78 \\ -2.68 & 1.78 & 9.24 \end{bmatrix}$$

$$J = \begin{bmatrix} 0.0738 & 0.0508 & -0.0081 \\ -0.0434 & 0.0762 & 0.0252 \\ 0.0298 & 0.001 & 0.1010 \end{bmatrix}$$

$$\begin{bmatrix} \Delta\delta_{4^0} \\ \Delta\delta_{3^0} \\ \Delta V_{4^0} \end{bmatrix} = \begin{bmatrix} 0.0738 & 0.0508 & -0.0081 \\ -0.0434 & 0.0762 & 0.0252 \\ 0.0298 & 0.001 & 0.1010 \end{bmatrix} \begin{bmatrix} 0.37 \\ -1.77 \\ 0.27 \end{bmatrix}$$

$$\Delta\delta_{4^0} = (0.0738\times 0.37) + (0.0508)\times(-1.77)$$
$$+ (-0.0081\times 0.27) = -0.064\,p.u.$$

$$\delta_{4^1} = \Delta\delta_{4^0} + \delta_{4^0} = -0.064\,p.u.$$

$$\Delta\delta_{3^0} = (-0.0434\times 0.37) + (0.0762)\times(0.0762\times(-1.77))$$
$$+ (-0.2520\times 0.27) = -0.112\,p.u.$$

$$\delta_{3^1} = \Delta\delta_{3^0} + \delta_{3^0} = -0.112\,p.u.$$

$$\Delta V_{3^0} = (0.0298\times 0.37) + (0.001)\times(-1.77)$$
$$+ (0.1010\times 0.27) = -0.0365\,p.u.$$

$$V_{4^1} = \Delta V_{4^0} + V_{4^0}$$
$$= 0.0365 + 1 = 1.0365\,p.u.$$

Using the formula in first iteration, other iterations can be obtained.

For 2nd Iteration:

$$P_{4^1} = 0.25\,p.u.;$$

$$P_{3^1} = 1.99\,p.u.;$$

$$Q_{4^1} = 1.65\,p.u.$$

Thus, $\delta_{4^2} = -0.454$; $\delta_{3^2} = -0.752$; $V_{4^2} = 0.9805\,p.u.$

Then for 3rd Iteration:

$P_{4^2} = -0.11\,p.u.$; $P_{3^2} = 0.53\,p.u.$; $Q_{4^2} = -0.15\,p.u.$

The network for this study consists of nine (9) generating stations, twenty-eight (28) buses and fifty-two (52) transmission line using Newton-Raphson as shown in Figure 3 and when modeled with PSSE, the following were obtained: active and reactive power losses, bus voltage magnitudes throughout the network. Table II shows the bus data [3] while Table III shows the transmission line data as shown in Appendix.

