International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 14 Issue 2 ǁ February 2026 ǁ PP. 93-111

Evaluation and Mitigation of Voltage Collapse in the Nigeria Power System Using Voltage Stability index In a Developing Economy.

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Abstract
The Mitigation of Voltage Collapse in the Nigeria Power System Using Voltage Stability index is necessary, voltage collapse which has been one of the major problems facing electric power industries and consumers in many countries. 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. In this research, the 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. The violation of the simulated network was compensated using static var compensator (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 selection, once least eigenvalues are identified, they are evidently recommended as weak node for probable solution. Following the criteria for ranking 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 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 for the 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. Evidently, three (3) of the five (5) predictive indices including NLSI, LMN, and FVSI are captured and investigated to analyse predictive behaviour in terms of line close to instability while the other two (2) (LQP, LD) do not have high predictive capacity for system collapse. That is LD and LQP are very slow to the prediction of system collapse.
Keywords: *Transmission Network, Voltage Collapse, Load Restoration, Performance, Modal Analysis, Network Configuration.*

Date of Submission: 07-02-2026 Date of Acceptance: 17-02-2026

I. INTRODUCTION

1.1 Background of the Study

The exact date when electricity was invented wasn't documented, many efforts have been made to understand accurate time 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, 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.

Following to the un-sustained investments and inefficiency in network and plant operations,

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

Due to the circumstance and overbearing government interferences, and inefficiency in the Distribution arm of the sector – customer satisfaction remained low and revenue collection very poor. Hence, the low revenue collection affected investment capability of the industry. At the onset of civilian administration in 1999, the Nigerian electric power sector had reached, the lowest point in its 100 years history, 79 generation units in the country, only 19 units are 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 enactment of a policy document.
- ❖ Provide 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

The increasing dependency on electricity is very important to have a constant, uninterrupted system. The cost to the society of a major power outage could be in billions of dollars. The present-day power supply is more complex than ever before and hence its operation in an economic and secure fashion offers the engineer formidable problems. Among these problems is maintaining a stable voltage profile to avoid loss of stability and voltage collapse.

Voltage collapse represents instability scenario of heavily loaded electric power systems which leads to declining voltage and blackout. It is associated with bifurcation and reactive power limitations of the power system. Power systems are expected to become more heavily loaded in the next decade as the demand for electric power rises while economic and environmental concerns limit the construction of new transmission and generation capacity. Heavily loaded power systems are closer to their stability limits while voltage collapse which may result into blackout will occur if suitable monitoring and control measures must be taken into consideration.

1.2 Statement of the Problem

Voltage collapse has been one of the major problems facing electric power industries and consumers in many countries. The concern for epileptic power system is enormous in 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 is 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 it may eventually collapse.

Thus, this research study, will close the gaps on the view to address prevailing circumstance in the system condition in order:

(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 consumer load demand to avoid system violations.

1.3 Aim of the Research

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

Power system stability and control are critical aspects for reliable operations of power grid, this means to achieve this goal, the following objectives are considered:

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

1.5 Scope the Research

Electricity power supply is the necessity required for the development of micro and macro-economic activities on daily basis. 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 of the Nigeria network using NEPLAN-tool and 48-buses system Nigeria 330KV power network using Etap tool.

1.6 Significance of the Research

The significant of this research is to enable the operators, power system planner and consumer in the Nigerian power network, to plan for the stability of the network. Thus, the following benefits are derivable in order to:
(i) Reduced the risk of blackouts: By identifying and mitigating potential vulnerabilities, utilities that can reduce risk of blackout and ensure a more reliable supply of electricity.
(ii) Improved power quality: By preventing voltage collapse, utilities can ensure power quality which is essential for sensitive equipment and industrial processes.
(iii) Cost savings: By optimizing power system operation and reducing energy losses, utilities can be achieved through cost saving and reduce economic impacts of the voltage collapse.
(iv) Increased grid resilience: By evaluating and implementing effective mitigation strategies, utilities can improve the resilience of power grid, making it better equipped to withstand the uncertainties.

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.

Omorogiuwa (2019), the Nigerian 330Kv transmission network is faced with various problems. It focused on the technical and non-technical losses estimated in the network. The network is characterized by high voltage drops and power losses which can be attributed to low generation, long and fragile radial network, making it highly prone to failure, unreliability, inefficiency and poor performance. The network was analyzed using Power World Simulator (PWS), the result showed that the energy loss due to 330Kv transmission network is about 454.73 GW amounting to over 4.4 billion naira.

Isaac (2012). Modern electric power system network (PSN) is typically a large and complex engineering system whose healthy existence is crucial to industrial and socio-economic development of the Nation. Voltage instability and collapse contribute largely to system collapse or blackouts and it is one of the major concerns for today's electric power system operations. The Nigerian National grid (NNG) experiences on an average of thirty-five (35) system collapse every year over the past ten (10) years. It represents an overview and classification of system collapse. Section II presents power system stability while section III discusses the Nigerian national grid (NNG). Section IV deals with classification of system collapse on the NNG and section V presents the conclusion.

Panda (2018). The use of Flexible AC Transmission System (FACTS) controllers for power system stability enhancement. They discuss the various types of FACTS controllers and their applications in power systems.

