Analysis of the Nigerian 330KV System Collapse Investigation Using Voltage Predictive index (VPI).

[1]S. .L. Braide and `[2] E. C. Obuah

[1, 2,] *Department of Electrical/Electronics Engineering, Power Option Rivers State University, Port Harcourt.*

ABSTRACT

The study on using voltage stability index to improve mitigation of voltage collapse was necessary, hence, Q-V modal analysis was used to predict voltage instability in the existing south-south/south-east 330Kv grid network. The application of NEPLAN 555 software package was used in the modelling of the south-south 330KV grid system. The violation of the simulated network was compensated using static var compensation (SVC) for improving deviation of loading margin of the buses close to the point of voltage collapse. This method was used because of the direct relation of the node voltage and reactive power changes which plays significant role in the analysis of voltage stability, the node voltage and reactive power change are also related to eigenvalues that give more accurate result for determining participation factors, this account for the prediction of weak buses that may consequently leads to voltage instability. The existing 330Kv grid consist of seven (7) generating station, twenty (20) transmission lines and eleven (11) load buses. The most critical node is identified by the least eigenvalues and from the selection once least eigenvalues are identified, they are evidently recommended as weak node for probable solution. Following the criteria of ranking as contained in table 4.2, which shows critical buses of the network exhibited higher participation factor particularly, bus-12 (New-heaven) followed by bus-18 (Ugwaji). These buses are selected as candidate buses targeted for intervention that required reactive power support for enhance system stability and prevent voltage collapse. Essentially, these buses are selected criteria and ranked as candidate's buses targeted for probable consideration in order to avoid system outages. Similarly, the Nigeria 330KV grid, 48 buses were also modelled using electrical transient analysers program (ETAP 19.0.1) on the view to assess the evaluation of five (5) predictive analyser for the examination of system operating condition for immediate remedial action. This 330Kv grid 48-buses provided the flexibility for the assessment and evaluation of five (5) predictive-indexes, including fast voltage stability index (FVSI), line stability index (LMN), line stability factor (LQP), Voltage stability index (LD) and novel line stability index (NLSI) are presented to predict the proximity of the line close to voltage collapse. These voltage stability indices are based on active and reactive power injection into the network configuration for system evaluation and performance measurement. The five (5) predictive indices actually examined and evaluated prediction of line voltage profile for the 330Kv transmission network, 48-buses. This study particularly engaged twenty-four (24) cases for each analysis of FVSI, LMN, LQP, LD and NLSI respectively which are graphically as contained in figure 4. Which show the predictive pattern, evidently, three (3) of the five (5) predictive indices including NLSI, LMN, and FVSI captured and investigated the predictive behaviour as line close to instability while the other two (2) (LQP, LD) do not have good predictive capacity for system collapse. That is LD and LQP are very slow to the prediction of system collapse. Qualitatively, in the case of line 1, the predictive value of the indices are: FVSI (0.895), LMN (0.89456), NLSI (1.04077.35) while LQP and LD are: (0.002975 and 0.00151002) this means that LQP and LD has slower property for the predictions of the line voltage instability order investigation. Consequently, the Nigerian 330Kv integrated power system is currently consisting of existing network, national independent power project (NIPP), and independent power producer (IPP). It contained generation stations, transmission line and buses. This complex network is highly challenging on daily basis to be attended to and given serious attention in the event of the unlikely to ensure quick restoration to allow the grid to gain synchronism to avoid system collapse using the study case as research-tool to enhanced reliable power supply.

Keywords: *Transient Analysis, Transmission Line, Voltage Collapse, Hybrid Renewable Energy Sources, Power System Stability Enhancement, Static Synchronous Compensator.*

I. INTRODUCTION

1.1 Background of the Study

     The exact date that electricity was invented wasn't documented, so many efforts have been made to understand the accurate time and place that electricity was first generated in the world till date haven't yielded

any result (Nenritmwa and Gotodok, (2022). It is, therefore, safe to say that electricity started in time immemorial. Before electricity came to be what we have now and use, various scientists played different yet complementary roles in the materialization of electricity, in 1752 Benjamin Franklin's famous kite experiment became the break-out moment for electricity cognizance. In 1831, British scientist Michael Faraday's discovery of basic principles of electricity generation is one of the major milestones in the evolution of electricity.

Uzoma (2020). The Nigerian electricity industry started in 1896 with the commissioning of Ijora Power Plant. The Electricity Corporation of Nigeria (ECN) was set up in 1951 for electricity distribution, while the Niger Dams Authority (NDA) was set up in 1961 for power generation and transmission. ECN and NDA were merged in 1972 to form the vertically integrated NEPA responsible for power generation, transmission, distribution and marketing throughout Nigeria. Major power generation for grid connection started in 1961. Between 1961 and 1990, total grid connected generation capacity grew to about 6,200MW, with over 10,000Km route length of transmission lines. Due to um-sustained investments and inefficiency in network and plant operations,

❖ Generation capability fell persistently and reached as low as below 2,000MW
❖ There was large scale transmission and distribution bottlenecks.

Due to graft and overbearing government inferences, and inefficiency in the Distribution arm of the sector

❖ customer satisfaction remained low
❖ revenue collection very poor

The low revenue collection affected investment capability of the industry; the viscous cycle continued. At the onset of the civilian administration in 1999, the Nigerian electric power sector had reached, perhaps, the lowest point in its 100 years history. Of the 79 generation units in the country, only 19 units were operationally reliable. Average daily generation was about 1,750 MW. No new power infrastructure was built between 1990 -1999. The newest plant was completed in 1990 and the last major transmission line built in 1987. An estimated 90 million people were without access to grid electricity. Accurate and reliable estimates of industry losses were unavailable, but were believed to be in excess of 40%. Based on the dismal state of the power sector, due to lack of investments, the government decided to embark on a power policy, which recommended reform of the sector.

Key objectives of the reform are to:

❖ Ensure an integrated and coordinated approach to power sector planning through the enactment of a policy document.
❖ Provide the enabling framework for private sector participation and competition in the power sector.
❖ Institutional Reform of the State owned vertically integrated utility towards commercialization and eventual privatization.
❖ Ensure proper governance accountability in the power sector.
❖ Meet the need of adequate, safe, reliable and affordable electricity

1.2 Statement of the Problem

The concern for epileptic power system is enormous in the power system operations and planning which can be characterized by continuous decrease in system voltage and poor power supply. However, current state of Nigeria power system shows that certain regions within the network still experienced incessant blackout. It is most likely that blackout will occur in the network due to some lapses, these lapses may be attributed to lack of technical know-how of operators of the system.

There are obvious challenges of real time integration of the existing computational techniques in real power transmission especially in the context of the national grids, it is very necessary to analyze systems situation where simulations are transformed into real time network before eventually collapse occurs. This will require:

(i) To reduce uncontrollable load capacity that may over stressed the power system that may result, into voltage collapse.
(ii) To match generating capacity to the consumer load demand to avoid system violations.

1.3 Aim of the Study

To improve the mitigation of voltage collapse in the Nigeria power system using voltage stability indices (fast voltage stability index, (FVSI), line stability index (LMN), Line stability factor (LQP), voltage stability index (LD), and novel line stability index (NLSI))

1.4 Objectives of Research

The following objectives are considered:

(i) To determine the voltage stability limits of the existing Nigeria 330KV and 132KV, using five (5) predictive analyzers (FVSI, LMN, LQP, LD and NLSI)
(ii) To determine voltage instability that may results into system collapse.
(iii) Comparison evaluation for five (5) predictive analyzers (FVSI, LMN, LQP, LD and NLSI).
(iv) To evaluate voltage collapse scenarios and probable mitigation measures for the south-south, south-east 330KV grid network (using NEPLAN).