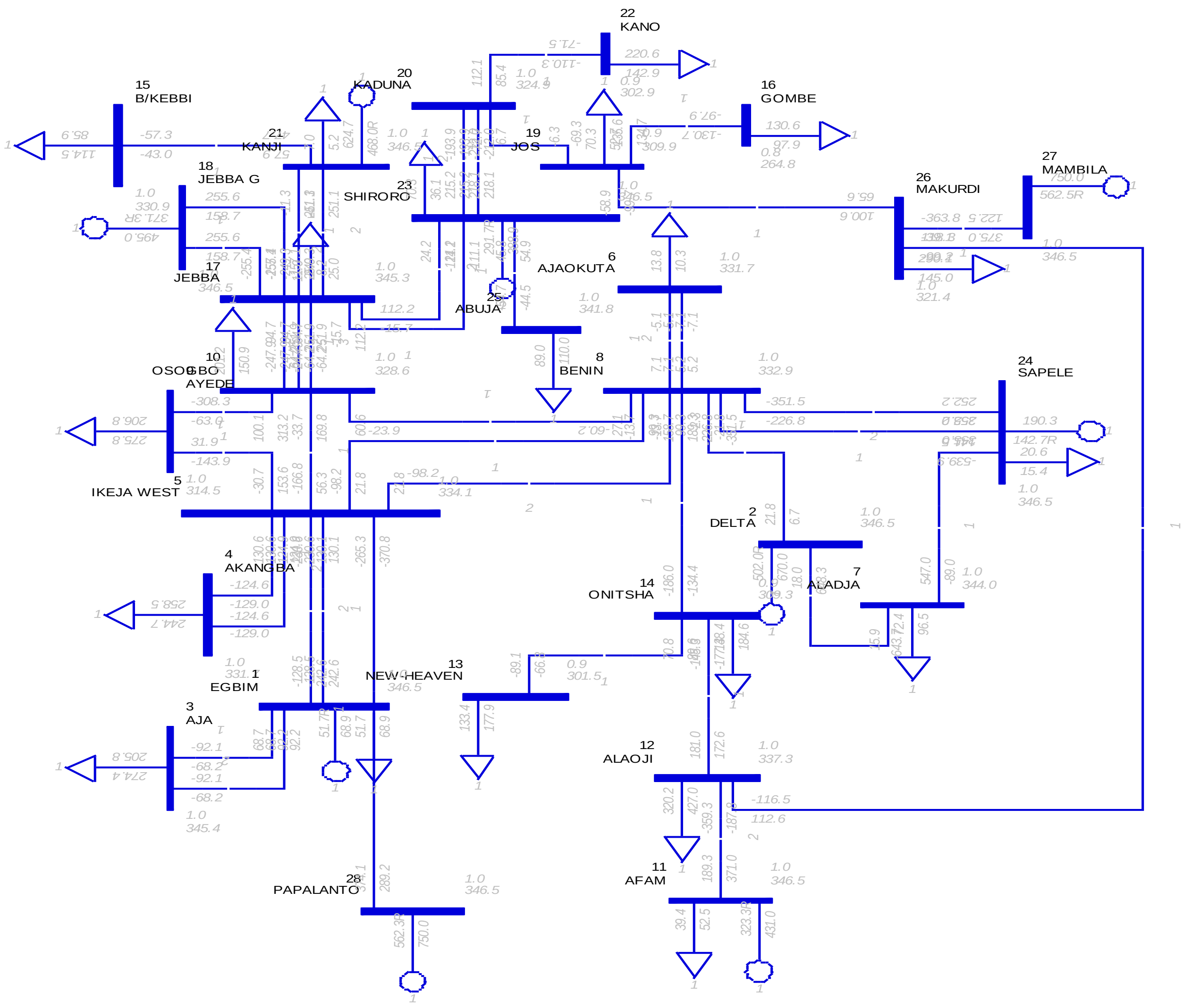

Fig. 3: The Nigerian 28-Bus Network.

III. RESULTS AND DISCUSSION

From the results obtained, the Nigeria 28-bus, 330kV integrated network converged with Newton Raphson load flow after four (4) iterations. A similar convergence was observed when the following lines were modeled using PSSE as shown in Figure 3: Onitsha-Alaoji, Ikeja-west-Papalanto, Abuja-Shiroro, B.Kebbi-Kainji, Makurdi-Mambila, Benin-Sapele1 (with one of the double transmission line taken out of service) and Benin-Sapele2 (with the two transmission lines out).