Ogbuefi*et al*. (2018). The repeated case of power system collapse in the Nigerian National Grid is of a great concern and need to be investigated. They discussed the effect of voltage collapse and the methods of power generation with respect to the Nigerian National Grid. Other major causes of voltage instability were also examined. Politics has been known to be one of the major factors responsible for epileptic power supply in the country as a result of corruption within the power sector. Single Line Diagram (SLD) showing all the generating stations and transmission network and the distances covered are also presented. Results recorded an average of twenty-five disturbances over a period of twenty-three years under investigation (January, 1995-July, 2017). 2003 is the year with the highest number of faults recorded over the period of twenty-three years, representing 8.95% of the total faults. Similarly, the year 1999 recorded the least number of faults representing 1.52% over the same period. The partial grid collapse and total grid collapse disturbances represent49% and 51% respectively. Only four power stations out of the fourteen are identified to be operating on full installed capacity. The thermal plants represent 76% while 24% for hydro power plants across the country. Collated results are tabulated, exhaustively discussed and analyzed using tables, charts and graphs. Appropriate recommendations are also presented such that if implemented will proffer lasting solutions to the challenges confronting the power sector in Nigeria.

Atef *et al*. (2022). After some damaging blackouts, voltage instability and collapse have become worldwide concern problems. Voltage instability is a nonlinear local phenomenon, which occurs due to insufficient reactive power production or as the inability to transfer it to consumers. In most dangerous cases, it can result in voltage collapse.

Preethi *et al*. (2011). Over the last two decades, voltage instability problem in power systems have become one of the most important concerns in the power industry. Recently, several network blackouts have been related to voltage collapse. The introduction of emerging Flexible AC Transmission Systems (FACTS) technology improves the Stability, reduces the losses and also reduces the cost of generation. FACTS controllers are used to control the voltage, current, impedance, phase angle and to damp the oscillations. Placing FACTS devices like SVC, TCSC, etc., in a suitable location will help to maintain bus voltages at a desired level and also to improve the Voltage Stability margins. This paper presents an effective method which is used to find the best optimal location of FACTS controllers by using metaheuristic algorithm called Genetic Algorithm. The load flow analysis is performed by using conventional Newton Raphson technique. Different loading conditions are considered and MATLAB coding is developed for simulation.

Preetha (2012). Voltage stability has become an important issue in planning and operation of many power systems. It includes multi-objective evolutionary algorithm techniques such as Genetic Algorithm (GA) and Non-dominated Sorting Genetic Algorithm II (NSGA II) approach for solving Voltage Stability Constrained-Optimal Power Flow (VSC-OPF). Base case generator power output, voltage magnitude of generator buses are taken as the control variables and maximum L-index of load buses is used to specify the voltage stability level of the system. Multi-Objective OPF, formulated as a multi-objective mixed integer nonlinear optimization problem, minimizes fuel cost and minimizes emission of gases, as well as improvement of voltage profile in the system. NSGA-II based OPF-case 1-Two objective-Min Fuel cost and Voltage stability index; case 2-Three objective-Min Fuel cost, Min Emission cost and Voltage stability index.

Raja *et al*. (2018). The boundary limitation of power systems in terms of generation and network growth, owing to lack of generation or transmission capacity, due to this power system operates near to its stability boundaries. The growing complexity of heavily loaded power systems stuck through disturbances and outages makes the problem of voltage uncertainty even worse, a blackout is usually the result of increasing load beyond the transmission capacity of the power system. Therefore, under voltage load shedding (UVLS) is performed as a final remedy to avoid larger scale voltage collapse, restore reactive power balance and finally re-establish the operating conditions, so it is considered, as state of the art to achieve voltage stability. Weak buses are identified using the Fast Voltage Stability Index (FVSI).

Isaac *et al.* (2017). The numerous power system blackouts in the past decade and in recent times attest to the fact that more work still needs to be done to tackle the problem of voltage instability and the resultant voltage collapse. They propose a new line stability index that is suitable for the prediction of voltage collapse in Power System Networks (PSNs). This index code-named the New Line Stability Index-1 (NLSI_1) was obtained by deriving from first principles equivalent expressions for the Line Stability Index (Lmn) and the Fast Voltage Stability Index (FVSI) and combining them through a switching logic based on the voltage angle difference since it can signal the imminence of voltage collapse. This new index (NLSI_1) was tested on the IEEE 14-bus system and it gives the same results as the other indices (Lmn and FVSI). For the base case, the IEEE 14-bus test system was found to be stable with all the three indices having approximately equal values (< 1) for all the lines. The contingency case reveals that bus 14 ranks as the weakest bus in the system with the smallest maximum permissible reactive load of 74.6 Mvar and the critical line with respect to bus 14, is the line connecting bus 13 to bus 14. The values of the three indices, Lmn, FVSI and NSLI_1, are approximately equal thereby further validating the accuracy of the new line stability index-1 (NLSI_1).

Ogbuefi *et al*. (2018). The repeated case of power system collapse in the Nigerian National Grid is of a great concern and need to be investigated. This research paper discusses the effect of voltage collapse and the methods of power generation with respect to the Nigerian National Grid. Other major causes of voltage instability were also examined. Politics has been known to be one of the major factors responsible for epileptic power supply in the country as a result of corruption within the power sector. Single Line Diagram (SLD) showing all the generating stations and transmission network and the distances covered is also presented.

Isaac *et al.* (2019). "The cumulative number of historical and recent power system outages substantiates the fact that further studies are necessary for an improved solution to the issue of voltage instability on the grid and the subsequent system collapse. Voltage collapse is a serious reliability issue which inhibits the objective of running a reliable and secure power system network. In this study, a new line stability index (NLSI_1) for predicting voltage collapse is presented. The new index considers a switching logic which is derived from the difference of voltage angle between the two load buses. The index is deployed for performance analysis using the 28-bus, 330-kV Nigeria National Grid (NNG). The simulation implemented in MATLAB shows that the index gives the same results as Line stability index (Lmn) and Fast Voltage Stability Index (FVSI) indices. The base case and the contingency scenarios were considered during the simulation. The base case analysis using the NNG values of all the three indices FVSI, Lmn, and NLSI_1 for simulation generates a value less than one for the entire lines which implies that the NNG is stable in this mode. The values of the three indices are almost the same, which confirms the accuracy of the novel index developed. The analysis for the contingency case reveals that the load bus 16 (Gombe) which has the lowest, maximum permissible reactive load of 139.5MVAR is the weakest; also, power line 16-19 is identified as the critical line. The result of the simulation confirms that the accuracy was improved by using NLSI_1.