1.5   Scope the study

This study will look at the evaluation for the mitigation of voltage collapse in the Nigeria power system using predictive voltage collapse indices. The scope is limited to 20-buses Nigeria network using NEPLAN-tool and 48-buses system Nigeria 330KV power network using ETAP tool.

1.6   Significance of the Study

The system stability and quality of power supply it is necessary to control and allow the system to be within permissible and acceptable level according to the statutory requirement of frequency and voltage. System stability is a subject of great interest to the system operators, planner on the view to enhance reliable electricity power supply. The following benefits are derivable as:

(i)   Reduced risk of blackouts: By identifying and mitigating potential vulnerabilities, utilities can reduce the risk of blackout and ensure a more reliable supply of electricity.

(ii)   Improved power quality: By preventing voltage collapse, utilities can ensure that power quality is maintained which is essential for sensitive equipment and industrial processes.

(iii)   Increased grid resilience: By evaluating and implementing effective mitigation strategies, utilities which can improve the resilience of the power grid, making it better equipped to withstand the uncertainties.

(iv)   Cost savings: By optimizing power system operation and reducing energy losses, utilities can be achieved through a cost saving and reduce economic impacts of the voltage collapse.

II.   LITERATURE REVIEW

2.1   Related Research

Power system stability and control are critical aspects of ensuring the reliable operation of power grids. Over the years, various methods and techniques have been developed to maintain the stability of the power system. In this literature review, we will summarize some of the recent research on power system stability and control.

Muyeen *et al.* (2014). focuses on the importance of power system stability and the need for enhancing it using hybrid renewable energy sources and hybrid control techniques. It provides a comprehensive review of the existing research on the topic, highlighting the advantages and limitations of different techniques. However, they note that further research is needed to optimize the integration of renewable energy sources into the power system and to develop more effective control strategies. Overall, it provides a valuable review of the current state of research on power system stability enhancement using hybrid renewable energy sources and hybrid control techniques.

Jena, (2019). Reviews the use of Hybrid Renewable Energy Sources and Hybrid Controllers (HRES-HC) for power system stability enhancement. It discusses the various types of HRES-HC and their applications in power systems. It highlights the advantages and limitations of different types of HRES-HC and provide a comprehensive review of the existing literature on the topic. It also examines the challenges associated with the integration of HRES-HC into the power system, including the impact of intermittent renewable energy sources on power system stability. It discusses the need for advanced control strategies to manage the variability and uncertainty of renewable energy sources and to maintain power system stability. It concludes that HRES-HC can significantly improve power system stability and reliability.

Jena *et al.* (2015). The paper titled "A Review of Power System Stability Enhancement Using Hybrid Renewable Energy Sources and H∞ Controller". Provides a comprehensive review of the use of Hybrid Renewable Energy Sources and H∞ Controller (HRES-H∞) for power system stability enhancement. The paper discusses the importance of power system stability and the need for efficient and effective control techniques to maintain it. The authors provide a detailed review of the various types of HRES-H∞ and their applications in power systems. They highlight the advantages and limitations of different HRES-H∞ techniques and provide insights into their ability to manage the variability and uncertainty of renewable energy sources.

Kumar (2019). Provides a comprehensive review of the use of Hybrid Renewable Energy Sources and Robust Control Techniques (HRES-RCT) for power system stability enhancement. They discuss the importance of power system stability and the need for efficient and effective control techniques to maintain it. They review the various types of HRES-RCT and their applications in power systems. They also highlight the advantages and limitations of different HRES-RCT techniques, including their ability to manage the variability and uncertainty of renewable energy sources. They examine the challenges associated with the integration of HRES-RCT into the power system, including the impact of intermittent renewable energy sources on power system stability and the need for advanced control strategies to manage them.

Joseph *et al.* (2018). This paper proposed two scenarios, the 1st scenario look at the analysis of transient stability study of 330KV super-grid voltage level of Nigerian power system network. Considering Alaoja (load-bus), Onitsha (load-bus) and Afam power station (generating-bus) referred as study case, from the Nigerian 330KV transmission grid (network) for purpose of investigation and findings. The analysis is based on swing-equation model approach and power transfer capability conditions. The activities of fault initiated were recorded

as "sustained fault" classified with respect to time setting of the protective relay and circuit breaker operations from Afam power generating station (GS) to the 330KV network in order to measure the behavior of the turbine rotor-angle with the clearing time setting of the relay. The collected data were simulated via MATLAB platform, with the clearing time setting of (t = 0.0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50) corresponding to the respective deviation of the rotor swinging angles of (rf1, rf2, rf3 and rf4). Where rf1 defined the deviation of the rotor-angle of the turbine power plant due to sustained fault condition with time, t. while rf2, rf3, and rf4; defined the restoration ability of the deviated rotor-angle (rf1) from instability to gradual progressive stability condition, with fault cleared at 2.5cycle (rf2), 6.5 cycle (rf3) and 8.25cycle (rf4) respectively.

Panda (2018), Provides an in-depth review of the use of Flexible AC Transmission System (FACTS) controllers for power system stability enhancement. They discuss the importance of power system stability and the need for efficient and effective control techniques to maintain it. They provide a detailed review of the various types of FACTS controllers, including Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), and Unified Power Flow Controller (UPFC). They examine the applications of FACTS controllers in power systems, including their ability to improve power system stability, voltage control, and load flow control. They also highlight the advantages and limitations of different FACTS controllers and provide insights into their performance under different operating conditions. They conclude that FACTS controllers can significantly enhance power system stability, reduce power losses, and increase the reliability of the power system. However, they note that further research is needed to optimize the integration of FACTS controllers into the power system and to develop more effective control strategies. Overall, the paper provides a valuable review of the current state of research on power system stability enhancement using FACTS controllers.

Sandhu (2013). Provides an overview of the various techniques used for power system stability and control. They discuss classical control techniques, modern control techniques, and intelligent control techniques, highlighting the advantages and limitations of each approach. They examine the applications of these techniques in power systems and their ability to improve power system stability, voltage control, and load flow control. They also analyze the challenges associated with power system stability and control, including the impact of renewable energy sources on power system stability and the need for advanced control strategies to manage them. They conclude that a combination of classical, modern, and intelligent control techniques can significantly enhance power system stability, reduce power losses, and increase the reliability of the power system.

Singh (2019). Provides an insightful review of the use of energy storage systems (ESS) for power system stability enhancement. They elaborate on various types of ESS and their applications in power systems. They highlight the importance of ESS in improving the power system stability and reliability. They have discussed the advantages and limitations of various types of ESS, including battery energy storage systems, flywheels, supercapacitors, and compressed air energy storage systems.

Mandal (2019). Provides a comprehensive review of the use of power system stabilizers (PSS) for power system stability improvement. They discuss the various types of PSS and their applications in power systems. It highlights the importance of PSS in improving the damping of power system oscillations and enhancing the power system stability. They have provided a detailed analysis of the different types of PSS, including conventional PSS, adaptive PSS, and fuzzy logic-based PSS.

2.2   Factors affecting Voltage Stability
Voltage instability and collapse are dynamic and normally large disturbance phenomena, involving load, transmission and generation subsystems of large power systems. Three key aspects of voltage stability are:
(i)   The reactive power support either through power transfer, or at loading point.
(ii)   The load characteristics as seen from the bulk power network.
(iii)   The available means for voltage control at generators and in the network

2.3   Voltage Stability
Niki (2010). Many a times, the term voltage collapse and voltage instability are overlooked as a similar phenomenon. At this point, it is necessary to make a statement clarifying the thin line of difference between the two terms. In a power system, there might be disturbances created leading to a gradual decrease in voltage profile at various buses. This is termed as voltage instability, while voltage collapse is an unfeasible value of voltage whose magnitude is decreasing fast. Voltage instabilities might lead to voltage collapse. Infact, it can be said that, during a disturbance caused in the power system, there is a point in time where the voltage becomes uncontrollable. This shows that actual voltage collapse may occur later than occurrence of Voltage instability.