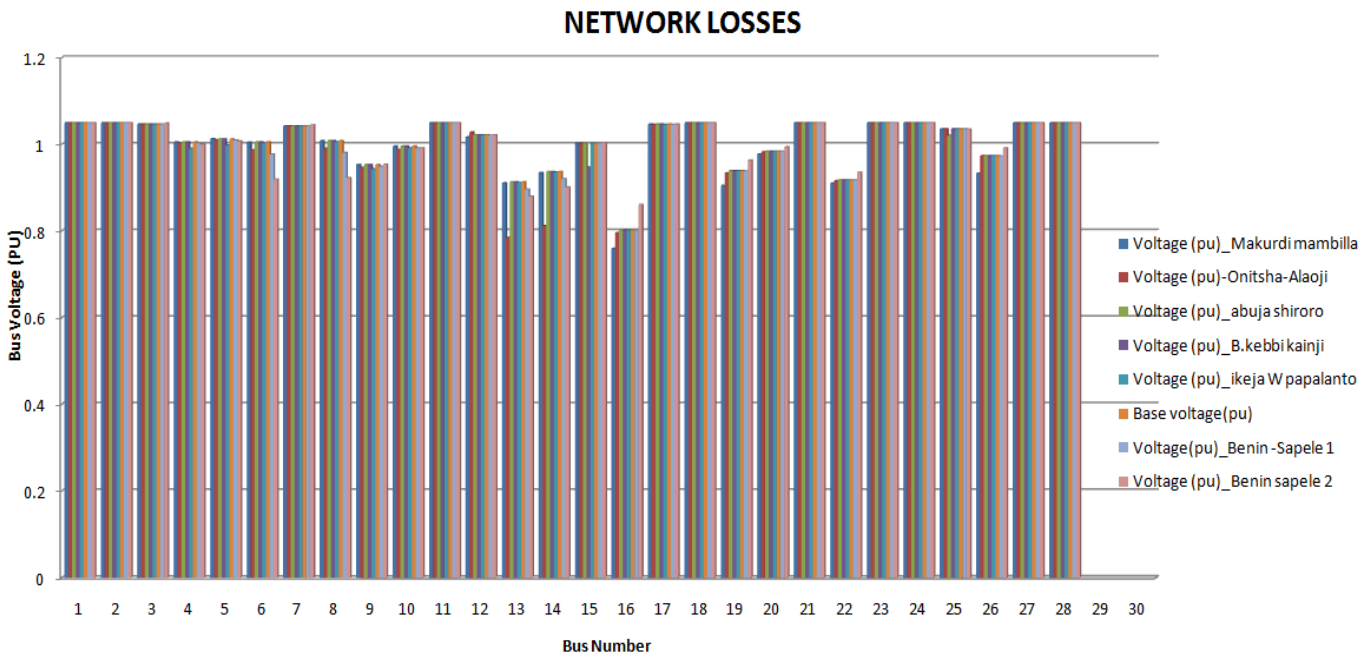

Fig. 4: Bus Network Voltage Profile

The Figure 3 above clearly shows the six (6) buses were below the statutory limit of $0.95 \leq V_i \leq 1.05$ and they include: bus 9 (Ayede), bus 13 (New-Heaven), bus 14 (Onitsha), bus 16 (Gombe), bus 19 (Jos), bus 22 (Kano)

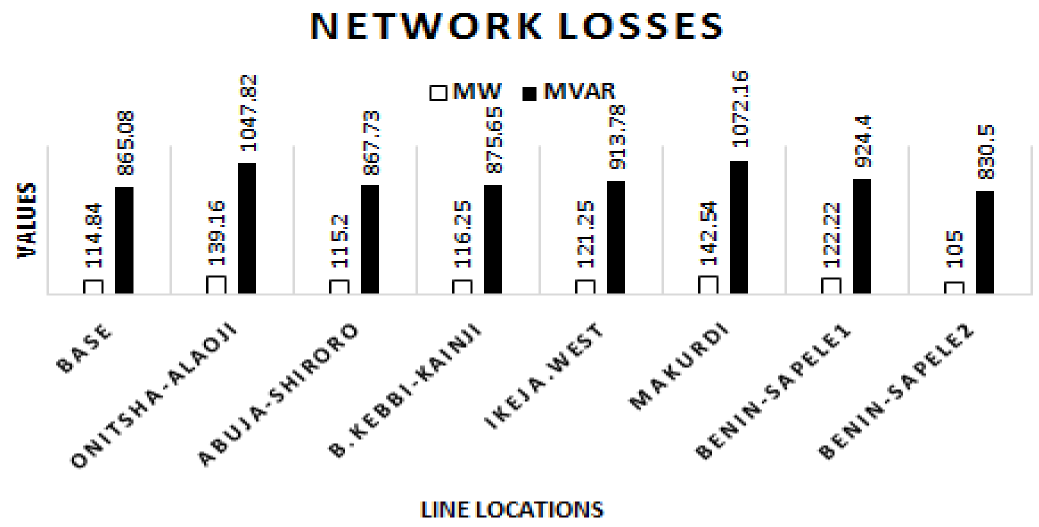

Fig. 5: Graph Showing Various Network Losses Observed in the System

From Figure 4, the losses obtained are quite high. Its observed that the highest power loss was obtained when Makurdi-Mambila line was out of service and the lowest obtained when Benin-Sapele 2 was taken out of service**.** Makurdi-Mambila line which gave the highest power loss could be as a result of low power factor and therefore needs compensation.