Ogbuefi*et al*. (2018). In this paper the incidences of power system voltage collapse have been studied, analyzed and discussed. The paper also looks at the causes of the voltage collapses in Nigeria power system and proffer some possible solutions. The method used in this research involves data collection and analysis. The data comprise of series of voltage collapses in the Nigeria power Network. The data were analyzed and simulated using MATLAB application software. Results from the study showed that the Nigeria power system experienced the highest number of total system collapse of about 53 in year 2003 and least voltage collapse of 9 in 2014. There are also fears that the cases of collapse which went down in 2015 could be rising at present. In the first six months of 2017, 12 Total collapses and two Partial collapses had been recorded on the grid. Nigeria power system needs total revamping so as to decrease the economic impact of the high incidence of system collapse in the country.

Murana *et al*. (2022), System collapse or cascaded outage within a power system is very hazardous to the power system equipment and operation. This work investigates the transient response of the generators in 132KV grid network of Afam power generating station to Port Harcourt Main (Zone 2) injection substation using 4th order RungeKutta numerical techniques to determine the critical clearing angle (CCA), then critical clearing time. When Electrical Transient Analysis Program (ETAP 19.1) is deployed with circuit breaker and relay time setting of (0.00,0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.14), the results obtained indicate that the protective device must be coordinated properly to quickly clear a 3-phase balanced fault at any bus, in order to enhance stability margin to avoid system collapse.

Akinloye *et al*. (2016). The term voltage collapse is often used in place of system collapse. It is the process by which the series of events accompanying voltage instability leads to a blackout or abnormally low voltages in a significant part of the power system. The cause of this can be categorized into two; technical and non-technical. The technical causes may be due to tripping of lines on account of faulty equipment or increase in load than the available supply. The data comprising the series of system collapse experienced by the Nigeria power system since 1987 to 2014 were presented and analyzed to view the frequency of the occurrence of the collapse. Also, suggestions were given on the ways to reduce the incidence of system collapse on the power system.

Airoboman *et al*. (2015). Assesses the trends in voltage instability in the Nigerian Power System Network (PSN). Data of voltage instability were collected for the year (1995-2013) and was analyzed sequentially using simple statistics and the result interpreted graphically. The result shows an average collapse of 5.1% recorded during this period. 50.8%of the voltage collapses are as a result of total grid collapse while 48.4% collapses are as a result of partial grid collapse while 0.9% collapses caused by foreign objects. The paper therefore emphasizes how poor government policies had led to poor power generation hence leading to voltage instability in the Nigeria power system network.

Almeida *et al*. (2017). The objective is to describe a process which was developed in the Portuguese TSO (REN – Rede Electrica Nacional, SA) whose main purpose is to identify voltage collapse situations without the need for the specific EMS module. The process is based on the power flow module of PSS/E software from Siemens Power Transmission Distribution, Inc., running automatically through an application developed in Python, which performs a SV analysis. Its results are available via browser from control room PC's and are updated every 30 minutes, allowing to monitor the system security levels and to take suitable remedial actions to prevent a voltage collapse situation.

2.2 Voltage Collapse

Niki (2010), Voltage collapse can be defined as the rapid and uncontrollable drop of bus voltage due to increase in load at a bus or group of busses, generally characterized by inadequate reactive support in a high-load area. Voltage collapse could be caused also by a sudden change in the system, such as a line outage. With the rest of the system conditions remaining unchanged, if the load at a particular bus is varied, the voltage at that bus will also vary. Also, the node voltage at other buses varies due to this change in load. Hence, it can be said that, voltage at a load bus is partially dependent on the power delivered to that node. This power can be broken into segments of active and reactive powers and hence the equations can be stated as: $\frac{\partial V}{\partial P}$ and $\frac{\partial V}{\partial Q}$ where P is active power, Q is reactive power and V is the voltage at that node. These last expressions cannot be expressly evaluated because V cannot be expressed as an analytic function of P and Q.

It is really hard to predict a voltage collapse as it has similar characteristics as that of a voltage drop due to alteration of operating condition. The main ideas of voltage collapse are low bus voltages, flow of more reactive power, and shortage of reactive support as well as heavy load on the system. Therefore, a proper diagnosis of the underlying factors causing low voltage is very important. The consequences of a voltage collapse is system outage as it often takes a long while to restore the system and a large area remains without supply for some time.

2.3 Assessment of Voltage Collapse

Niki (2010). To assess voltage collapse, there are two main categories: Static and Dynamic. There are different events that affect the speed and probability of voltage collapse. A few of them are equipment outages or faults due to equipment outages, load disturbances etc, Load disturbances can either be fast like a sudden outage of a large block of load or slow, gradual random load fluctuation. The slow load fluctuation can be treated as a static phenomenon as the voltage changes in small discrete steps of steady states while the fast load change as well as equipment outage or faults due to it are to be counted in the dynamic phenomenon.

