Implementation of a Dynamic Network Model of the Nigerian Transmission Grid for Investigations on Power System Stability

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Abstract - *Electricity is the backbone of any modern society and economy. Therefore, economic growth and increase in social wealth of a country usually lead to an increase in demand for electrical energy especially for a country as Nigeria. As the population of Nigeria is increasing exponentially, there exist a need to make basic needs constantly available, for the wellbeing of the increasing population. This is possible through mechanization. Reliable and stable electricity supply is the surest means to this end. As a result, there is need to constantly review the dynamics of the power system while more energy sources and loads are being added to the existing power network grid. This creates a demand for precise models for the corresponding network. In this paper, the power network system of the Nigerian transmission grid was implemented at normal operations to include the dynamic models to the corresponding network elements (i.e. generation Units based on their installed capacities and controllers). With the help of this model, stationary load flow calculations, as well as network's model performance in steady state was conducted. The network's model performance in the case of load changes and fault operations was also carried out. These allowed for investigations on the stability status of the Nigerian transmission grid.*

Key Words: Power System Stability Analysis (RMS), Dynamic Network Model, Nigerian Transmission Network, DigSILENT PowerFactory Analysis, Short Circuit Analysis, Load-Flow Calculations, Load Events.

1.INTRODUCTION

Due to the present state and challenges facing the Nigerian Electricity market and industries, there are almost frequent power-cuts and long periods of power outage that are seen in some areas of the country. The frequent power-cuts affect the profiles of Bus-voltages which is seen in some areas having constant low and/ flickering voltages for long periods. This affects the stability of the entire power network. This is believed to be resulting from inefficient network modelling and no dynamics considerations in the usual stationary load flows performed by the National Control Centre (NCC) of the Nigerian Transmission company of Nigeria (TCN). As a result, there is need to introduce it into the Nigerian Electricity network to enable us to constantly study the effective loadings of network elements at almost all instants as well as estimate the stability of the entire network prior to addition or removal of any element in the existing infrastructure of the Nigerian Grid system.

The scope of this research is limited to the highest voltage (HV) infrastructure in the Nigerian transmission power network, which is the 330 kV Network. The Network operators step down voltage from 330 kV voltage network to 132 kV voltage network and then to 33 kV voltage network. This ends the transmission network of the Transmission Company of Nigeria (TCN).

The main reason for this scope is predominantly because almost all the power plants in the Nigerian power network are connected to this voltage level after generation and so it serves as the intermediate grid in the entire network, thus making it the most sensitive, important and the most consciously monitored Grid by the TCN in Nigeria.

2. A brief on the Nigerian Electricity System

Electricity generation in Nigeria was thought to have begun in 1896 during the British colonial times. In 1929, the first recognised electrical company was set up to control electricity generation, transmission and distribution in the country. The arm which was charged with power generation (then hydro plants power) was known as the Nigerian Dams Authority (NDA) while the arm charged with the electricity transmission and distribution was known as the Electricity Corporation of Nigeria (ECN). Because of the country's division into different regions, other electrical companies began springing up in various regions that saw to the running of the electricity generation and consumption [1]. It was not until 1972 that the only hydroelectric company at that time – Nigerian Dams Authority, merged with the Electricity Corporation of Nigeria (ECN) – the conglomeration of the small companies, to found the National Electrical Power Authority (NEPA). As this was the only federal parastatal that controlled electricity generation in the country. They were in control of 94% of the total electricity generation and maintained 100% of the transmission, distribution, the marketing sector and the system operators [2]. This monopoly hindered the needed development in the sector that later led to the deregulation of electric power in Nigeria [3]. After the deregulation, 11 distribution companies (DISCO) took over the distribution of electricity, 6-generation companies (GENCO) took over the generation arm while the transmission company of Nigeria still manages the electricity transmission from 330kV to 33kV high voltage infrastructures in the electricity system of Nigeria. The power plants owned by the Niger Delta Power Holding Company (NDPHC) are controlled by the three tiers of government in Nigeria (Federal, State and Local). These power plants are classified as being part of the National Integrated Power Project (NIPP) while others are wholly owned by the state governments and/or private companies/individuals. Such a power plant is referred to as an Independent Power Producer (IPP).

A brief history and structure of the Nigerian electricity system is summarized in figure 1.

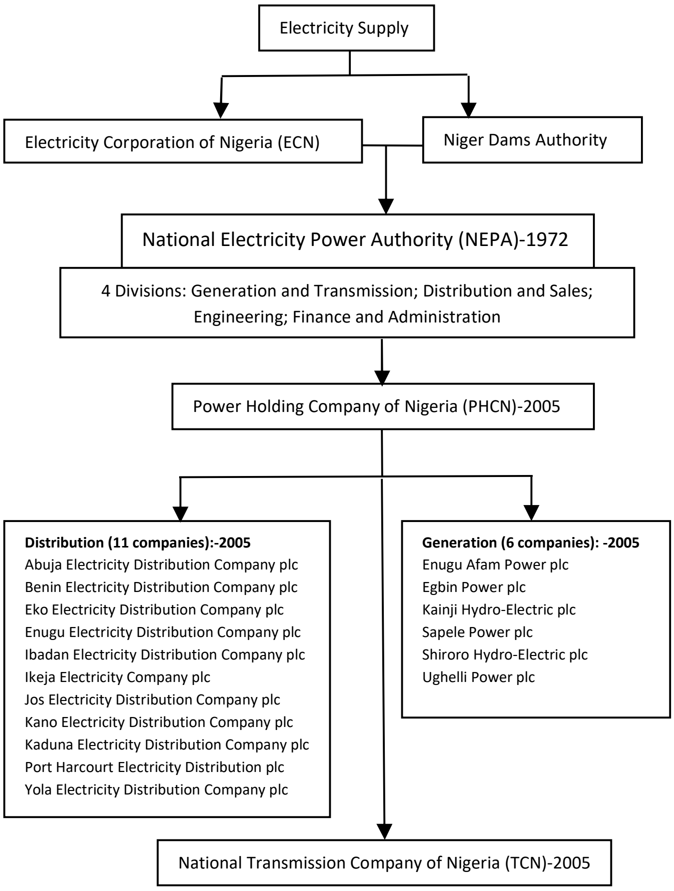

Fig -1: Overview of the History of Nigerian Electricity System

2. THE NIGERIAN POWER NETWORK

Electricity is generated in Nigeria between 10.5 kV to 16 kV from the generators in power plant stations. From these voltage levels, they are stepped-up by transformers depending on the choice of the injection voltage level but mostly to 330kV. Transmission of Electricity sets in immediately from this point. Transmission starts with the transportation of the generated power through the 330kV voltage network along transmission lines/conductors and is stepped-down by transformers to 132 kV at the transmission substations. This voltage is again transported along 132 kV transmission lines to the injection substations and stepped down by a transformer to 33 kV.

This is where the Distribution of electricity starts. The voltage is further transported along the 33 kV transmission lines and is stepped down to 11 kV which in turn, is stepped down again to 0.415 kV before it find its way to Nigerian homes and/ offices [4].

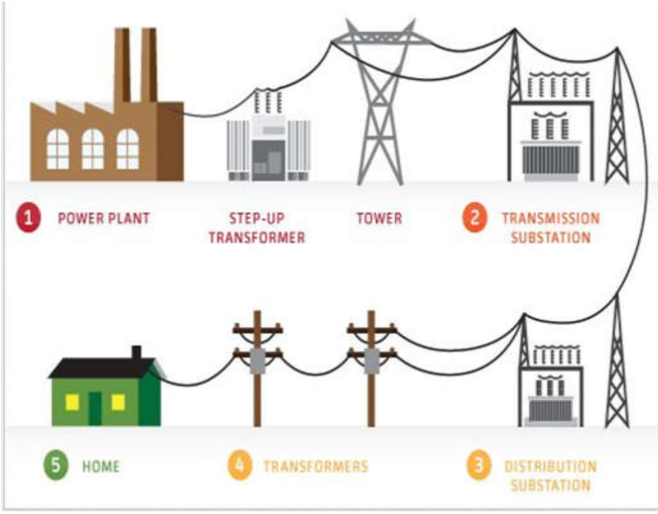

Fig -2: How Electricity is transported to Nigerian Homes [4].

These normal procedures does not disprove the fact that there are other voltage levels (e.g. 66 kV etc.) used by industries in Nigeria but these are subject to specific voltage requirements of these industries. This is a function of their machines and equipment.

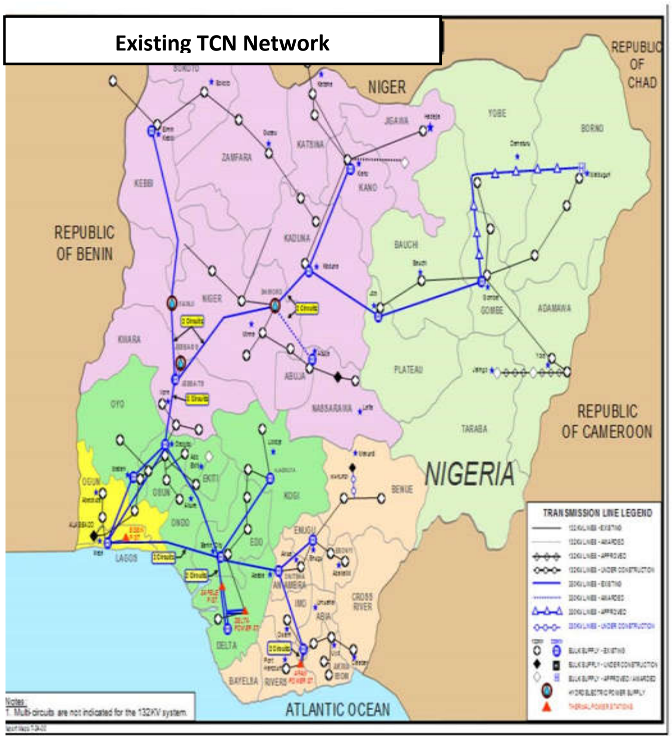

Fig -3: Map of Nigerian Power Network [5]

At present, the total installed generation capacity in the entire network based on the received data from Transmission Company of Nigeria (TCN) in November 2018 is approximately 12,908 MW. The Power plants that contribute to this Capacity comprises of less-decommissioned units and therefore, were used in the analysis of the stability of the Nigerian network and Table 1 to Table 4 show their list.