Prabha (2006), Voltage control and stability problems are not new to the electric utility industry but are now receiving special attention in many systems. Once associated primarily with weak systems and long lines, voltage problems are now also a source of concern in highly developed networks as a result of heavier loadings. In recent years, voltage instability has been responsible for several major network collapses.

2.3.1 Basic Concepts Related To Voltage Stability

Prabha (2006), Voltage stability problems normally occur in heavily stressed systems. While the disturbance leading to voltage collapse may be initiated by a variety of causes, the underlying problem is an inherent weakness in the power system. In addition to the strength of transmission network and power transfer levels, the principal factors contributing to voltage collapse are the generator reactive power/voltage control limits, load characteristics, characteristics of reactive compensation devices, and the action of voltage control devices such as transformer under-load tap changers (ULTCs).

2.3.2 Transmission System Characteristics

The characteristics of interest are the relationships between the transmitted power (P_R), receiving end voltage $(T^\wedge)$, and the reactive power injection $(£)/)$. Such characteristics were discussed for a simple radial system and for transmission lines of varying lengths. For complex systems with a large number of voltage sources and load buses, similar characteristics can be determined by using power-flow analysis.

III. MATERIALS AND METHODS

3.1 Materials Used

The materials used for this paper were collected from Transmission Company of Nigerian (TCN) with focus on South-South/South-East 330kV grid network. The materials collected includes:

(i)Bus data consisting of available generating capacity in MW for seven (7) generators and eleven (11) load buses in the South-South/South-East 330kV grid network.

(ii)Line data consisting of nine (9) single circuit, nine (9) double circuit, one (1) triple circuit and one (1) quadruple circuit.

(iii)Static Var compensator used for improving the loading margin of the buses close to the point of voltage collapse

(iv)NEPLAN 555 software package was used for modeling the South-South/South-East 330kV grid network.

(v)ETAP version (19.0.1) was used for modeling the single line diagram of 48 bus, 330KV Nigeria grid system Nigeria system.

3.2 Method Used

Q-V modal analysis with predictive indices as (FVSI, LMN, LQP, LD, and NLSI), were used to predict voltage instability in the existing South-South/South-East 330kV grid network, the techniques used considered:

(i)The node voltage and reactive power change are directly related and plays a significant role in voltage stability analysis.

(ii)The node voltage and reactive power change are related to eigenvalues which gives more accurate result for determining the participation factors

(iii)The participation factor plays a useful role in the prediction of weak buses or nodes with high voltage instability.

3.3 Description of the Existing South-South/South-East 330kV Grid Network.

The existing south-south 330kV grid on investigation consist of seven (7) generating stations, twenty (20) transmission lines and eleven (11) load buses. The network is managed and controlled by the Benin regional control center which is responsible for monitoring the grid operations in all the 330kV and 132kV transmission network with south-south/south-east region. Figure 3.1 shows the single line diagram of the existing South-South/South-East 330kV Grid Network.
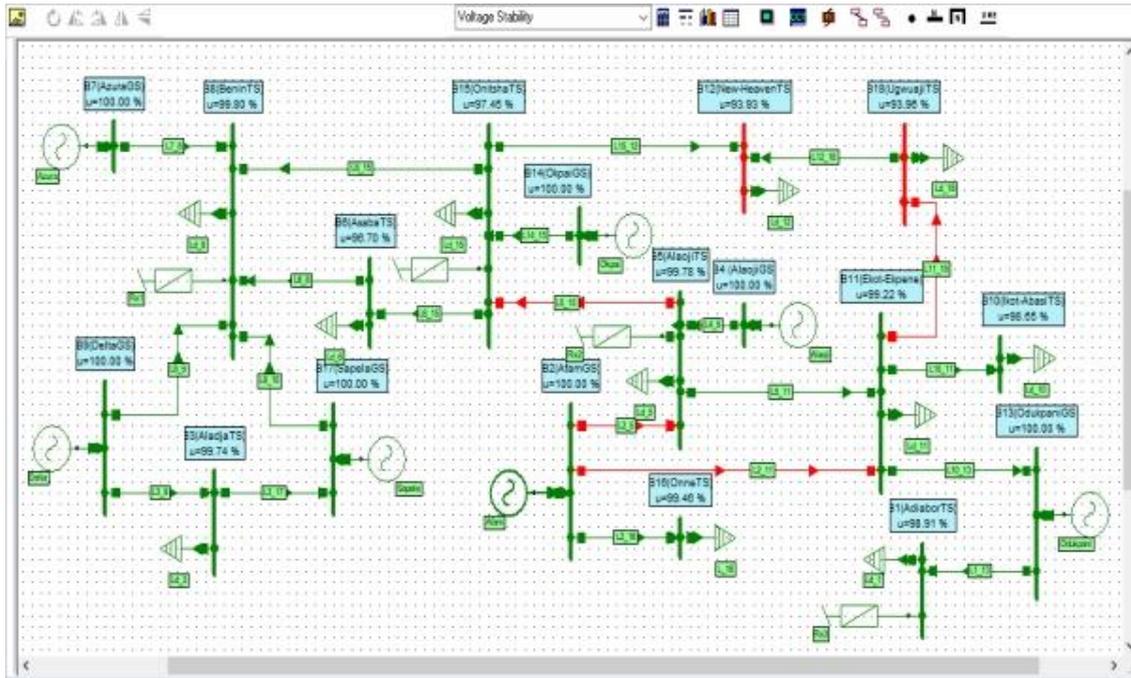
**Figure 3.1 Existing South-South/South-East 330kV Grid network in NEPLAN
Software application tool.**

Table 3.1: Bus Data

Bus Information			Load Data			Generation	
Bus No	**Name**	**Type**	**MW**	**MVar**	**B-Shunt**	**MW$_{Instal}$**	**MW$_{Aval}$**
1	Adiabor TS	PQ	140	90	-75Mvar	-	-
2	Afam GS	Slack	-	-	-	1376	800
3	Aladja TS	PQ	100	70	-	-	-
4	Alaoji GS	PV	-	-	-	450	126
5	Alaoji TS	PQ	400	150	-	-	-
6	Asaba TS	PQ	185.7	169.5	-	-	-
7	Azura GS	PV	-	-	-	450	300
8	Benin TS	PQ	383	150	-150Mvar	-	-
9	Delta GS	PV	-	-	-	900	620
10	Ikot-Abasi TS	PQ	146	85	-	-	-
11	Ikot-Ekpene TS	PQ	321	160	-	-	-
12	New Heaven TS	PQ	180	130	-	-	-
13	Odukpani GS	PV	-	-	-	565	226
14	Okpai GS	PV	-	-	-	450	300
15	Onitsha TS	PQ	184	134	-75Mvar	-	-
16	Onne TS	PQ	80	50	-	-	-
17	Sapele GS	PV	-	-	-	1020	120
18	Ugwaji TS	PQ	230	115	-	-	-

Source: Transmission Company of Nigeria, TCN.

3.4   Transmission Line Parameters
The transmission line conductor used for the study is a 4-bundle ACSR 350mm^2 per phase.