The disturbances that require dynamic analysis are leading causes for transient instability but they may cause voltage instability only if the voltage values after the disturbance are low, the transient voltage dips are too long or the voltage equilibrium attained after the disturbance is unstable and adding any reactive power support that that bus will lower the voltage at that bus

2.4 Voltage Collapse Indicators

Static simulators are usually used for planning and operating purposes to determine things like reactive support requirements as well as system loading capabilities. Time domain simulations are also used for voltage stability analysis.

Similarly, to investigate voltage unstable conditions, attempts were made to improve the solution of static load flow programs applied to heavily loaded power systems having low voltage profiles. At higher loads and near to the point of voltage collapse there is no real steady state solution to load flow; hence it was difficult to arrive at a solution.

2.5 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

2.6 Load Restoration

Koishikawa *et al*, (1990) Voltage stability is closely related to load characteristics. The load is the aggregate load seen at the transmission system high voltage buses, and includes the effect of sub transmission and distribution systems. After sudden disturbances causing changes in voltage magnitudes these aggregate loads can be restored to near pre-disturbance values by three mechanisms.

2.7 Voltage Instability

As a consequence, the terms “voltage instability” and “voltage collapse” are appearing more frequently in the literature and in discussions of system planning and operation. Although low voltages can be associated with the process of rotor angles going out of step, the type of voltage collapse related to voltage instability can occur where “angle stability” is not an issue. The gradual pulling out of step of machines, as rotor angles between two groups of machines approach or exceed 180°, results in very low voltages at intermediate points in the network. However, in such cases the low voltage is a result of the rotors falling out of step rather than a cause of it.

Voltage stability is concerned with the ability of a power system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable decline in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power.

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

(i) To collate numerical dataset from existing 330KV and 130kv Nigeria network.
(ii) To formulate governing equations for the study case under investigation.
(iii) To model the existing study case in a single line diagram using NEplan software (20 buses) and ETAp-software application tool for 48- Buses.

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 Centre 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.

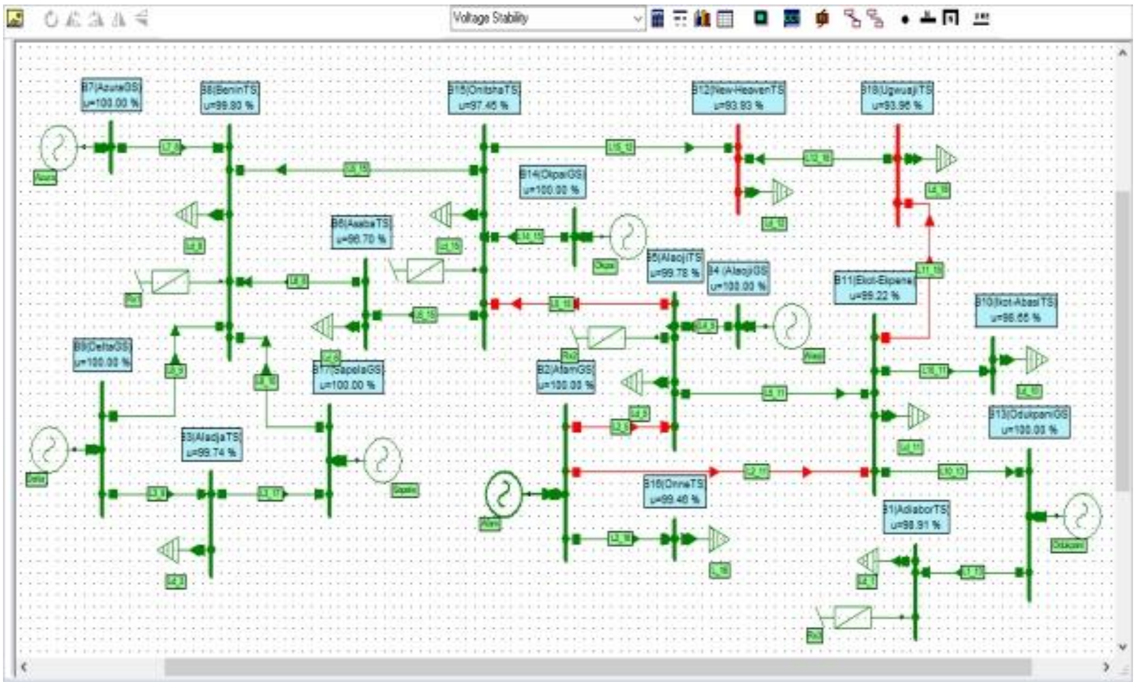

Figure 3.1 Existing South-South/South-East 330kV Grid network in NEPLAN Software application tool.

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
Aluminium	381.6 mm^2	54/3.0 mm
Steel	49.4 mm^2	49.4 mm
Total	431 mm^2	431 mm

On the basis of the above specification with 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

$$R = \frac{R_s}{4}\,\Omega/\text{km} \qquad (3.1)$$

3.4.2 Inductance Reactance of the conductor

The GMR for a single Bison ACSR 350mm^2 conductor is giving by

$$GMR = D_s = 0.7788r \qquad (3.2)$$

Where;
r: overall radius of one conduction in ft
The GMR for a 4-bundled conductor, the GMR is giving by

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

The equivalent spacing between phases between conductors is giving by

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

The Inductive Reactance of the conductor is giving by

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

Where
F: supply frequency
Dm: equivalent spacing
D_s^b: equivalent spacing

3.4.3 Capacitance of the Conductor

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

$$C_n = \frac{0.02411}{log\frac{D_m}{D_{sc}^b}}\,\mu F/km \qquad (3.7)$$

Where
D_{sc}^b: equivalent GMR for capacitance calculation
r: radius of the outer diameter

3.4.4 Susceptance of the Conductor

$$B = \omega C \qquad (3.8)$$

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 this study, Newton Raphson (NR) power flow was considered in figure 3.2