IV. CONCLUSIONS

The voltages of bus 9, 13, 14, 16, 19 and 22 which were observed to be below the statutory limit and can be termed weak buses proves that the 28-bus, Nigeria 330kV need a better voltage profile. These low voltages on these buses were recurring when the line outages were carried out. The lowest power loss which occurred when Benin-Sapele2 was taken out of service, it was also clear that despite being out of service, electricity supply to Benin could still be made available by the Delta generating station. From the results obtained compensation of these weak buses and high losses is recommended for expansion of the network. These will help in the improvement of the network and provide a better voltage profile of the network.

APPENDIX

Table II: Load data of the Nigeria 28-bus power network

Bus Number	Bus Name	Voltage Magnitude	MW (Load)	MVAR (Load)
1	Egbin	1.05	68.90	
2	Delta	1.05	0	0
3	Aja	1.0	274.40	205.80
4	Akangba	1.0	244.70	258.50
5	Ikeja-West	1.0	633.20	474.90
6	Ajaokuta	1.0	13.80	10.30
7	Aladja	1.0	96.50	72.40
8	Benin	1.0	383.30	287.50
9	Ayede	1.0	275.80	206.8
10	Oshogbo	1.0	201.20	150.90
11	Afam	1.05	52.50	39.40
12	Alaoji	1.0	427.0	320.20
13	New-Heaven	1.0	177.90	133.40
14	Onitsha	1.0	184.60	138.40
15	B.Kebbi	1.0	114.50	85.90
16	Gombe	1.0	130.60	97.90
17	Jebba	1.0	11.00	8.20
18	Jebba G	1.05	0	0
19	Jos	1.0	70.30	52.70
20	Kaduna	1.0	193.0	144.70
21	Kanji	1.05	7.00	5.20
22	Kano	1.0	220.60	142.90
23	Shiroro	1.05	70.30	36.10
24	Sapele	1.05	20.60	15.40
25	Abuja	1.0	110.0	89.00
26	Makurdi	1.0	290.10	145.00
27	Mambila	1.05	0	0
`28	Papalanto	1.05	0	0

Table III: Transmission Line data of the Nigeria 28-bus power network

Bus From	Bus To	Resistance (p.u.)	Reactance (p.u.)
3	1	0.0006	0.0044
3	1	0.0006	0.0044
3	1	0.0006	0.0044
4	5	0.0007	0.0050
4	5	0.0007	0.0050
1	5	0.0023	0.0176
1	5	0.0023	0.0176
5	8	0.0110	0.0828
5	8	0.0110	0.0828
5	9	0.0054	0.0405
5	10	0.0099	0.0745
6	8	0.0077	0.0576
6	8	0.0077	0.0576
2	8	0.0043	0.0317
2	7	0.0012	0.0089
7	24	0.0025	0.0186
8	14	0.0054	0.0405
8	10	0.0098	0.0742
8	24	0.0020	0.0148
8	24	0.0020	0.0148
9	10	0.0045	0.0340
15	21	0.0122	0.0916
15	21	0.0122	0.0916
10	17	0.0061	0.0461
10	17	0.0061	0.0461
10	17	0.0061	0.0461
11	12	0.0010	0.0074
11	12	0.0010	0.0074
12	14	0.0060	0.0455
13	14	0.0036	0.0272
13	14	0.0036	0.0272
16	19	0.0118	0.0887
17	18	0.0002	0.0020
17	18	0.0002	0.0020

17	23	0.0096	0.0721
17	23	0.0096	0.0721
17	21	0.0032	0.0239
17	21	0.0032	0.0239
19	20	0.0081	0.0609
20	22	0.0090	0.0680
20	22	0.0090	0.0680
20	23	0.0038	0.0284
20	23	0.0038	0.0284
23	25	0.0038	0.0284
23	25	0.0038	0.0284
12	26	0.0071	0.0532
12	26	0.0071	0.0532
19	26	0.0059	0.0443
26	27	0.0079	0.0591
26	27	0.0079	0.0591
5	28	0.0016	0.0118
5	28	0.0016	0.0118

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