Table 3.2: Design Specification for 330kV OHL

Cross sectional Area		Stranding and diameter
Aluminum	381.6 mm^2	54/3.0 mm
Steel	49.4 mm^2	49.4 mm
Total	431 mm^2	431 mm

The spacing between each conductor d = 400 mm (1.32ft)

3.4.1 Resistance of the conductor
The Resistance (Rs) per km of a single B is on ACSR 350mm^2 conductor at 20°C is 0.0757Ω.
Therefore, for a 4-bundled conductor the Resistance per km is giving by
$$R = \frac{R_S}{4} \Omega/\text{km} \qquad\qquad (3.1)$$

3.4.2 Inductance Reactance of the conductor

The GMR for a single Bison ACSR 350mm² conductor is giving by

$$GMR = D_s = 0.7788r \tag{3.2}$$

Where;

r: overall radius of one conduction in ft

The GMR for a 4-bundled conductor, the GMR is giving by

$$D_s^b = 1.09\sqrt[4]{D_s * d^3} \tag{3.3}$$

The equivalent spacing between phases between conductors is giving by

$$D_m = \sqrt[3]{D_{12} * D_{23} * D_{13}} \tag{3.4}$$

The Inductive Reactance of the conductor is giving by

$$X_L = 2.8937x10^{-3} * f * log\frac{D_m}{D_s^b} \, \Omega/k \tag{3.5}$$

Where, F: supply frequency

Dm: equivalent spacing

D_s^b equivalent spacing

3.4.3 Capacitance of the Conductor

$$D_{sc}^b = 1.09 \sqrt[4]{r * d^3} \tag{3.6}$$

$$C_n = \frac{0.02411}{log\frac{D_m}{D_{sc}^b}} \mu F/km \tag{3.7}$$

Where, D_{sc}^b: equivalent GMR for capacitance calculation

r: radius of the outer diameter

3.4.4 Susceptance of the Conductor

$$B = \omega C \tag{3.8}$$

Where, C = capacitive reactance

ω = angular frequency

Table 3.3: Transmission Line data of Bison ACSR 350mm² conductor

From Bus	To Bus	L (km)	R (Ω)	X (Ω)	C (μF)	B (μS)
Afam	Alaoji	25.0	0.48	6.25	0.35	109.75
Afam	Ikot Ekpene	65.0	1.24	16.25	0.91	285.35
Afam	Onne	53.5	1.02	13.38	0.75	234.87
Alaoji	Ikot Ekpene	55.0	1.05	13.75	0.77	241.45
Alaoji	Onitsha	138.0	2.62	34.50	1.93	605.82
Benin	Onitsha	137.0	2.60	34.25	1.92	601.43
Benin	Asaba	137.0	2.60	34.25	1.92	601.43
Delta	Aladja	30.0	0.57	7.50	0.42	131.70
Delta	Benin	107.0	2.03	26.75	1.50	469.73
Ihovbor	Benin	20.0	0.38	5.00	0.28	87.80
Ikot Ekpene	Ugwuaji	162.0	3.08	40.50	2.27	711.18
Ikot Ekpene	Ikot Abasi	84.9	1.61	21.23	1.19	372.71
Odukpani	Ikot Ekpene	70.3	1.34	17.58	0.98	308.62
Odukpani	Adiabor	17.7	0.34	4.43	0.25	77.70
Okpai	Onitsha	56.0	1.06	14.00	0.78	245.84
Onitsha	Asaba	65.8	1.25	16.45	0.92	288.86
Onitsha	New Haven	96.0	1.82	24.00	1.34	421.44
Sapele	Benin	50.0	0.95	12.50	0.70	219.50
Sapele	Aladja	63.0	1.20	15.75	0.88	276.57
Ugwaji	New Heaven	6.5	0.12	1.63	0.09	28.54

Source: Transmission Company of Nigeria, TCN.

3.5 Power Flow Method

The power flow is widely used in power system analysis. It plays a key role in planning the power system for future expansion as well as aiding to the existing systems to perform in the best possible way. The solution of power flow predicts the operating condition of the network. The result of the power flow are voltage magnitude and phase angle the system which permits other system quantities such as real and reactive power flows, current flows, voltage drops, power losses to be computed. Power flow solution is closely associated with voltage stability analysis because it is an essential tool for voltage stability evaluation.

For a 2-bus system which consists of a load fed from a source via a transmission line. For any ith bus.

Let $V_i = V_i\angle\delta_i$ and $V_i^* = V_i\angle\delta_i$ (3.9)

For kth bus,

$V_k = V_k \angle \delta_i$ and $V_{ik} = Y_{ik} \angle \theta_{ik}$ (3.10)

The real and reactive power injected in the network is given by

$S_i = V_i I_i^* = P_i + jQ_i$ (3.11)

$I_i = \left(\frac{S_i}{V_i}\right)^* = \frac{P_i + jQ_i}{V_i^*}$ (3.12)

$I_i = \frac{P_i - jQ_i}{V_i^*} = \sum_{k=1}^{n} Y_{ik} V_k$ (3.13)

$P_i - jQ_i = V_i^* (\sum_{k=1}^{n} Y_{ik} V_k)$ (3.14)

$P_i - jQ_i = V_i^* (\sum_{k=1}^{n} Y_{ik} V_k \angle \delta_k + \theta_{ik} \delta_i)$ (3.15)

$P_i - jQ_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k|[\cos(\delta_k + \theta_{ik} - \delta_i) + j\sin(\delta_k + \theta_{ik} - \delta_i)]$ (3.16)

Separating (3.18) into real and imaginary parts we have,

$P_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k|\cos(\delta_k + \theta_{ik} - \delta_i)$ (3.17)

$Q_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k|\sin(\delta_k + \theta_{ik} - \delta_i)$ (3.18)

Where

Y_{ik}= the admittance matrix

P_i= the injected real power

Q_i= the injected reactive power

δ_i= phase angle

Expanding (3.16) and (3.17) in Taylors series neglecting higher order terms we have

$$
\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} & \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n} & \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \\ \frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n} & \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n} & \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{bmatrix} \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix}
$$ (3.19)

The Jacobian matrix gives the linearized relationship between mall changes in voltage angle $\Delta \delta_i^{(k)}$ and magnitude $\Delta |V_i^{(k)}|$ with small change in real $\Delta P_i^{(k)}$ and reactive power $\Delta Q_i^{(k)}$ respectively.

$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_3 \\ J_2 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$ (3.20)

Where

ΔP and ΔQ active and reactive power mismatch vector

$\Delta |V|$ and $\Delta \delta$ unknown voltage and angle correction vector

J_1, J_2, J_3, J_4 are the elements of the Jacobian matrix

3.6 Modal Analysis Method of Voltage Stability

The modal analysis is an effective analytical technique used to predict voltage instability in large power system networks. It basically depends on the values of eigenvalue and eigenvector obtained from reduced Jacobian matrix obtained from the conventional Newton-Raphson power flow solution. Power system in recent time, has improved in terms of size and complexity and the conventional Newton-Raphson method fails to converge in multiple contingencies, due to the singularity of the Jacobian matrix at the point of maximum loading because any change in the modal reactive power will cause an infinite change in the modal voltage and the system will collapse.

3.6.1 Determination of Reduced Jacobian Matrix

The first step in the modal analysis technique is the determination of the reduced Jacobian Matrix (Jr) which is obtained from the Newton Raphson power flow method by putting the value of $\Delta P = 0$, in the conventional Newton-Raphson method then solving (3.19) simultaneously to eliminate the angle part we have

$0 = J_{11}\Delta\theta + J_{12}\Delta V$ (3.21)

$\Delta Q = J_{21}\Delta\theta + J_{22}\Delta V$ (3.22)

From (3.21) making $\Delta\theta$ subject of the equation we have

$\Delta Q = [-J_{21}J_{11}^{-1}\Delta V]$ (3.23)

Substituting (3.22) into (3.21)

$$\Delta Q = J_{21}[-J_{21}J_{11}^{-1}\Delta V] + J_{22}\Delta V \tag{3.24}$$
$$\Delta Q = \Delta V[J_{22} - J_{21} - J_{11}^{-1}J_{12}] \tag{3.25}$$
$$J_R = [J_{22} - J_{21} - J_{11}^{-1}J_{12}] \tag{3.26}$$
$$\Delta Q = J_R\Delta V \tag{3.27}$$
$$\Delta V = J_R^{-1}\Delta Q \tag{3.28}$$

The matrix Jr represent the linearized relation between the incremental changes in bus voltage
ΔV and reactive power injection ΔQ. It's well known that, the system voltage is affected by both real and reactive power variations.