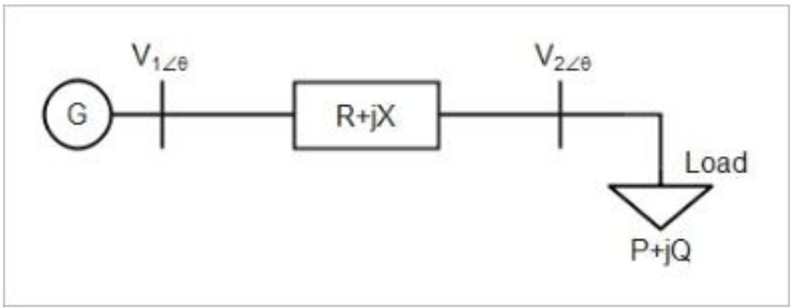

Figure 3.2: Single Line diagram of a two bus system

Figure 3.2 shows 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)

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

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

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

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

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

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

Where
$\Delta P$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 from the conventional Newton-Raphson power flow solution. Power system in recent time has improved in term 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.

3.7 Modal Analysis

The modal (eigenvalue) analysis can be used essentially as a formidable analytical tool to investigate both proximity and mechanism of voltage instability (Subramani *et al.,*2019). Modal analysis method is capable of calculating voltage collapse or instability in power system networks, the major aspect of this technique involves the estimation of the smallest eigenvalues and related eigenvectors of the reduced Jacobian matrix acquired from performing load flow analysis.

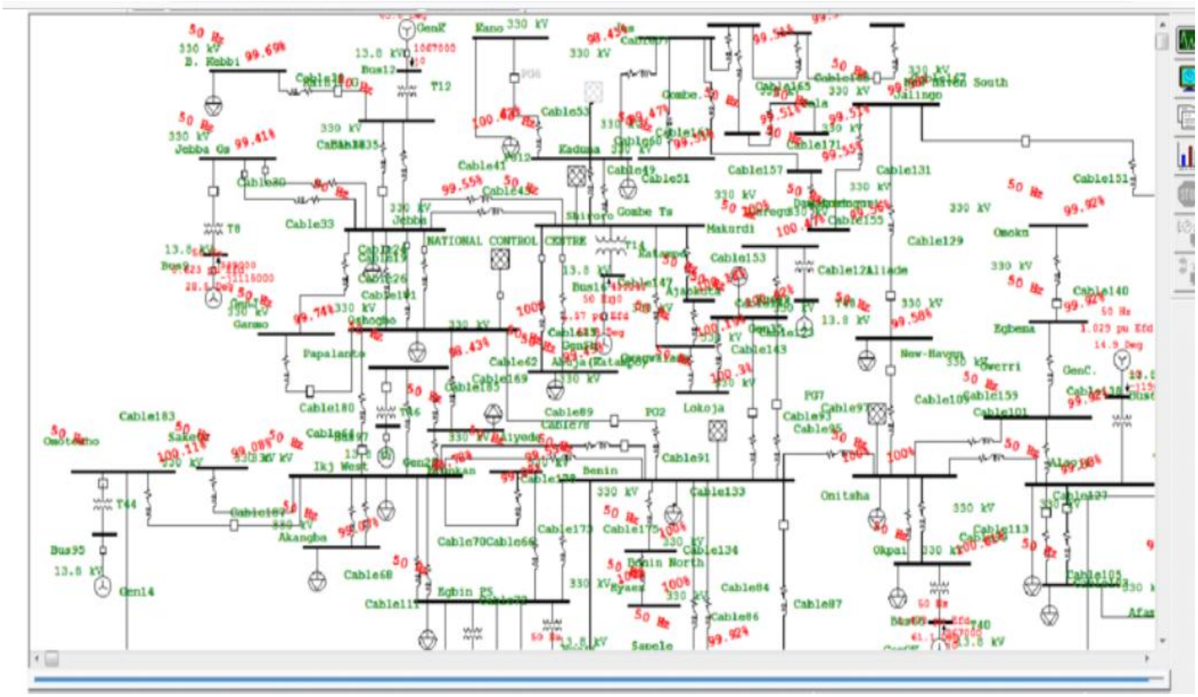

Figure 3.7: Shows the Single-Line Representation of the Existing Study Case (330KV Nigerian Network Simulated).

Modal analysis method is capable of calculating voltage collapse or instability in power system networks, the major aspect of this technique involves the estimation of the smallest eigenvalues and related eigenvectors of the reduced Jacobian matrix acquired from performing load flow analysis. Eigenvalues have a-great deal of relationship with the mode of voltage and reactive power variation, and are employed to estimate voltage instability in a power network system (Yari&Khoshkhoo, 2017). After execution of modal analysis, the participation factors are usually utilized to easily identify the weakest connections or buses in the system. The participation factor values can adequately be, used to determine the weakest bus in the system. The participation factor values are usually obtained from the eigen-vectors analysis of eigenvalues.