Table -1: Privatised Companies- Hydro Stations [5]

Plant	**Installed Capacity (Less-Decommissioned Units) (MW)**
Kainji G.S (Niger)	760.00
Jebba G.S (Niger)	578.40
Shiroro	600.00
SUB-TOTAL	**1,938.40**

Table -2: Privatised Companies- Thermal Stations [5]

Egbin (Lagos)	1,320.00
Sapele Steam (Delta)	720.00
Transcorp Delta II-IV G.S. (Delta)	900.00
Afam IV & V (Rivers)	351.00
Geregu G.S. (Kogi)	414.00
Omotosho G.S.(Ondo)	335.00
Olorunsogo (Ogun)	335.00
SUB-TOTAL	**4,375.00**

Table -3: NIPP- Thermal Stations [5]

Sapele NIPP (Delta)	500.00
Alaoji NIPP (Abia)	500.00
Olorunsogo NIPP (Ogun)	750.00
Geregu NIPP (Kogi)	450.00
Omotosho NIPP (Ondo)	500.00
Ihovbor NIPP (Edo)	500.00
Odukpani (Cross-River)	625.00
Gbarain (Bayelsa)	120.00
SUB-TOTAL	**3,945.00**

Table -4: IPP- Thermal Stations [5]

Okpai G.S (Delta)	480.00
Afam VI G.S (Rivers)	650.00
Asco G.S (Kogi)	110.00
Ibom G.S (Akwa Ibom)	155.00
AES (Lagos)	294.00
Trans-Amadi (Rivers)	100.00
Rivers IPP (Rivers)	180.00
Azura IPP (Edo)	459.00
Omoku G.S (Rivers)	150.00
Paras-Energy (Lagos)	72.00
SUB-TOTAL	**2650.00**
GRD TOT./WTD AVERAGE	**12,908.40**

3. IMPLEMENTED DYNAMIC COMPONENTS FOR THE NIGERIAN NETWORK

The representation of the network dynamics was done using the standard dynamic models for synchronous machine and their control devices. The reason for the choice of the controllers is based on the condition to use standard IEEE recommended models in order to facilitate the tuning processes for better and expected results. The dynamic components of the Generators in the power plants listed in Table 1 to Table 4 were implemented. These included the Synchronous generator, the Turbine/Governor (TGOV), the Automatic Voltage Regulator (AVR), as well as Power System Stabilizer (PSS). Below are the graphic diagrams of the above components modelled in the network.

3.1 Power Plant Model

A synchronous generator standard model in PowerFactory was used to define the characteristics of the power plants and their dynamic components in the design. The power plant frame is shown in figure 4. The choice of this model is based on IEEE guide for synchronous generator modeling practice and applications in power system stability analysis [6]. In the power plant frame shown below, it is important to state that the meter bus placed to introduce voltage and frequency measurements to the power system stabiliser (PSS) input, the over-excitation limiter (OEL) and the under-excitation limiter (UEL), all situated at the left side of the power plant frame was not considered in this design and therefore does not contribute to the overall activity of the entire system.

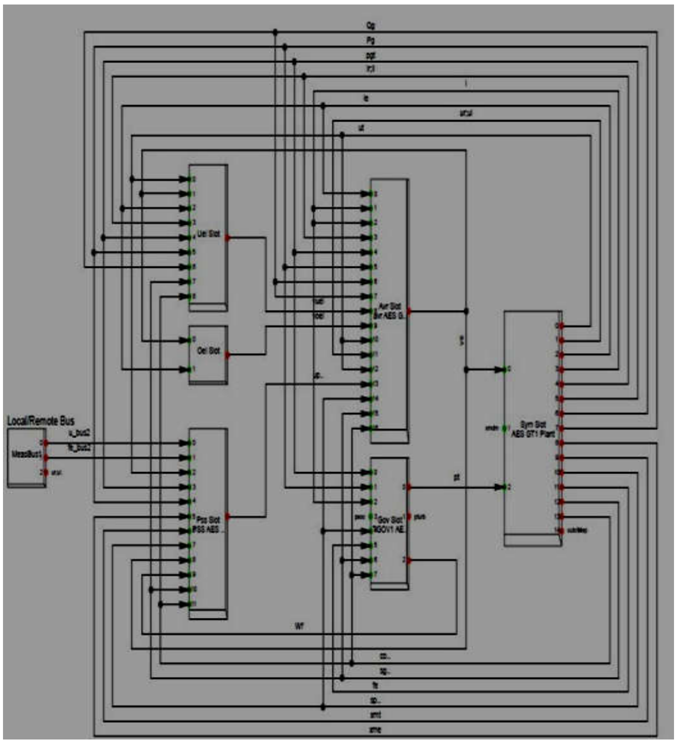

Fig -4: Standard Power Plant in PowerFactory [7].

Irrespective of the type of synchronous generator and the controllers used, the power plant frame in figure 3 remains almost the same for most configurations. Hence, for any type of controller used depending on its input variables, the synchronous generator will deliver the necessary input variables for efficient operation of its controllers.

Table -5: Generator Basic Signals

Generator Input Signals	Details
ve	Excitation voltage from the AVR
pt	Mechanical Turbine Power
Output Signals	**Details**
ut	Terminal voltage
pgt	Electrical Power
fe/wf	Frequency
speed/xspeed	Shaft speed
xmt	Mechanical Torque
xme	Electrical Torque
cosn	Powerfactor
Sgnn	Apparent power

3.2 Turbine/Governor Model

A steam turbine converts the stored energy of high pressure and high temperature steam into a rotating energy. This energy is in turn converted into electrical energy by the generator whose speed is controlled by the governor [8]. In Nigeria, the heat source for the boiler supplying the steam is typically fired by Liquefied natural gas (LNG). The Turbine/Governor models used in the design were of IEEE recommendations for dynamic models of Turbine-Governor in power system studies [9]. Two models were used, one for the hydro-plant (HYGOV) and the other for the thermal plants (TGOV1).

In these two models (HYGOV and TGOV1), the operations and basic signals are the same. The basic input signals of measured frequency and electrical power are compared at the summation point (-) against their reference set values in order to decode any deviation. The result of these deviations in the frequency and power to the reference values is necessary to enable creation of the necessary primary control Droop instruction needed to be fed into the controller for valve adjustment (steam/gas open/close time) in the event of any disturbance. The signal gate Limiter, which serves as valve adjustment regulator, is also placed alongside the necessary delay constant functions considering the effect of frictional losses and are also compared with other signals like the apparent power and powerfactor from the synchronous generator to be able to effect a controlled change in the turbine input (pt) of that power plant.

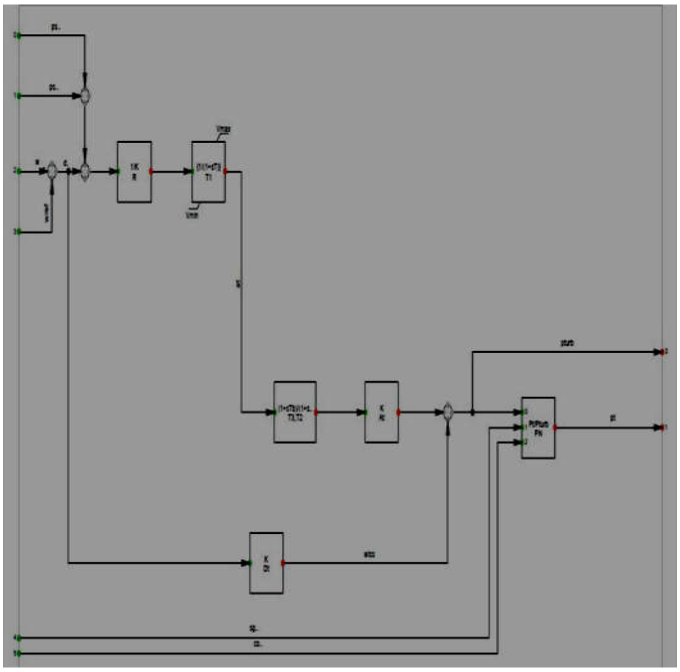

Fig -5: Frame of the Thermal Turbine-Governor (TGOV1)

The important signals to the studies are shown in Table 6.

Table -6: Turbine-Governor Basic Signals

TGOV-Input Signals	Details
Pgt	Electrical Power Generated
fe/wf	Frequency
Speed	Synchronous machine speed
Output Signals	**Details**
At	Controlled valve relative position to the position
Pt	Mechanical Turbine Power
fe/wf	Frequency
Sgnn	Apparent power
Cosn	Powerfactor

3.3 Automatic Voltage Regulator Model

Here, the choice of the Automatic Voltage Regulator (AVR_SEXS) as the voltage regulator and the excitation system used for the synchronous generator was influenced by ENTSO-E in [10].

The basic operations of the automatic voltage regulation of SEX standard is significantly the same with any other AVR device. One of its few advantages can be attributed to low number of input parameters as against many other standard models. It is important to state that the voltage input signals of OEL and UEL are not considered in this model.

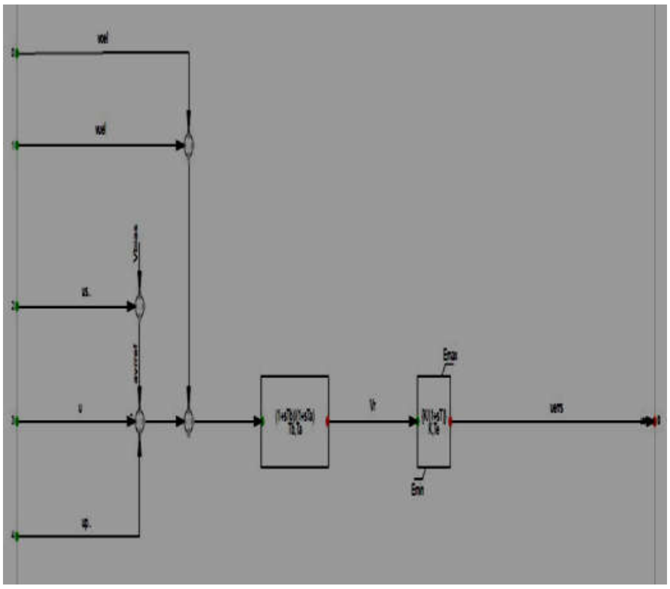

Fig -6: Frame of the AVR Device (AVR_SEXS) in PowerFactory

Here, the reference voltage (Usetp) alongside any bias (Vbias), terminal voltage (ut) and the voltage output of the PSS (Upss) are compared. Any deviation at this stage is fed to the filter in the lead-lag block. The output of this filter is then fed into the excitation limiter controller. With the help of its gain, the controller output is tuned in such a way that its output signal, excitation voltage (ve/ueers), is to control the generator stator terminal voltage.