3.6.2   Determination of the Most Critical Mode

The second step in modal analysis is the determination of the most critical mode. The eigenvalues of the Jacobian matrix (**J_R**) can be used to determine the modes of the power network. The least eigenvalue of the reduced Jacobian matrix (J_R) determines the most critical mode of the power system. The mode indicates the system nearness to voltage instability. Once the least eigenvalue is identified, the rest are ignored because they are considered to be strong enough modes.

$$J_R = \lambda\phi\xi \tag{3.29}$$
$$I_R^{-1} = \lambda^{-1}\phi\xi \tag{3.30}$$

Where
ϕ: right eigenvector matrix of J_R
ξ: left eigenvector matrix of J_R
λ: diagonal eigenvalue matrix of J_R
Substituting (3.30) into (3.28)

$$\Delta V = \lambda^{-1}\phi\xi\Delta Q \tag{3.31}$$
$$\Delta V = \frac{\phi_i\xi_i}{\lambda_i}\Delta Q \tag{3.32}$$
$$\phi_i\xi_i = 1 \tag{3.33}$$
$$\Delta V = \frac{1}{\lambda_i}\Delta Q \tag{3.34}$$

(i)   If all eigenvalues are positive, the system is voltage stable because the ith mode voltage and i^{th} reactive power change are in the same direction.

(ii)   If at least one of the eigenvalues is negative, the system is voltage unstable because the i^{th}mode voltage and i^{th} reactive power change are in opposite direction.

(iii)   If eigenvalues become zero, the system will collapse because any change in the modal reactive power will cause an infinite change in the modal voltage

3.6.3   Determination of Bus Participation Factor

The last process of the modal analysis is the determination of the participation factors for load buses. The factor is an indicator the close proximity of a particular bus to voltage instability and is calculated for bus that has the most critical mode.

$$P_{ki} = \xi_i\eta_i \tag{3.35}$$

Where ξ_i: column right eigenvector matrix of J_R
   η_i: row left eigenvalue matrix of J_R
Substituting (3.23) into (3.22)

$$\Delta Q = J_{21}[-J_{21}J_{11}^{-1}\Delta V] + J_{22}\Delta V \tag{3.36}$$
$$\Delta Q = \Delta V[J_{22} - J_{21} - J_{11}^{-1}J_{12}] \tag{3.37}$$
$$J_R = [J_{22} - J_{21} - J_{11}^{-1}J_{12}] \tag{3.38}$$
$$\Delta Q = J_R\Delta V \tag{3.39}$$
$$\Delta V = J_R^{-1}\Delta Q \tag{3.40}$$

The matrix Jr represent the linearized relation between the incremental changes in bus voltage
ΔV and reactive power injection ΔQ. It's well known that, the system voltage is affected by both real and reactive power variations.

3.6.4   Determination of Bus Participation Factor

The last process of the modal analysis is the determination of the participation factors for load buses. The factor is an indicator the close proximity of a particular bus to voltage instability and is calculated for bus that has the most critical mode.

$$P_{ki} = \xi_i\eta_i \tag{3.41}$$

Where ξ_i: column right eigenvector matrix of J_R
   η_i: row left eigenvalue matrix of J_R

3.7 Optimization Technique used for Reactive Power Compensation

Optimization is the act of obtaining the best results under given circumstances. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. There are various optimization techniques used for reactive power compensation. For this thesis, static var placement is the optimization techniques for reactive power compensation. However, its placement may impact negatively on the system if not optimally placed and sized.

$$SVC = \frac{Q_{load} - Q_{gen}}{1 - \left(\frac{V_{min}}{V_{ref}}\right)^2} * \left(\frac{\Delta V}{V_{ref}}\right) \tag{3.42}$$

Where

Q_{load}: reactive power demand of load in Mvar

Q_{gen}: reactive power generated by other sources in the system

V_{min}: minimum allowable voltage in p.u

V_{ref}: reference voltage in p.u

V_{ref}: voltage deviation from reference in p.u

3.8 Load Flow Equation and Method of Solution

Complex power injected into an *ith* bus of a power system is given as:

$$S_i = P_i + jQ_i = V_i I_i^* \quad i = 1,2, \tag{3.43}$$

Where V_i is the voltage at the *ith* bus with respect to ground and I_i^* is the complex conjugate of source current I_i injected into the bus. Since it is more convenient to work with I_i rather than I_i^* in load flow problems, the complex conjugate of the above equation is given as:.

$$S_i^* = P_i + jQ_i = V_i^* I_i \tag{3.44}$$

But
$$I_i = \sum_{k=1}^{n} Y_{ik} V_k \tag{3.45}$$

Thus $S_i^* = P_i - jQ_i = V_i^* \sum_{k=1}^{n} Y_{ik} V_k \quad i = 1,2, \dots n \tag{3.46}$

In Polar form
$$\begin{aligned} V_i &= |V_i| < \delta_i, V_i^* = |V_i| < -\delta_i \\ V_k &= |V_k| < \delta_k, V_{ik}^* = |V_{ik}| < -\theta_{ik}` \end{aligned} \tag{3.47}$$

Real Power, $P_i = |V_i| \sum_{k=1}^{n} |Y_{ik}||V_k| cos(\theta_{ik} + \delta_k, - \delta_i) \tag{3.48}$

Reactive power, $P_i = |V_i| \sum_{k=1}^{n} |Y_{ik}||V_k| sin(\theta_{ik} + \delta_k, - \delta_i) \tag{3.49}$

3.9 Power System Line Parameters

$$R_0 = \frac{1000\,\ell}{A} (\Omega/km) \tag{3.50}$$

Where ℓ is the design resistivity of conductor *(Q,m)*

A is the cross-sectional area of conductor *(m²)*

3.9.1 Per-Kilometre Inductive Reactance (Non-stranded conductor)

$$= x_0 = 0.445 \left(\frac{D_{GMD}}{r}\right) + 0.0157 (\Omega/km) \tag{3.51}$$

Where *r* is the conductor radius

D_{GMD} is the geometric mean distance between phase conductors.

3.9.2 Per-Kilometre Capacitive Susceptance b_o

$$b_0 = \frac{7.58}{Log\left(\frac{D_{GMD}}{r}\right)} (1/\Omega/km) \tag{3.52}$$

3.9.3 Geometric Mean Distance

For a single Circuit

$$D_{GMD} = \sqrt[3]{D_{RB} D_{YR} D_{BY}} \tag{3.53}$$

Where *D* is the spacing between the conductors.

For overhead conductors arranged horizontally

$$\begin{cases} D_{GMD} = \sqrt[3]{2D^3} \\ \quad\quad = \sqrt[3]{2} \\ \quad\quad = 1.26D \end{cases} \tag{3.54}$$

3.10   Percentage Load analysis on Feeder

Where Active Power (P_D) on feeder $= \frac{\text{Average Current on Feeder}}{60} \times 100$ (3.55)

3.11   Complex Load on Distribution Transformers

Complex load demand =Transformer Capacity × Percentage Loading on transformer

Where percentage loading on transformer $= \frac{I_R + I_Y + I_n}{3I_n} \times 100$ (3.56)

3.12   Voltage Drop (V_D)
$V_D = V_s - V_r$ (3.57)
Where V_s= *Sending end Voltage*
V_r = *Receiving end Voltage*
and $V = I Z$ (3.58)
Thus, $V_D = V_s - V_r = IZ$ (3.59)
Where I = *Average Current on Feeder*
$\quad\quad Z \quad$ = Impedance *of feeder*

Therefore, percentage voltage drop $= \frac{V_D}{V_s} \times 100$ (3.60)

3.13   Transformer Tap Changing
The principle of regulating the secondary voltage is based on changing, the number of turns on the primary or secondary in changing the transformation ratio are presented as,
$= \frac{V_2}{V_1} = \frac{N_2}{N_1} = K$ (3.61)
$= V_2 = \frac{V_1 N_2}{N_1} = E_1 K$ (3.62)
Where K = Transformation ratio
V_1= Primary voltage
V_2 = Secondary voltage
Decrease in primary turns causes increase in emf per turn, and so in secondary output voltage. Secondary output voltage can also be increased by increasing secondary turns and keeping primary turns fixed.