By solving linearized power flow equation. The DP and DQ matrix I s obtained

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \quad (3.21)$$

Considering .PA = 0, the reduced Jacobian matrix obtained in equation 2.65 is expressed as:

$$\Delta J_L = [J_4 - J_3 J_1^{-1} J_3] \quad (3.22)$$

$$\Delta Q = J_L \Delta V \quad (3.23)$$

$$\Delta V = J_1^{-1} \Delta Q \quad (3.24)$$

Putting

$$J_L = \xi \wedge \eta \quad (3.25)$$

Where;

ξ,: *is* right eigenvector matrix

his left eigenvector matrix

D: diagonal eigenvalue matrix

Then, inverting equation 3.69 produces

$$J_L^{-1} = \xi \wedge^1 \eta \quad (3.26)$$

And substituting equation 3.70 in equation 3.69 given as;

$$\Delta V = \xi \wedge^1 \eta \, \Delta Q \quad (3.27)$$

And;

$$\Delta V = \Sigma_i \frac{\xi_i \eta_i}{\delta_i} \Delta Q \quad (3.28)$$

Where η_i is the i[th] row of the left eigenvector of *JR*, and ξ_i is the i[th] column of the right eigenvector. The i[th] mode of the Q-V response is defined by the i[th] eigenvalue $d_{i,}$ and the corresponding right and left eigenvectors ξ and h_i, Equation (3.71) can be presented as;

$\eta\Delta V = \wedge^{-1}\eta\Delta Q$ (3.29)

By defining $v = \wedge^{-1}$ as the vector of modal voltage changes and as the vector of modal reactive power changes, the first-order equations can be broken down given as;

$v = \wedge^{-1}q$ (3.30)

Therefore, for the i[th] mode, to obtain

$v_i = \frac{1}{\delta_i}q_i$ (3.31)

At the instant where $d_i > 0$, the i[lh] modal voltage and the i['h] modal reactive power changes align in the same direction, indicating voltage stability of the system; whereas $d_i < 0$ denotes the instability of the system. The magnitude of d_i signifies an average level of instability of the i[th] modal voltage.

A system voltage is assumed to be stable if the eigenvalues of J_r are all positive. However, in the analysis of dynamic systems the eigenvalues with negative real pails are stable. The interaction between system voltage stability and eigenvalues of the J_R matrix is best understood by relating the eigenvalues with the V-Q sensitivities of each bus (which must be positive for stability). J_r can be taken as a. symmetric matrix and therefore the eigenvalues of J_r are close to being purely real. If all the eigenvalues are positive. J_r is positive definite and the V-Q sensitivities are also positive, indicating that the system is voltage stable. The system is considered voltage unstable if one or more of the eigenvalues is found to be negative. A zero eigenvalue of J_r means that the system is on the point of voltage instability, In essence, small eigenvalue of J_r determines the proximity of the system to being voltage unstable (Enemuoh*et al.,* 2016). There is no need to evaluate all the eigenvalues of Jr of a large power system because it is known that once minimum, eigenvalues become zero the system Jacobian matrix becomes singular and voltage instability occurs. Therefore, the eigenvalues that are vital are the critical eigenvalues of the reduced Jacobian matrix J_r.

$P_{ki} = \xi_{k2}\eta_{ki}$ (3.32)

Participation factors show the most critical nodes which can lead the system to instability. Generally, the higher the magnitude of the participation factor of a bus in a specific mode, the easier the solution can be applied on that bus in stabilizing the node.

3.8 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;

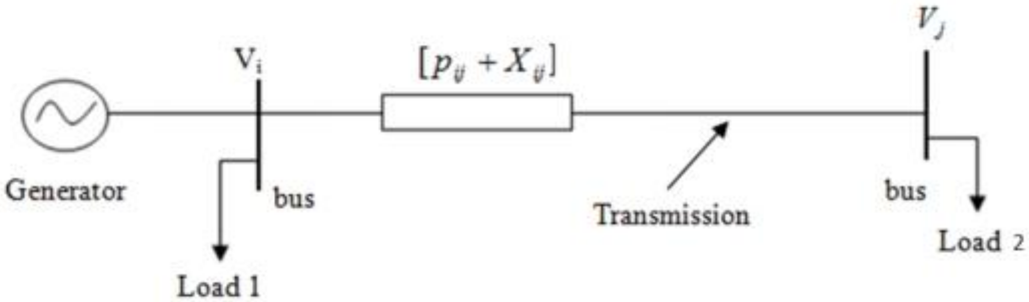

Figure 3.8: Single line representation of a two (2)-bus system

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 i[th] and j[th] bus
Q_i and Q_j : Reactive power load at i[th] and j[th] bus
R_{ij} and X_{ij} : Resistance and reactance of the line correcting i[th] and j[th] bus
I_{ij} : Brand –current of each line connecting i[th] and j[th] 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;

$FVSI_{ij} = \frac{4 \times Z_{ij}}{V_i^2 x_{ij}}$ (3.33)

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;

$$lmn = \frac{4X_{ij}Q_j}{V_i sin(\theta_{ij} - \delta)} \quad (3.34)$$

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;

$$LQP = 4\left(\frac{X_{ij}}{V_i^2}\right)\left(Q_j \frac{P_i^2 X_{ij}}{V_i^2}\right) \quad (3.35)$$

That is for stable operation,
LQP <1

Analysis 4: Voltage Stability Index (LD)
The index is also developed to determine voltage stability conditions, this is stated mathematically as;

$$Ld = \frac{\sqrt[4]{(P_i^2 + Q_i^2)(R_{ij}^2 + X_{ij}^2)}}{V_i^2} \quad (3.36)$$

Analysis 5: Novel Line Stability Index (NLSI)
The NLSI are developed to describe the behaviour of system conditions, for purpose of avoiding voltage instability. This is expected mathematically as;

$$NLSI = \frac{P_j R_{ij} + Q_j X_{ij}}{0.25V_i^2} \quad (3.37)$$

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

IV. RESULTS AND DISCUSSION

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 of capacitor –bank capacity 800MVar are requested for improvement of the existing case to enhance reliable power supply.