Table -7: Automatic Voltage Regulator (AVR) Basic Signals

AVR Input Signals	Details
ut	Terminal voltage
Upss	Power system stabilizer (PSS) output
Speed	speed
Pgt	Electrical Power
Usetp	Reference voltage/voltage setpoint
Output Signals	**Details**
ve/ueers	Excitation voltage

3.4 Power System Stabilizer (PSS) Model

Here, PSS is used to enhance damping of power system oscillations through excitation control. The PSS (i.e. PSS2A) standard model used in this design was influenced by the IEEE recommended practice for Excitation system models for power system stability studies [11]. The PSS2A standard Frame in Powerfactory is shown in figure 7.

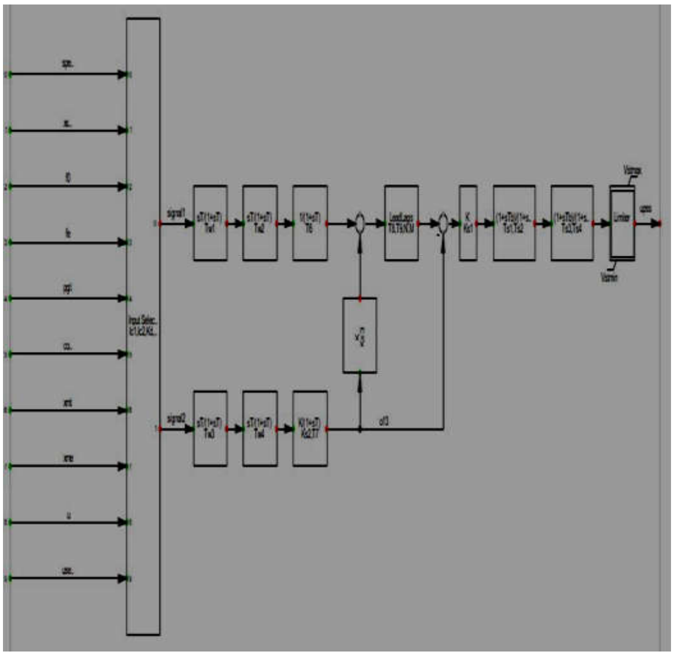

Fig -7: Frame of the PSS Device in PowerFactory

The Dual Input selector of the PSS2A model selects from the following input signals: 0-Reference Speed (speed-ref), 1-Speed (xspeed), 2-Reference Frequency (f0), 3-Frequency (fe), 4-Power generated, 5-Rotor angle, 6-Mechanical torque (xmt), 7-Electrical torque (xme), 8-Terminal voltage (u), 9-reference voltage/ Voltage set point (Usetp).

The Ic1-first input code, Ic2-second input code, Input base (IPB) selector: 1-Generator MVA, 0-Generator MW base). From any input selected, Signal 1 and/ Signal 2, almost the same process is followed. The selected input signal either takes the MVA or MW base as assigned to it by the IPB selector, is fed into necessary first order lag differentiators and then to the signal transducer block (T6 and T7) represented by their time constants. Again, their outputs are compared and the result fed into the Lead-Lag block which allows for ramp-tracking in the input signals. The output of the Lead-Lag block is then compared with the gain-tuned input of the Signal 2 and the result fed into the PSS controller.

The output at this stage is also fed into other necessary first and second Lead-Lag derivative and delay blocks which is responsible for the control of phase compensations. The output of this lead-Lag block serves as input to the voltage Limiter block used for excitation control to output the controlled-voltage signal input (Upss), which in turn, as an input to the AVR device, is used to add damping to the synchronous generator stator oscillations in the case of any disturbance in the network.

Table -7: Power System Stabiliser Basic Signals

PSS-Input Signals	Details
fe/wf	Frequency from Turbine-Governor
ve	Excitation voltage from AVR
Speed	Rotor Speed
cosn	Powerfactor

Pgt	Electrical Power
ut	Terminal voltage
Usetp	Voltage setpoint
xmt	Mechanical torque
xme	Electrical torque
Output Signals	**Details**
Upss	Power system stabilizer (PSS) output

4. LOAD FLOW CALCULATIONS

A load flow calculation determines the voltage magnitude (V) and the voltage angle (θ) of the nodes, as well as the active (P) and reactive (Q) power flow on branches. In this design, Powerfactory was used to implement the Newton-Raphson (power equation, classical) method as its non-linear equation solver because of its fast-convergence nature. This Newton-Raphson algorithm is sufficient for Load-flow calculations for large transmission systems, most especially when heavily loaded. This method was used for A.C. Load flow calculation during the top of the hour at Off –Peak Minimum (OPM-8:00 Hours) and also at Maximum Power Flow (MPF-22:00 Hours)

The currents at steady state are calculated from [12]:

$$I_i = \frac{S_i^*}{V_i} = \frac{P_i - jQ_i}{V_i}$$

where i=1,2,3,…m where m = 107 generators from 28 Power Plant stations.

V_i is the terminal voltage of the generator; and P_i and Q_i represents the true and reactive powers. For the 71-bus system, the voltages at the nodes can be represented by the equation in matrix form given as:

$$\begin{bmatrix} I_1 \\ I_2 \\ \cdots \\ \cdots \\ \cdots \\ I_{71} \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1i} & \cdots & Y_{1n} \\ Y_{21} & Y_{22} & \cdots & Y_{2i} & \cdots & Y_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ Y_{n1} & Y_{n2} & \cdots & Y_{n1} & \cdots & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \cdots \\ \cdots \\ \cdots \\ V_{71} \end{bmatrix}$$

Where n = 71= number of buses or simply put;

$$I_{bus} = Y_{bus} V_{bus}$$

Where I_{bus} is the vector of the injecting bus currents and V_{bus} is the vector of bus voltages measured from the reference node. Y_{bus} can also be referred to as the admittance matrix. The diagonal element of each node is the sum of admittances connected to it. It is also known as self-admittance given by [12]:

$$Y_{ii} = -\sum_{j=0}^{n} y_{ij} \quad \text{where } j \neq i$$

The off-diagonal element is equal to the negative of the admittance between the nodes. It is known as mutual admittance and it is shown below.

$$Y_{ij} = Y_{ji} = -y_{ij}$$

In summary, the flow chart for the Newton-Raphson Load flow calculation algorithm is shown in figure 8.

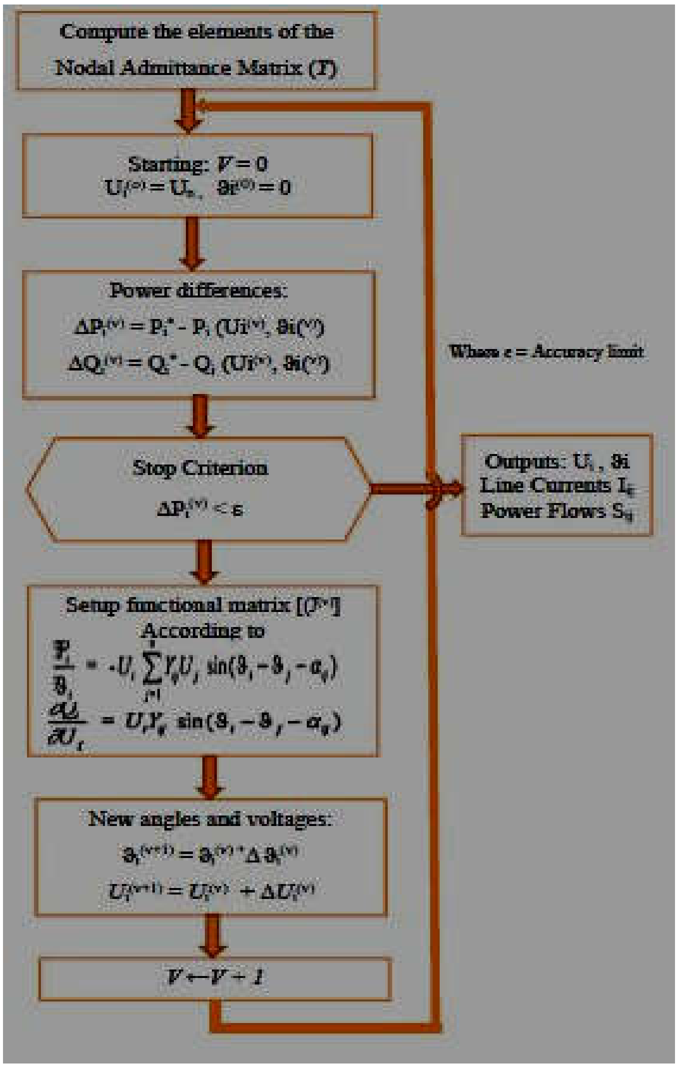

Fig -8: Flow Chart for Load Flow Calculations using Newton-Raphson method [12]

The figures below show the Single line diagram of the Load flow calculation in the DigSILENT PowerFactory software.

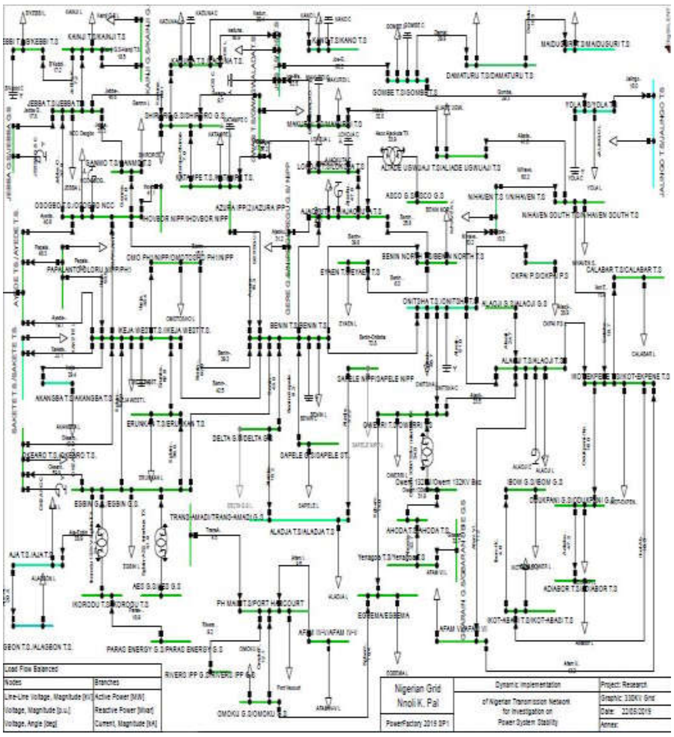

Fig -9a: Single Line Diagram of the Nigerian Transmission Grid (OPM; 08:00 Hours)