3.14   Shunt Capacitors for Compensation
Shunt capacitors are installed near load terminals to provide leading Volt-Ampere-Reactive (VAR) and thus to reduce the line current. Hence, by using shunt capacitors, line drop is reduced, and voltage profile is improved. Shunt capacitors are switched in when capacity demand on the distribution system rises and voltage of the buses drop.

3.15   Objective Function of Optimal Capacitor Placement (OCP)
The objective of OCP is to minimize the cost of the system. This cost is measured in four ways:
(i)   Fixed capacitor installation cost
(ii)   Capacitor purchase cost
(iii)   Capacitor bank operating cost (maintenance and depreciation)
(iv)   Cost of real power losses.
Mathematically, cost can be represented as:

Min objective function $\displaystyle\sum_{i=1}^{N_{bus}} \left(xC_{0i} + Q_{ci}C_{1i} + B_i C_{2i} T \right) + C_2 \sum_{i=1}^{N_{bus}} \left(T_1 P_L^1 \right)$ (3.63)

Where N_{bus}:Number of bus candidates

X_i:0/1, 0 means no capacitor installed at bus i

C_{0i} :Installation cost

C_{1i} : Per Kvar cost of capacitor banks

Q_{ci} : Capacitor bank size in Kvar

B_i: Number of capacitor banks

C_{2i} :Operating cost of per bank, per year

T: Planning period (years)
C_2: Cost of each KWh loss, in $/KWh
l: Load levels, maximum, average and minimum
T_1: Time duration, in hours, of load level

P_L^1 ; Total system loss at load level

The single line diagram of 48-bus 330KV transmission network using ETAP 19.0.1 are presented in figure 3.6, for the analysis of voltage instability prediction.
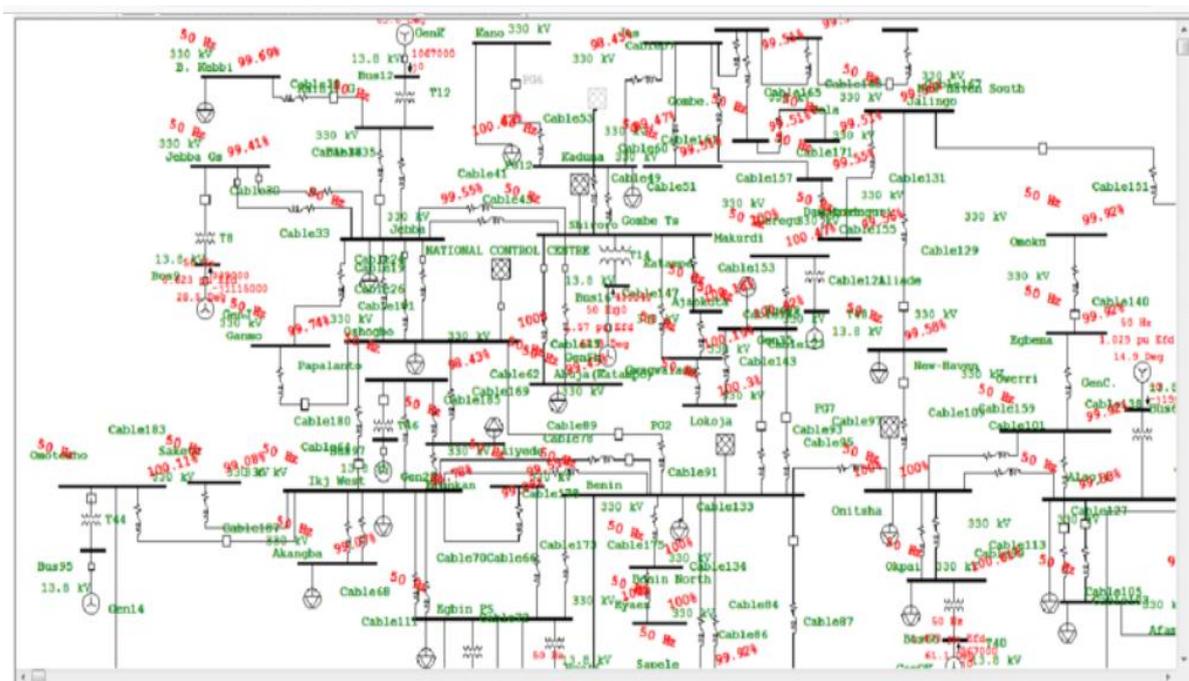
Figure 3.6: Shows the Single-Line Representation of the Existing Study Case (330KV Nigerian Network Simulated).

3.18   Voltage Stability Indices Application for Power Flow Solutions

This research considered the study of various line voltage stability indices (VSIs) for the assessment of voltage collapse. The indices are relied on the two bus – network, as represented as;
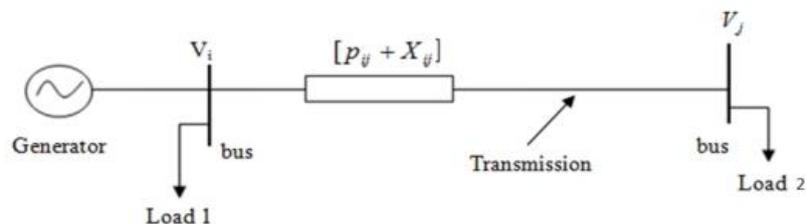

Figure 3.8: Single line representation of a two (2)-bus system

V_i and V_j : voltage at i^{th} and j^{th} bus.
δ_i and δ_j : power angle at i^{th} and j^{th} bus
θ_{ij}: Line impedance angle

P_i and P_j : Real power load at ith and jth bus

Q_i and Q_j : Reactive power load at ith and jth bus

R_{ij} and X_{ij} : Resistance and reactance of the line correcting ith and jth bus

I_{ij} : Brand –current of each line connecting ith and jth bus

$\delta = \delta_i - \delta_j$: Power angle difference between sending and receiving end buses

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

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

$$FVSI_{ij} = \frac{4 \times Z_{ij}}{V_i^2 x_{ij}}$$
(3.64)

Where,

      Z_{ij}: impedance between bus i and j

      V_i : voltage at sending-end

      X_{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, two-bus system, represented mathematically as;

$$lmn = \frac{4X_{ij}Q_j}{V_i \sin(\theta_{ij}-\delta)}$$
(3.65)

Analysis 3: Line Stability Factor (LQP)

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

$$LQP = 4\left(\frac{X_{ij}}{V_i^2}\right)\left(Q_j \frac{P_i^2 X_{ij}}{V_i^2}\right)$$
(3.66)

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;

$$Ld = \frac{\sqrt[4]{(P_i^2+Q_i^2)(R_{ij}^2+X_{ij}^2)}}{V_i^2}$$
(3.67)

Analysis 5: Novel Line Stability Index (NLSI)

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

$$NLSI = \frac{P_j R_{ij}+Q_j X_{ij}}{0.25 V_i^2}$$
(3.68)

Essentially, it is required that for purpose of stability, NLSI should be less than one.