4.4 Result of PV Curve for Existing Network Condition

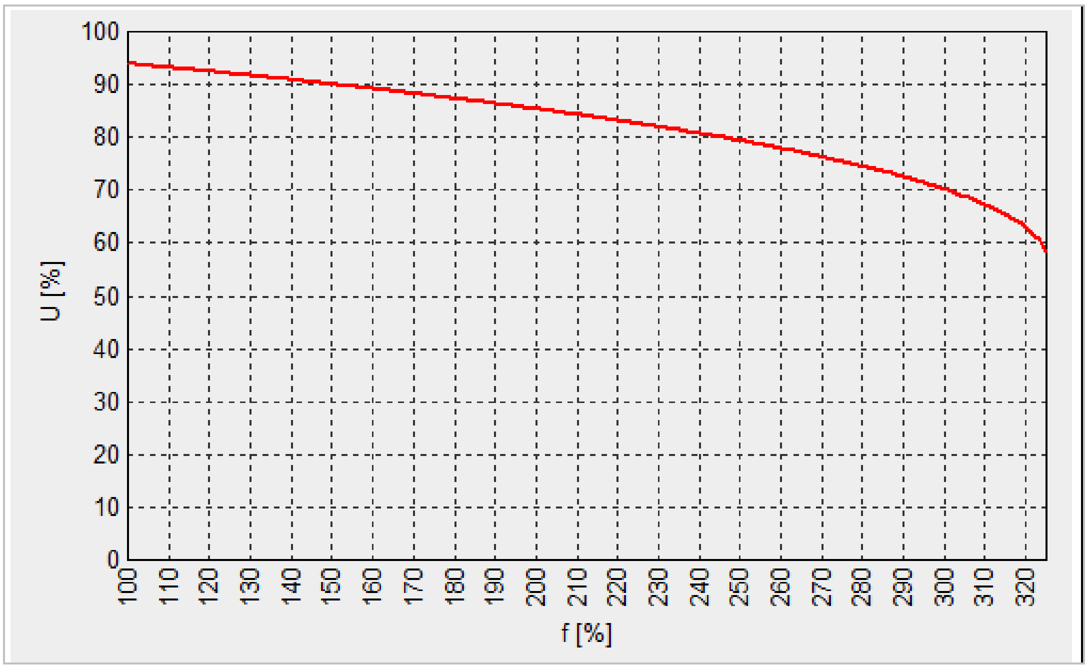

Figure 4.1: Base Case P-V Curve for Bus 12 (New Heaven)

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. Figure 4.4 shows the operating voltage of Bus 12 (New Heaven) as 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: stable, unstable, critical as shown

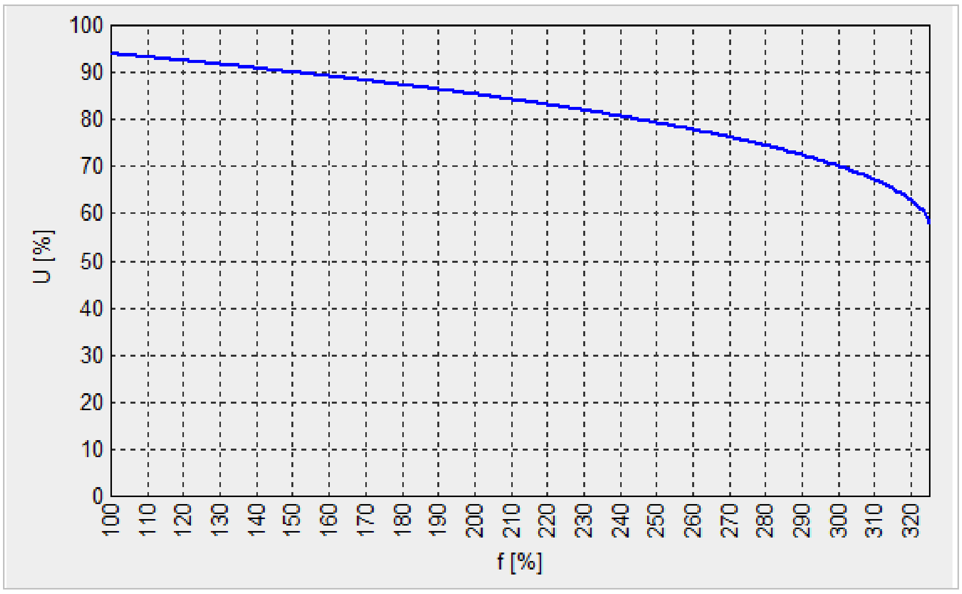

Figure 4.2: Base Case P-V Curve for Bus 18 (Ugwaji)

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. 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 which will not recover from the operating voltage at the point of collapse as 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 network when compensated with an SVC of 75Mvar capacity at bus 12 and 18 respectively. It can be seen from Table 4.1 that all buses are within the acceptable statutory limit of 0. 95pu - 1.05pu with no bus voltage violation. Table 4.1 shows that Bus12: 0.984p.u and Bus18:0.985 are within the acceptable statutory limit of 0.95pu-1.05 with no bus voltage violation.