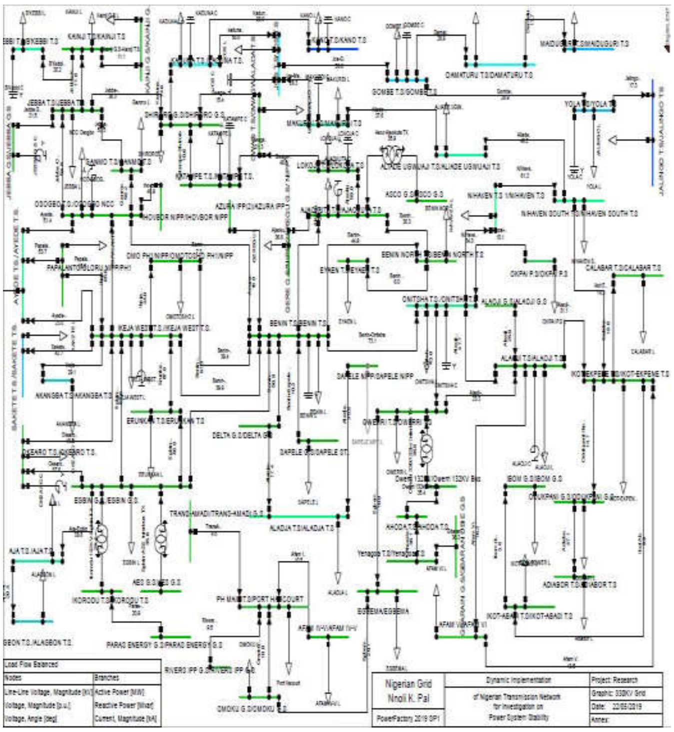

Fig -10a: Single Line Diagram of the Nigerian Transmission Grid (MH; 22:00 Hours)

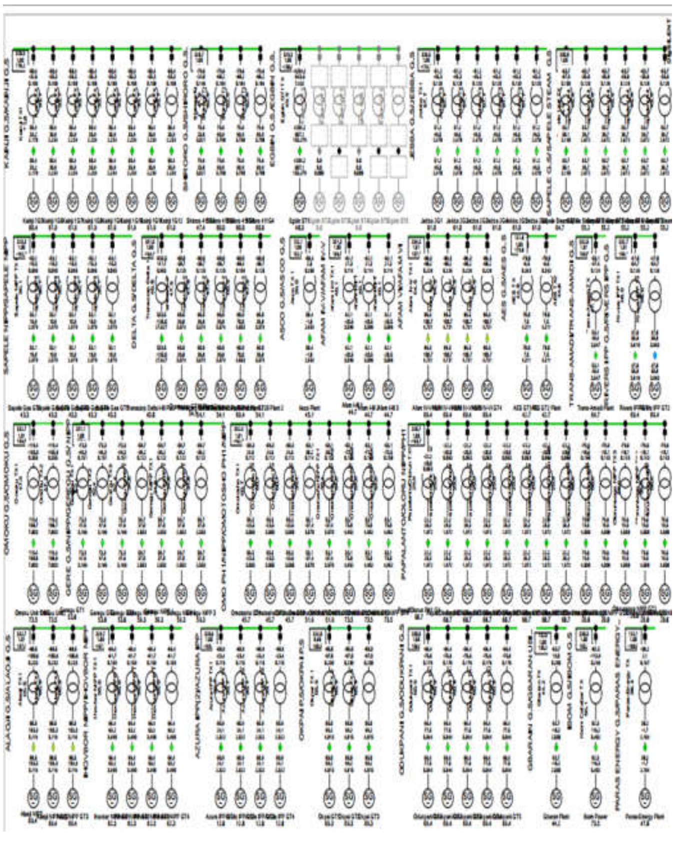

Fig -9b: Single Line Diagram of the Nigerian Transmission Grid (OPM; 08:00 Hours) Continuation

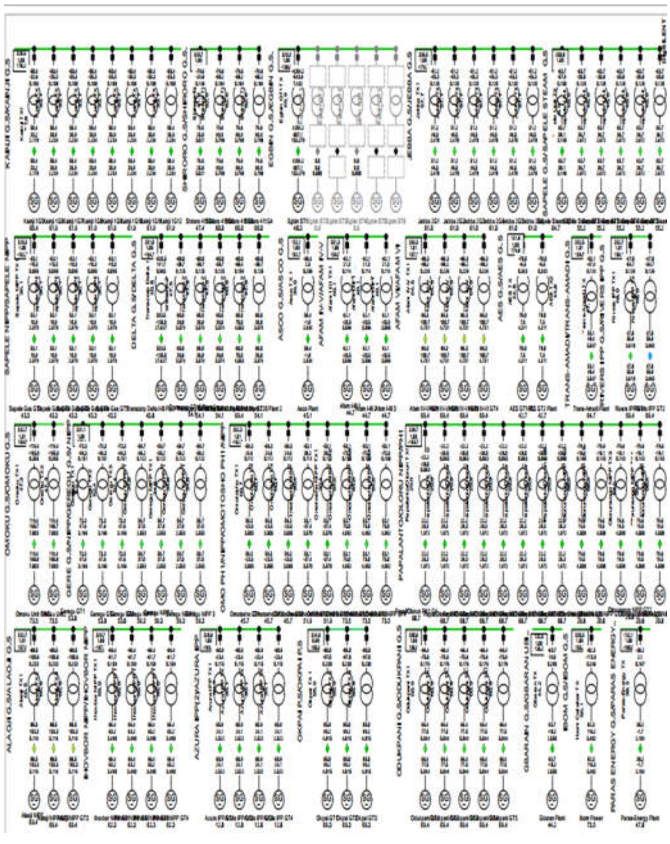

Fig -10b: Single Line Diagram of the Nigerian Transmission Grid (MH; 22:00 Hours) Continuation

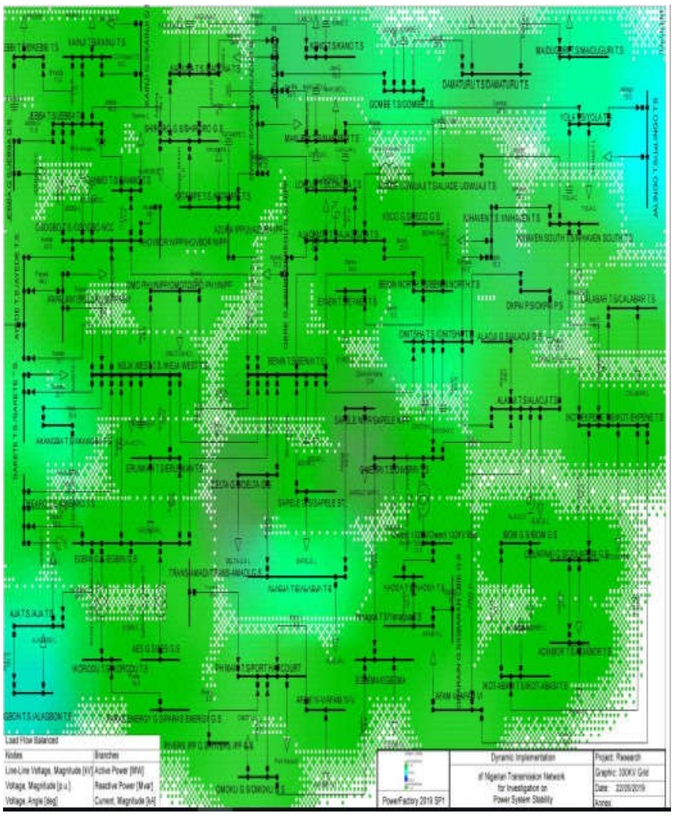

Fig -11a: Heat Map of the Single Line Diagram of the Nigerian Transmission Grid (OPM; 08:00 Hours)

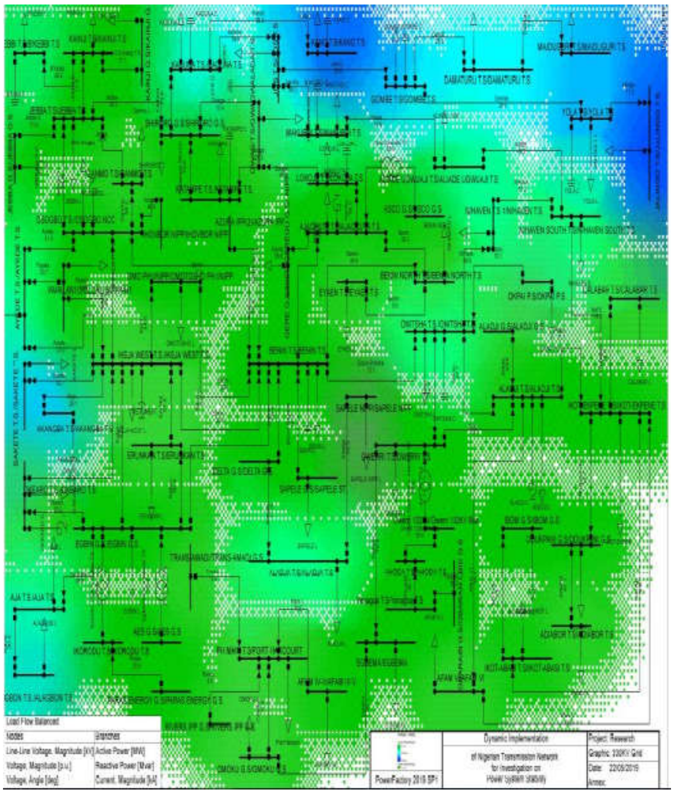

Fig -11b: Heat Map of the Single Line Diagram of the Nigerian Transmission Grid (MH; 22:00 Hours)