IV. RESULTS AND DISCUSSION

      In determining the voltage magnitudes and phase angle, active and reactive power losses; the assessment of various voltage stability indices (VSIs) is presented to predict proximity of the transmission line close to voltage collapse. The predictive optimizer model is based on load flow numerical solutions. These indices considered the fast-voltage stability index (FVSI), line stability index (LMN), line stability factor (LQP), voltage stability index (LD) and Novel line stability index (NLSI) respectively. The simulation of the existing transmission network (330kv) shows violations of the buses voltage and transmission line system deviations from standard statutory limits. The network was simulated using ETAP - application tool which is verified by the five (5) system voltage indices in their respective degree of violations for network collapse. Following the study case simulation of the system violations condition, proposed power electronic controller installation of capacitor –bank capacity 800MVarare requested for improvement of the existing case to enhance reliable power supply detailed calculation is shown in appendix A2.

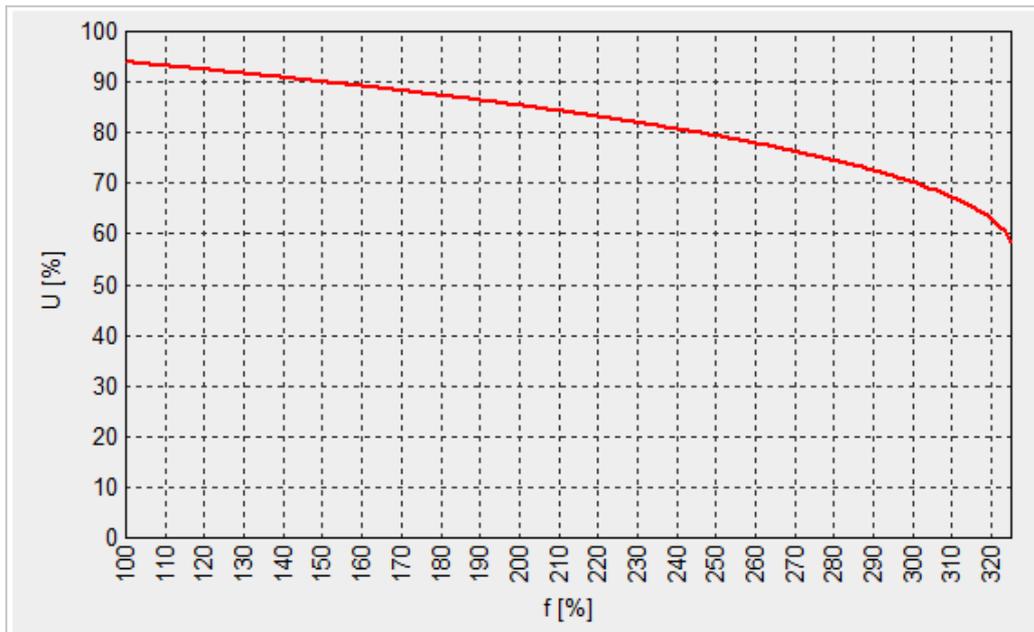**4.1   Result of PV Curve for Existing Network Condition**

Figure 4.1: Base Case P-V Curve for Bus 12 (New Heaven)

Figure 4.1 shows a comparison P-V curve plot used for analyzing steady state voltage stability. The blueline curve shows the operating point of Bus 12 (New Heaven) for base case network condition. The curve indicates how the bus voltage falls as real power increases to the point of voltage collapse which defines the maximum demand that can be served after which the system will not recover. A quick look at figure 4.4 shows that the operating voltage of Bus 12 (New Heaven) is 93.925% at 710.0 MW loading and can be increased by1597.5MW before a voltage collapse can be seen beyond which the system will not recover, the operating voltage at the point of collapse is 58.198%at 2307.5 MW loading.

The presentation of voltage stability predictive indices, for the determination of system operating condition: table, unstable, critical as shown in Table 3.3 etc.
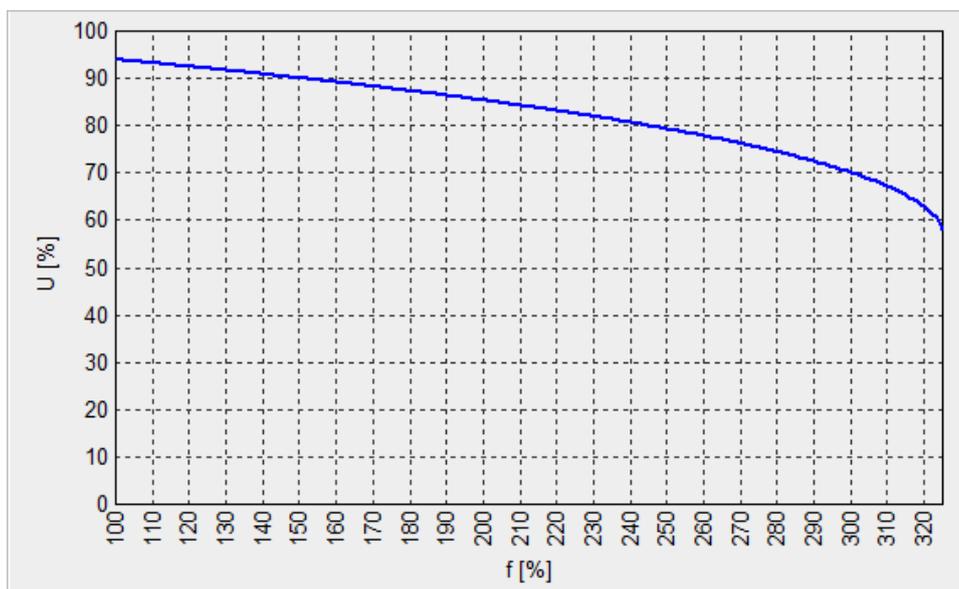

Figure 4.2: Base Case P-V Curve for Bus 18 (Ugwaji)

Figure 4.2 shows a P-V curve plot used for analyzing steady state voltage stability. The blueline curve shows the operating point of Bus 18 (Ugwaji) for base case network condition. The curve indicates how the bus voltage falls as real power increases to the point of voltage collapse which defines the maximum demand that can

be served after which the system will not recover. A quick look at figure 4.5 shows that the operating voltage of Bus 18 (Ugwaji) is 93.956% at 710.0 MW loading and can be increased by1597.5MW before a voltage collapse can be seen beyond which the system will not recover, the operating voltage at the point of collapse is 58.069%at 2307.5 MW loading.

4.5   Determination of Steady State Operating Condition for Fortified Network

Table 4.1: Bus Operating Voltage for Base Case Network Condition

Bus No	Bus Name	Bus Type	Nominal	Operating	
			kV	kV	p.u
1	Adiabor TS	PQ	330	326.387	0.989
2	Afam GS	Slack	330	330.000	1.000
3	Aladja TS	PQ	330	329.145	0.997
4	Alaoji GS	PV	330	330.000	1.000
5	Alaoji TS	PQ	330	329.455	0.998
6	Asaba TS	PQ	330	322.077	0.976
7	Azura GS	PV	330	330.000	1.000
8	Benin TS	PQ	330	329.494	0.999
9	Delta GS	PV	330	330.000	1.000
10	Ikot-Abasi TS	PQ	330	327.570	0.993
11	Ikot-Ekpene TS	PQ	330	329.420	0.998
12	New Heaven TS	PQ	330	324.842	0.984
13	Odukpani GS	PV	330	330.000	1.000
14	Okpai GS	PV	330	330.000	1.000
15	Onitsha TS	PQ	330	324.922	0.985
16	Onne TS	PQ	330	328.227	0.995
17	Sapele GS	PV	330	330.000	1.000
18	Ugwaji TS	PQ	330	325.076	0.985

Table 4.1 shows the operating voltage of the fortified network when compensated with an SVC of 75Mvar capacity at bus 12 and 18 respectively (See Appendix D for base load flow simulation of fortified network). It can be seen from Table 4.4 that all buses are within the acceptable statutory limit of 0. 95p.u - 1.05 with no bus voltage violation. A quick look at the Table 4.4 shows that Bus12: 0.984p.u and Bus18:0.985 are within the acceptable statutory limit of 0.95p.u-1.05 with no bus voltage violation.