4.6 Result of Improved PV Curve in the Network Condition

Figure 4.3 shows the improved P-V curve plot used for Bus 12 (New Heaven) when a controlled SVC are installed. 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 1242.5MW

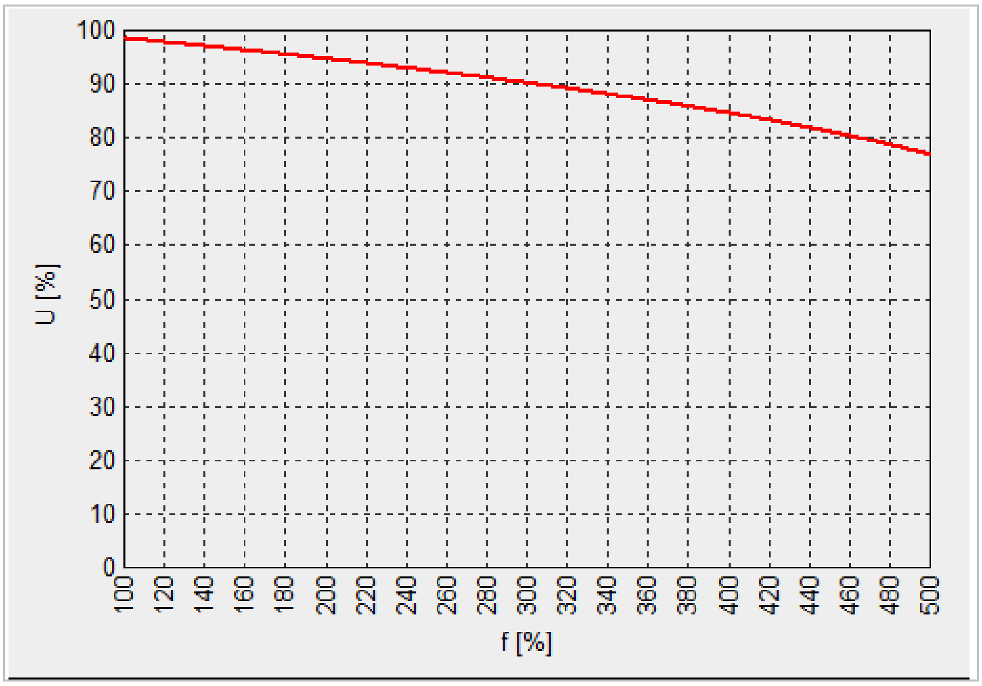

Figure 4.3: Improved P-V Curve for Bus 12 (New-Heaven)

Figure 4.4 shows the improved P-V curve plot used for Bus 18 (Ugwaji) when an SVC are installed. Figure 4.4, 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, with SVC installed at Bus 18 the load ability can be increased by 1242.5MW.

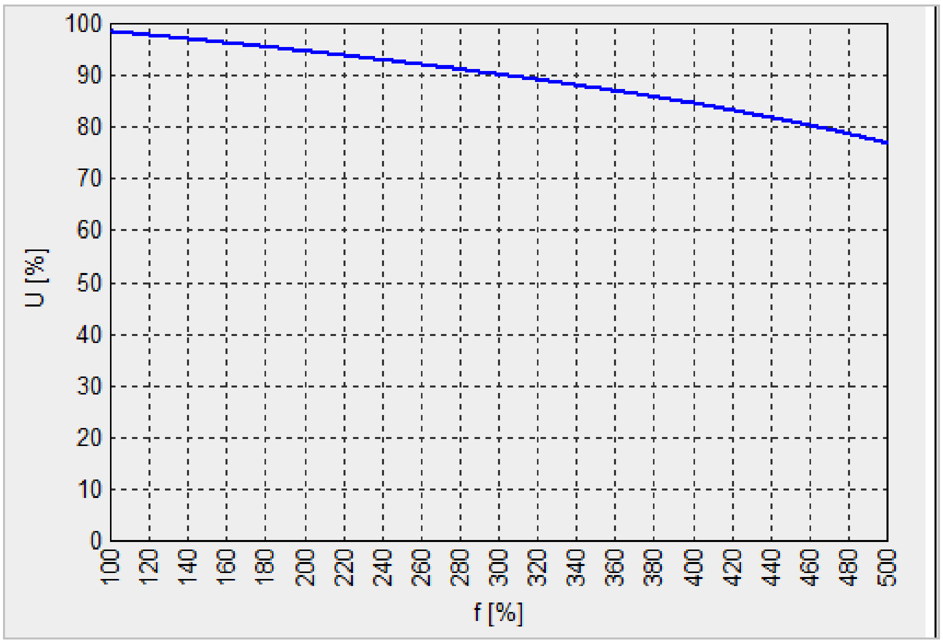

Figure 4.4: Improved P-V Curve for Bus 18 (Ugwaji)

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study determined the activities of voltage control and stability problems associated 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 study 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 constituted 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, application of modal analysis with participation factor tool was used as criteria for determining weak and stronger bus 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 predictive capacity of line voltage instability of 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 using embedded model analysis tool to determine the participation factor for voltage stability in line with eigen-vector and eigen-values.
Similarly, 330Kv network 48-buses was modeled using electrical transient analyser (Etap 19.0.1) to evaluate voltage stability limit for instability condition using predictive optimizer (FVSI, LMN, LQP, LD, NLSI)

5.3 Recommendations

Recommendations of this paper are presented as follows:

(i) All generation stations should be on free governor mode of operation.
(ii) GenCos should harmonize gas pipeline outages with gas turbine maintenance.
(iii) GenCos should adhere to its declaration in accordance with NERC Regulatory Practice.
(iv) Acquisition of sufficient gas for generation to match demand.
(v) Gen stations should abide by NCC instructions on dispatch of both Active (MW) and Reactive power (MVAr)
(vi) The Annual Maintenance Plan should be maintained
(vii) 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
(viii) Stations with allowances for future stations.
(ix) Upgrade of aged transformers and re-conducting of transmission lines
(x) Provision of Hotlines communication to NCC.
(xi) Provision of spare part for adequate maintenance.
(xii) Provision of spinning reserve.
(xiii) Provision of adequate Voltage compensating devices.
(xiv) Proper relay coordination across the entire power supply chain to avert uncoordinated and spurious tripping.

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