4.1 Load flow calculation results during the top of the hour at Off –Peak Minimum (OPM) Hours

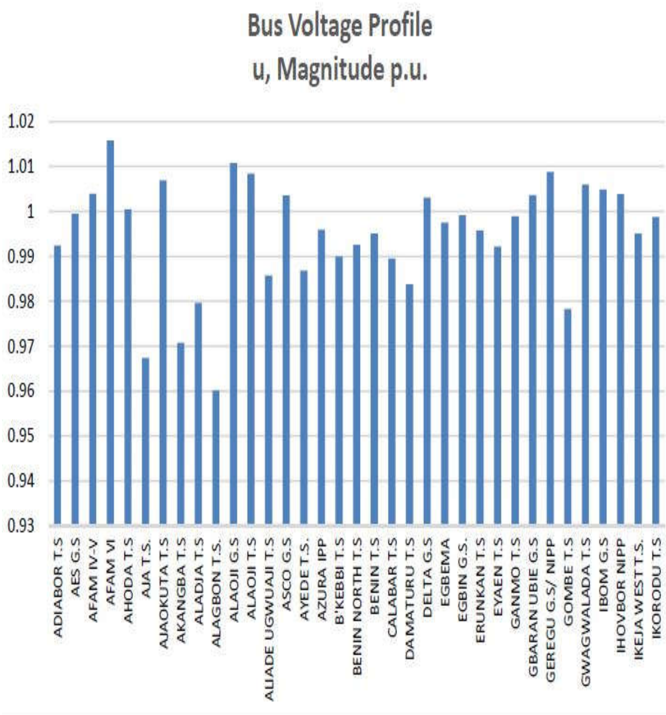

Fig -11a: Bus Voltage Profile in Per-Unit after Load Flow Calculations

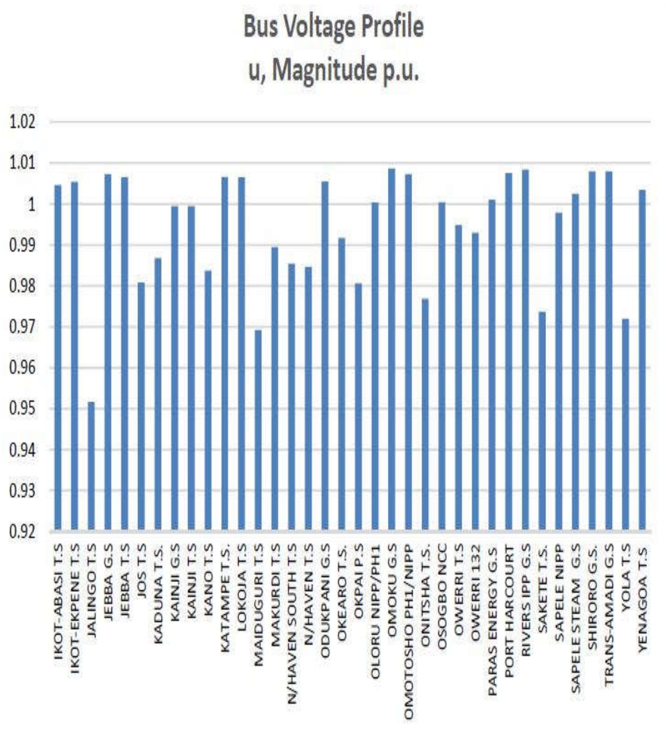

Fig -11b: Bus Voltage Profile in Per-Unit after Load Flow Calculations (Continuation)

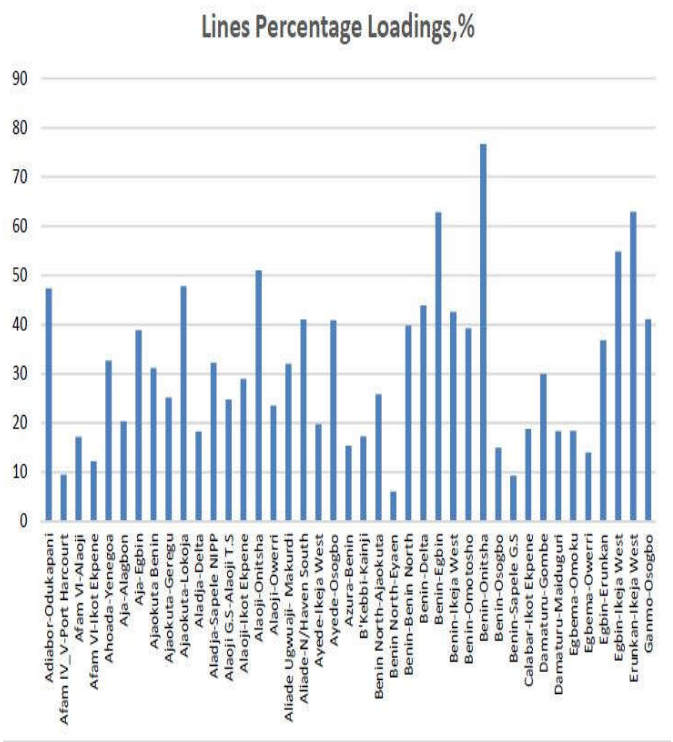

Fig -12a: Transmission Line Loadings in Percentage, %

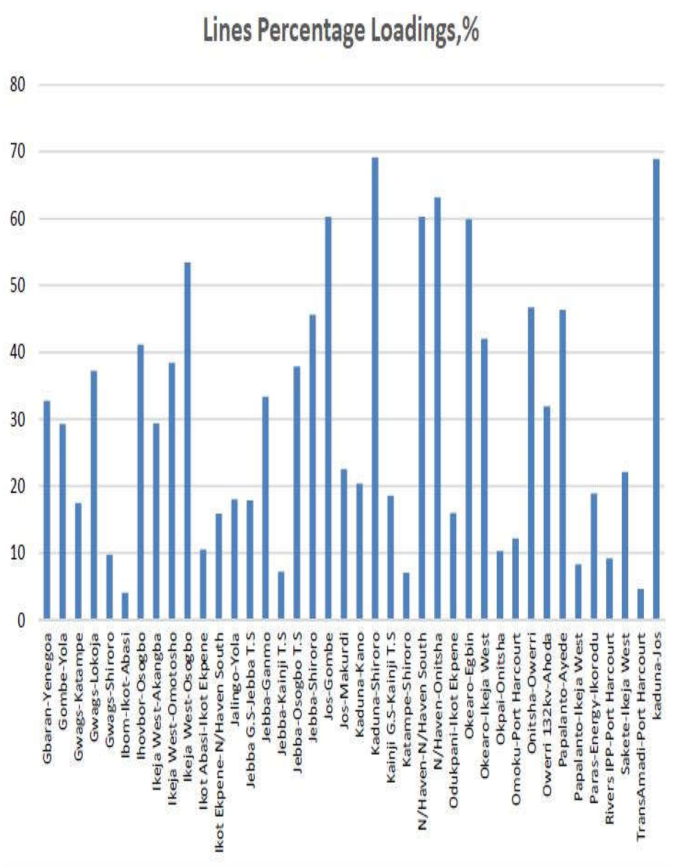

Fig -12b: Transmission Line Loadings in Percentage, % (Continuation)

4.2 Load Flow Calculation Results during the top of the Maximum Hour (MH-22:00 Hours) Power Flow

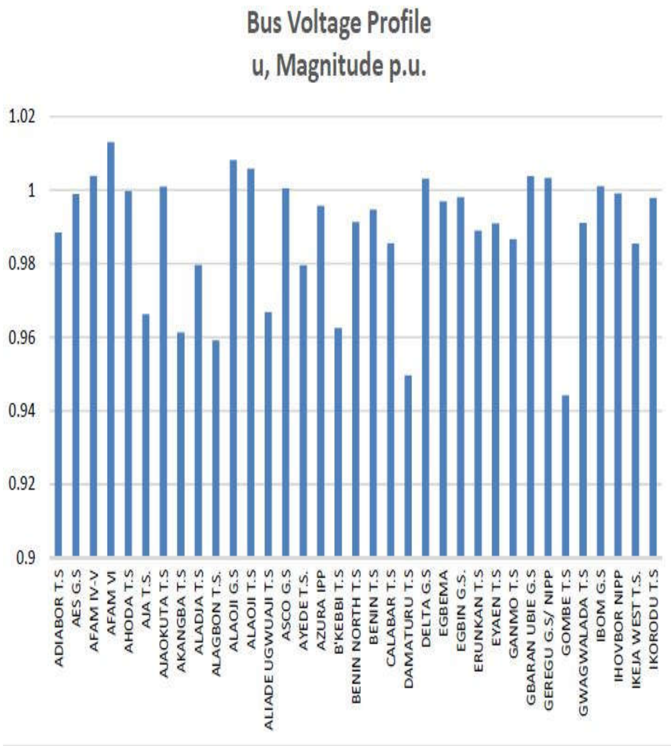

Fig -13a: Bus Voltage Profile in Per-Unit after Load Flow Calculations

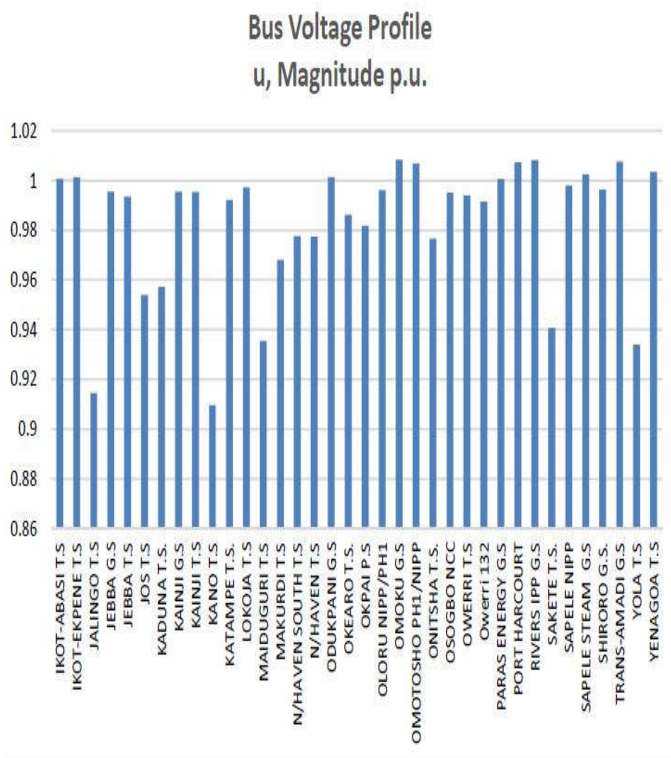

Fig -13b: Bus Voltage Profile in Per-Unit after Load Flow Calculations (Continuation)