4.6 Result of Improved PV Curve in the improved Network Condition
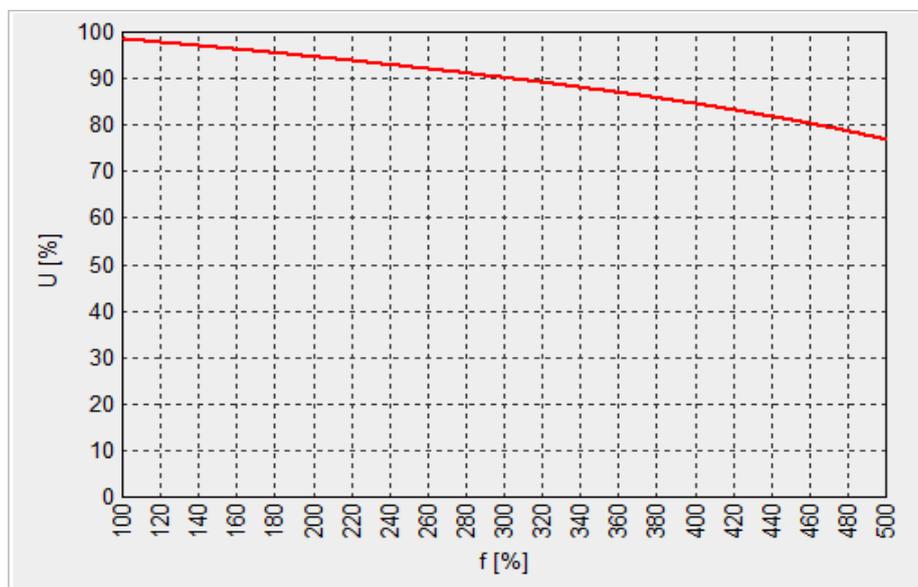

Figure 4.3: Improved P-V Curve for Bus 12 (New-Heaven)

Figure 4.3 shows the improved P-V curve plot used for Bus 12 (New Heaven) when a controlled SVC are installed. It is seen from Figure 4.6, that the operating voltage is increased to 98.437% at 710.0 MW loading and can be increased by 2840 MW before a voltage collapse can be seen beyond which the system will not recover, the operating voltage at the point of voltage collapse is 76.821%at 3550 MW loading. Therefore, it is seen that with SVC installed at Bus 12 the load ability of bus 12 (New Heaven) can be increased by 1242.5MW5
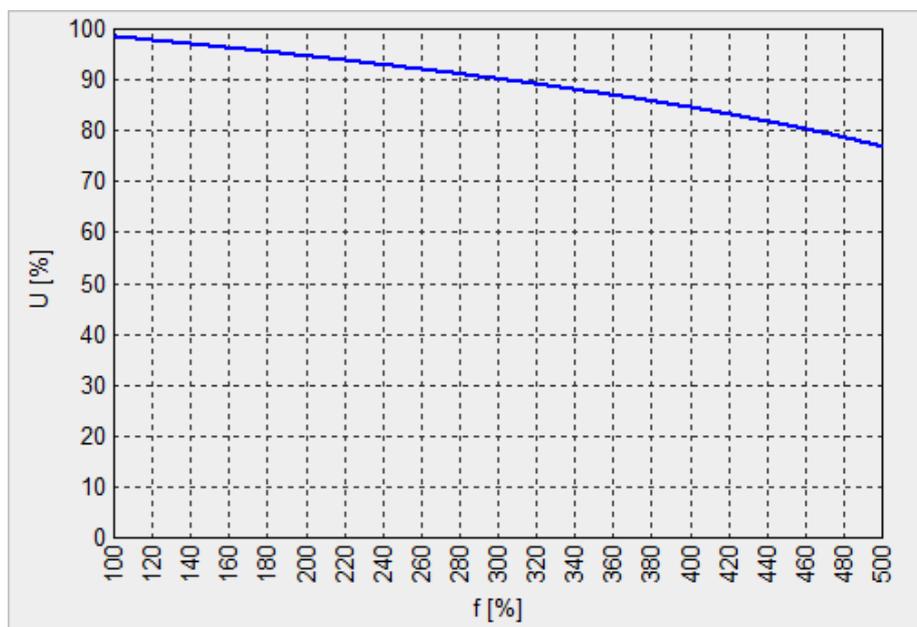

Figure 4.4: Improved P-V Curve for Bus 18 (Ugwaji)

Figure 4.4 shows the improved P-V curve plot used for Bus 18 (Ugwaji) when an SVC are installed. It is seen from Figure 4.7, that the operating voltage was increased to 98.508% at 710.0 MW loading and can be increased by 2840 MW before a voltage collapse can be seen beyond which the system will not recover, the operating voltage at the point of voltage collapse is 76.801%at 3550 MW loading. Therefore, it is seen that with SVC installed at Bus 18 the load ability can be increased by 1242.5MW.

V.   CONCLUSION AND RECOMMENDATIONS
5.1   Conclusion
The research determined the activities of voltage control and stability problems which are not new to the electric utility industry and consumer at the receiving ends. Nigeria power network consists of limited numbers of generating transmission stations situated at remote areas. This research has considered and determined the collation of numerical data from existing 330Kv and 132Kv grid network for analysis and evaluation.

The research study has also formulated governing equations (model analysis, Newton-Raphson load flow solution, five predictive optimizers: (FVSI, LQP, LMN, LD AND NLSI) for the prediction of system condition.

Essentially, the application of modal analysis with participation factor tool was used as criteria for determining weak and stronger buses under investigation. That is the critical buses exhibits higher participation factor close or greater than 1, particularly the highest participation is bus 1-2: New heaven followed by Bus 18: Ugwaji, these buses are selected as candidate buses targeted intervention such as reactive power support or load shedding to enhance system stability and prevent voltage collapse.

The results obtained from five (5) predictive indices shows the capacity of line voltage, instability of the 330Kv and 132Kv network with FVSI, LMN, and NLSI as stronger predictive tool over LD and LQP.

Consequently, the existing network was modeled in a single line diagram using Neplan software (20buses) and ETAP – software application tool for 48-buses which are used as study case under investigation. The network was modeled and simulated while violated buses are been compensated using static var. The 330Kv network was modeled using Neplan -555 which is embedded in the analysis tool to determine participation factor for voltage stability in line with eigen-vector and eigen-values.

5.3   Recommendations
Considering the findings and conclusion of this research, the following recommendation were made:
  (i)   All generation stations should be on free governor mode of operation.
  (ii)   GENCO's should harmonize gas pipeline outages with gas turbine maintenance.

(iii) All generation stations should be on free governor mode of operation.

(iv) GENCO's should harmonize gas pipeline outages with gas turbine maintenance.

(v) GENCO's should adhere to its declaration in accordance with NERC Order.

(vi) Acquisition of sufficient gas for generation to match demand.

(vii) Gen stations should abide by NCC instructions on dispatch of both Active (MW) and Reactive power (MVAr)

(viii) The Annual Maintenance Plan should be maintained.

(ix) Provision of SCADA/EMS facilities. (20.2.3. The System Operator shall have information available for System incident analyses by means of: (a) The System Operator's SCADA system(s) and other data collection systems). The new SCADA system will ensure visibility of all the existing 330kV, 132kV and Power Generation.

(x) Stations with allowances for future stations.

(xi) Upgrade of aged transformers and re-conducting of transmission lines.

(xii) Provision of Hotlines communication to NCC.

(xiii) Provision of spare part for adequate maintenance.

(xiv) Provision of spinning reserve.

(xv) Provision of adequate Voltage compensating devices.

(xvi) Proper relay coordination across the entire power supply chain to avert uncoordinated and spurious tripping

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