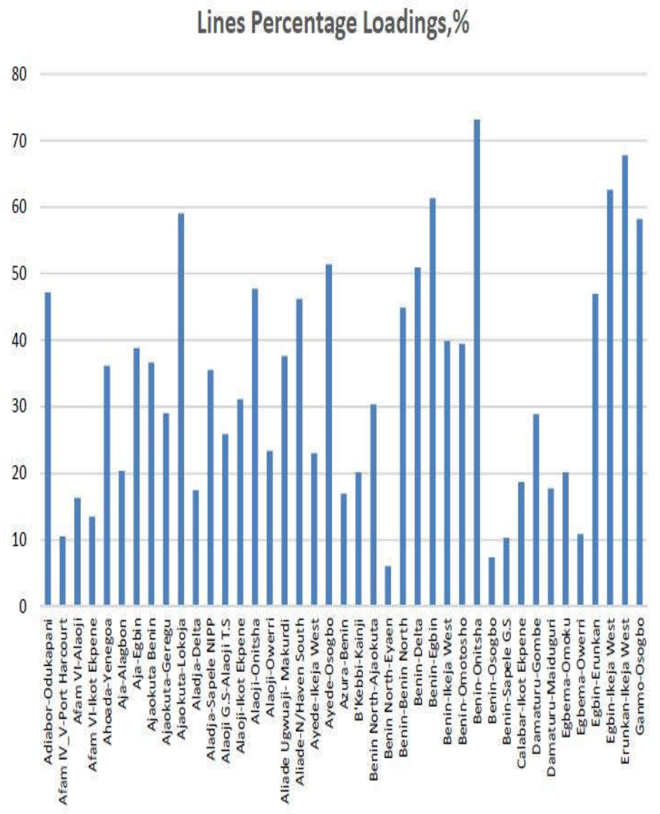

Fig -14a: Transmission Line Loadings in Percentage, %

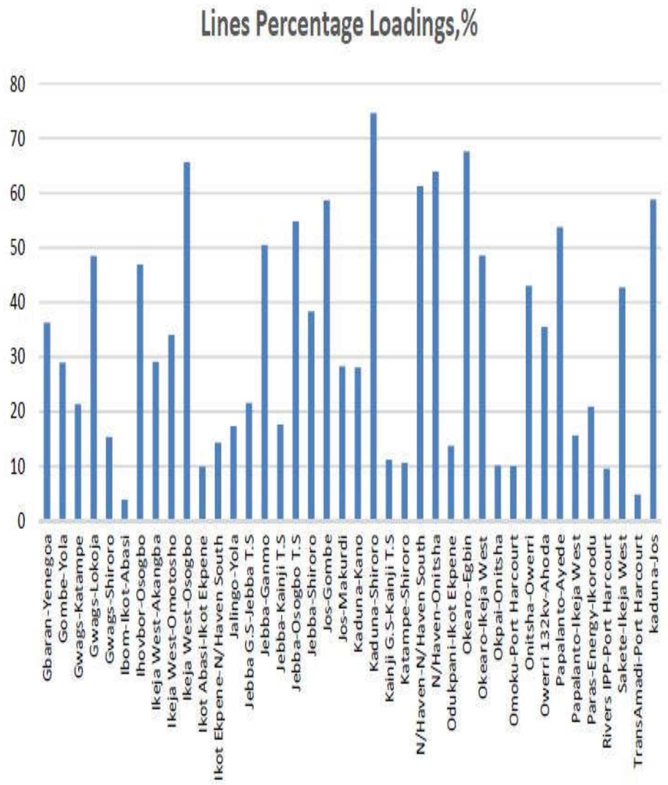

Fig -14b: Transmission Line Loadings in Percentage, %
(Continuation)

5. STABILITY INVESTIGATIONS

The Stability Analysis, RMS simulation (electromechanical transient) was implemented using previously discussed control devices following analysis and results were collected during the top of Maximum Hour power flow (MH-22:00 Hours). This 22-hours analysis is chosen because it is the hours of maximum power flow at maximum load utilities.

For this study case, six (6) Buses, B'Kebbi (North-West), Osogbo NCC (South-West), New-Haven (South-East), Ikot-Ekpene (South-South), Maiduguri (North-East), including the Slack Bus, Egbin (West) were selected for the terminal voltage and frequency behaviour analysis. They were selected because of their strategic locations in the Nigerian Map.

In addition, short circuit event was created on the longest line, B'Kebbi-Kainji (310km) with a switch event of 100ms. The behaviour of this short circuit event on the transmission network was monitored on the three (3) longest lines that included, B'Kebbi-Kainji (310km), Osogbo-Ikeja West (235km) and New Haven-Ikot Ekpene (143km) lines, the above mentioned Buses in our case study as well as on the randomly selected Power Plants units, which included, the Egbin Plant (ST1-slack machine), Shiroro (411G1-hydro station), Sapele Gas GT1 (thermal station) and Asco Plant (thermal station). One of the importance of this short circuit analysis is to be able to simulate and investigate single and/ multiple faults as well as be able to check the ratings of network equipment during the planning period. Below are the results of the analysis as shown by DigSILENT PowerFactory software.

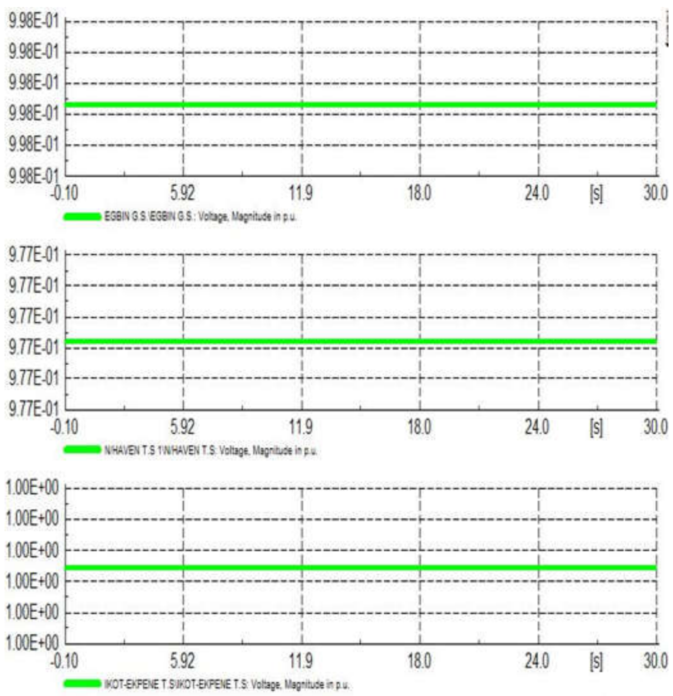

Fig -15a: Terminal Voltage Profile of Case study Bus Bars over 30 seconds at No Event

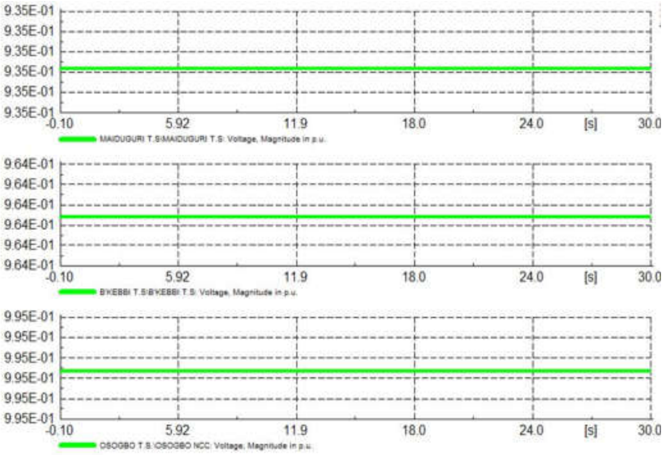

Fig -15a: Terminal Voltage Profile of Case study Bus Bars over 30 seconds at No Event (Continuation)

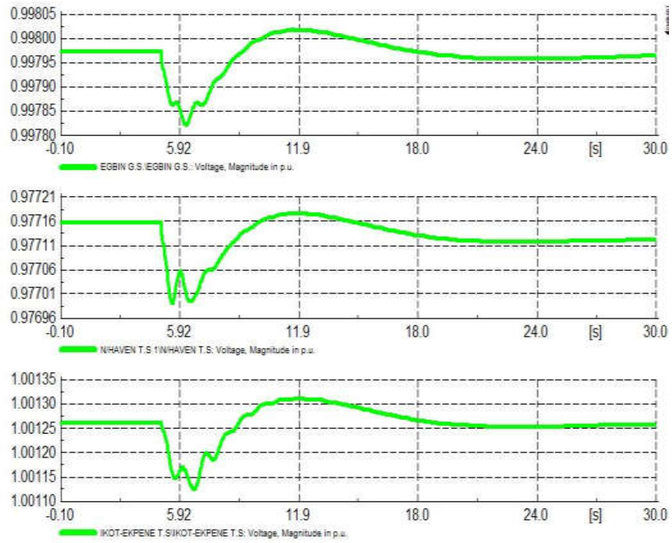

Fig -15c: Terminal Voltage Profile of Case study Bus Bars over 30 seconds at B'Kebbi Load Event

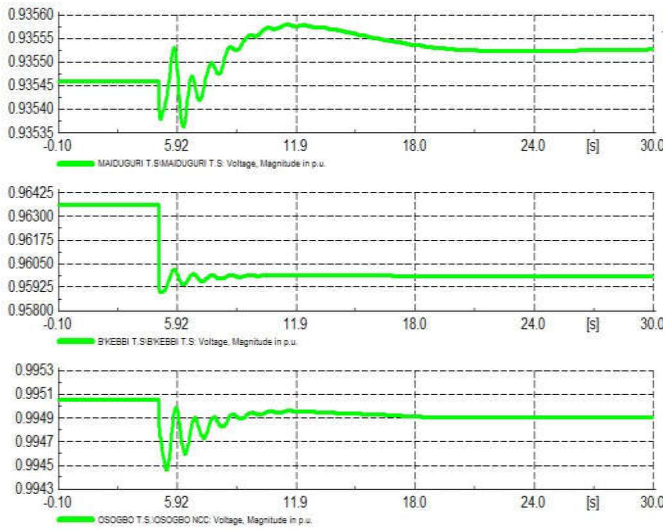

Fig -15d: Terminal Voltage Profile of Case study Bus Bars over 30 seconds at B'Kebbi Load Event (Continuation)

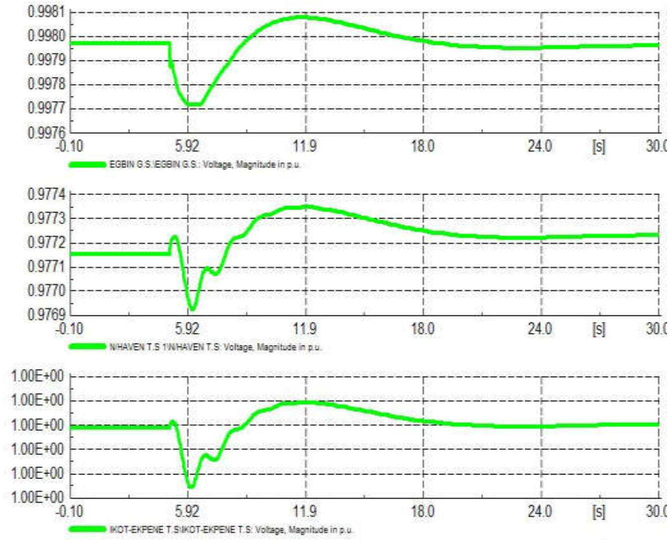

Fig -15e: Terminal Voltage Profile of Case study Bus Bars over 30 seconds at Ikeja-West Load Event

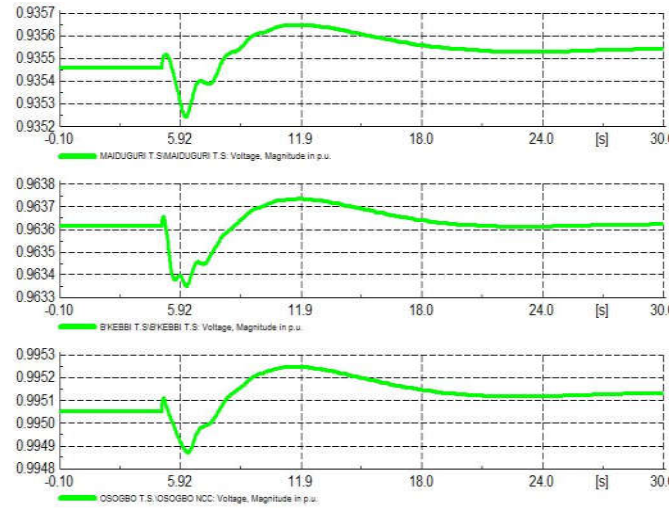

Fig -15f: Terminal Voltage Profile of Case study Bus Bars over 30 seconds at Ikeja West Load Event (Continuation)

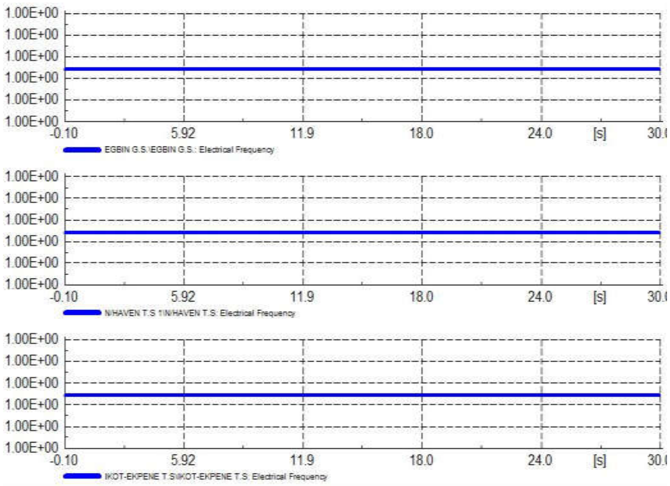

Fig -15g: Frequency Profile of Case study Bus Bars over 30 seconds at No Event

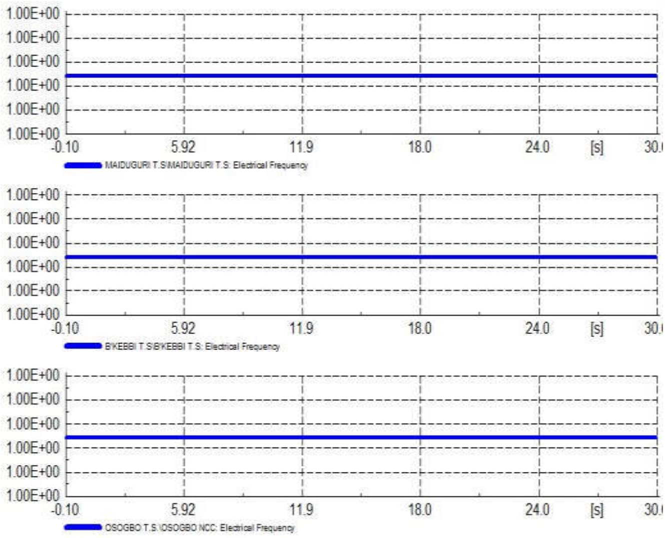

Fig -15h: Frequency Profile of Case study Bus Bars over 30 seconds at No Event (Continuation)

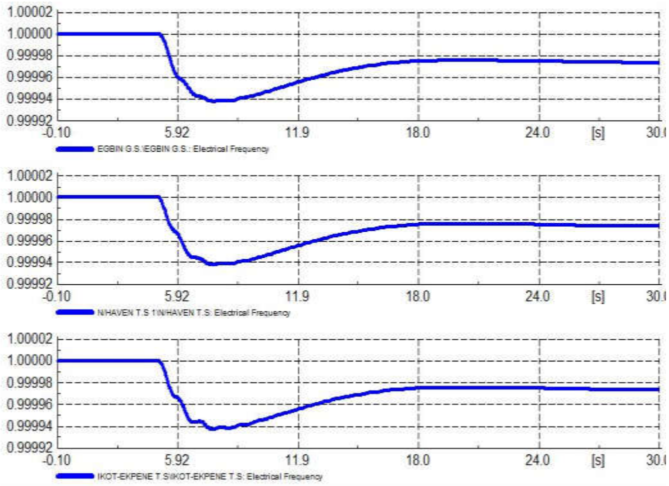

Fig -15i: Frequency Profile of Case study Bus Bars over 30 seconds at B'Kebbi Load Event

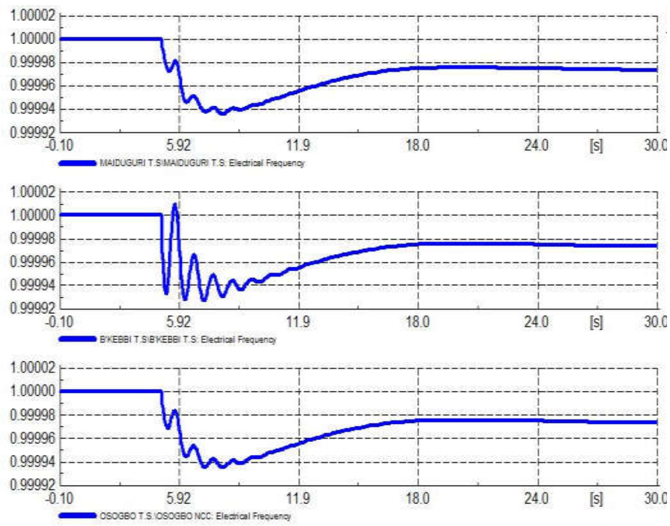

Fig -15i: Frequency Profile of Case study Bus Bars over 30 seconds at B'Kebbi Load Event (Continuation)

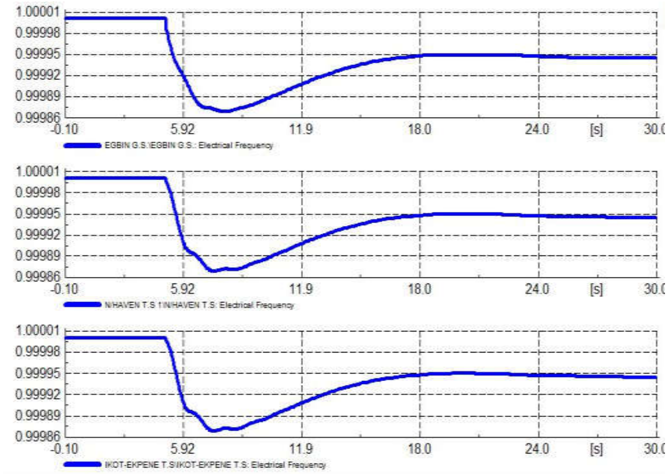

Fig -15j: Frequency Profile of Case study Bus Bars over 30 seconds at Ikeja-West Load Event

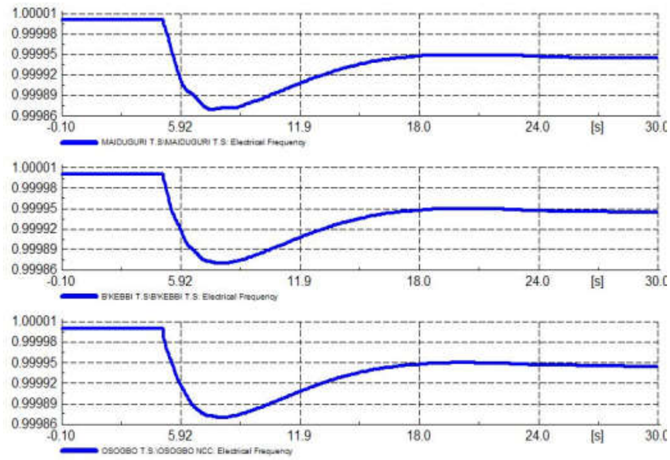

Fig -15k: Frequency Profile of Case study Bus Bars over 30 seconds at Ikeja-West Load Event (Continuation)

Various characteristics of the selected network elements to the Short Circuit Event at B'Kebbi-Kainji transmission line (310 km) over 30 seconds are shown below.

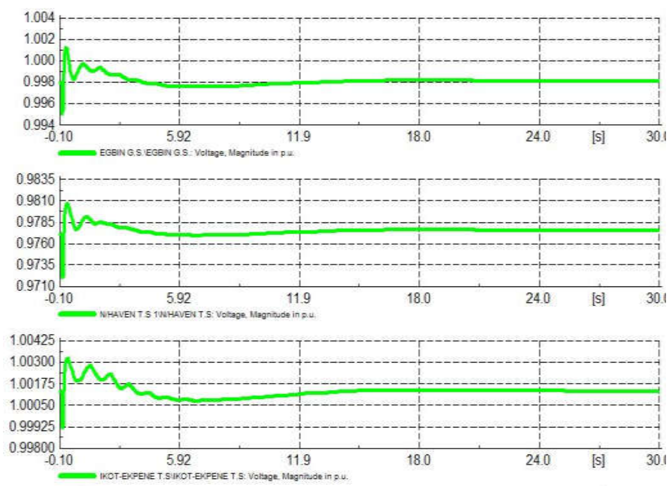

Fig -16a: Voltage Profile of Case study Bus Bars over 30 seconds at B'Kebbi-Kainji Line Short Circuit Event

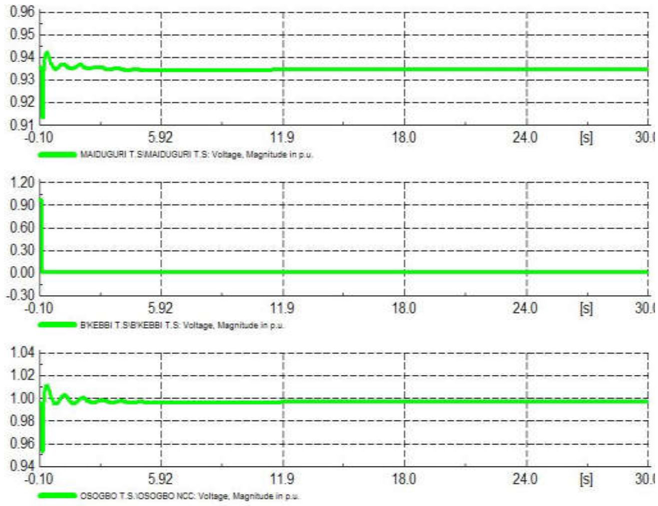

Fig -16b: Voltage Profile of Case study Bus Bars over 30 seconds at B'Kebbi-Kainji Line Short Circuit Event (Continuation)

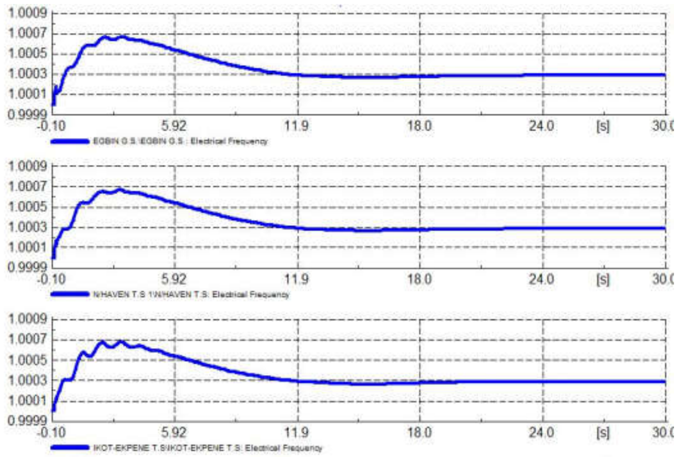

Fig -16c: Frequency Profile of Case study Bus Bars over 30 seconds at B'Kebbi-Kainji Line Short Circuit Event

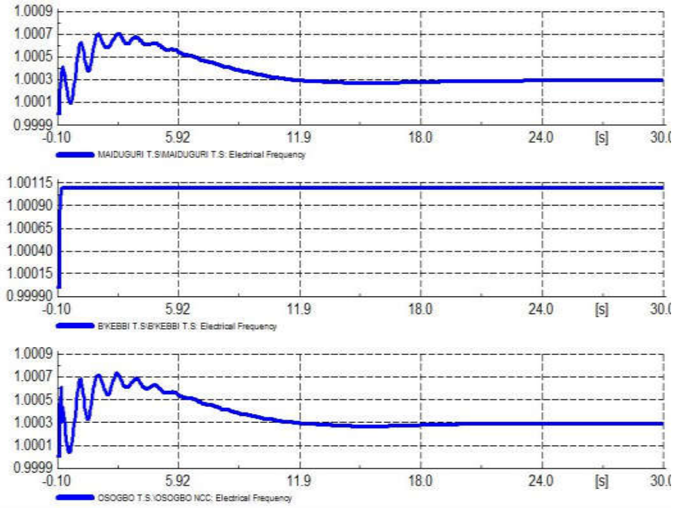

Fig -16d: Frequency Profile of Case study Bus Bars over 30 seconds at B'Kebbi-Kainji Line Short Circuit Event (Continuation)

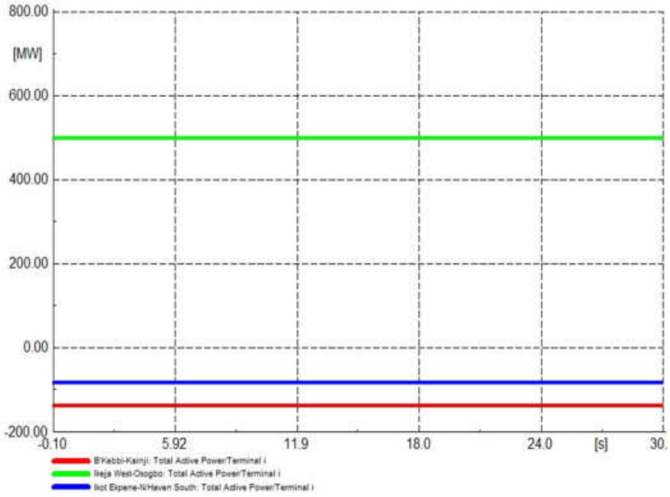

Fig -17a: Total Active Power/Terminal i (MW) of Case study Lines over 30 seconds at No Event

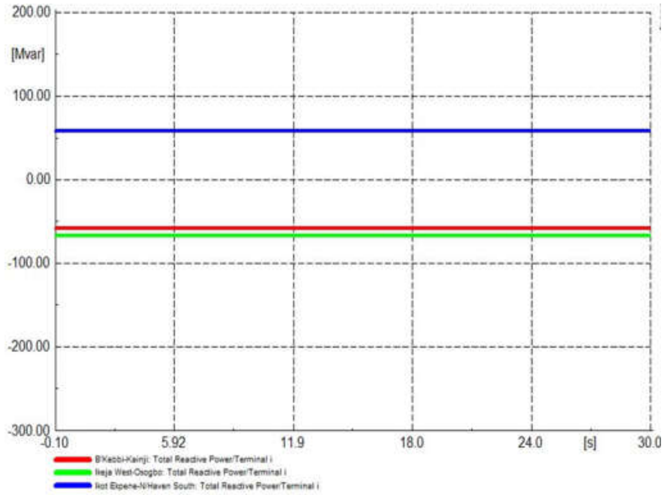

Fig -17b: Total Reactive Power/Terminal i (MVar) of Case study Lines over 30 seconds at No Event

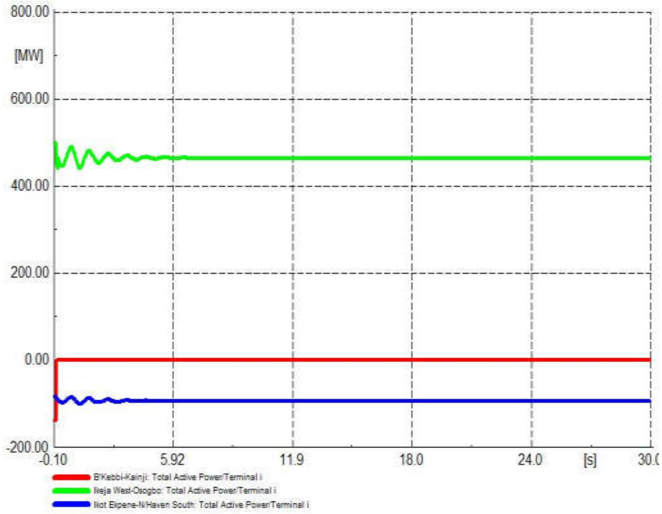

Fig -17c: Total Active Power/Terminal i (MW) of case study Lines over 30 seconds at B'Kebbi-Kainji Short Circuit Event

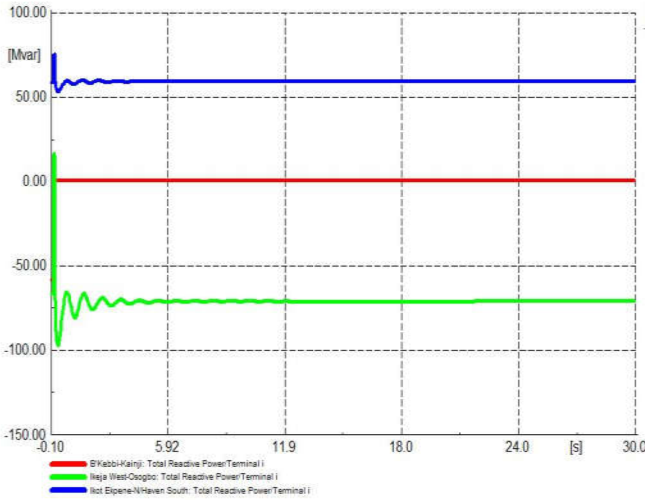

Fig -17d: Total Reactive Power/Terminal i (MVar) of case study Lines over 30 seconds at B'Kebbi-Kainji Short Circuit Event

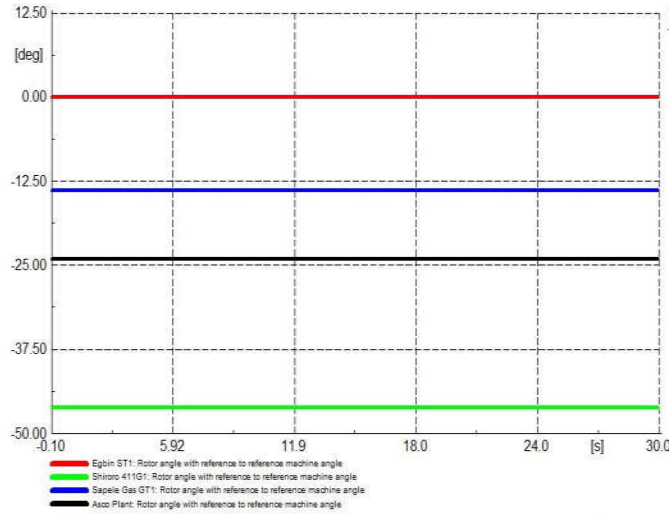

Fig -18a: Rotor Angle Profile of Case study Power Plants over 30 seconds at No Event

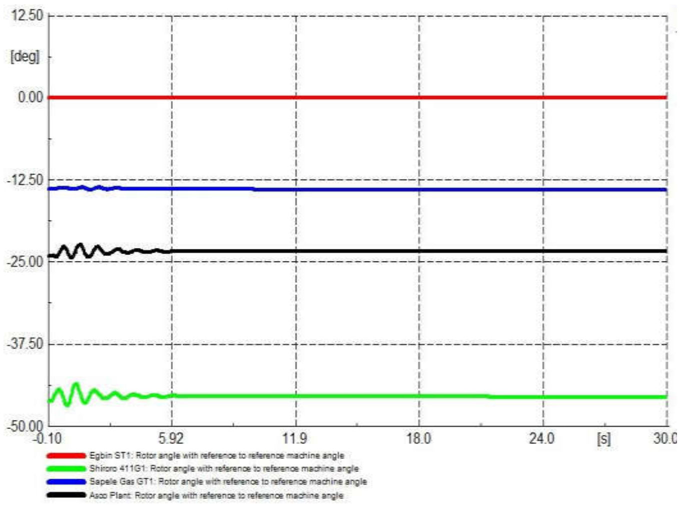

Fig -18b: Rotor Angle Profile of Case study Power Plants over 30 seconds at B'Kebbi-Kainji Line Short Circuit Event

6. SUMMARY AND CONCLUSION

From the entire characteristic figures shown in part 5, it is clear that the voltage and frequency characteristics of the modelled dynamic components of the Nigerian transmission network resulted to expected and favourable outcomes, prior to addition of further controllers to increase fast damping during system oscillations because of transient events.
This shows in a greater extent the accuracy and fitting of the standard dynamic models used in the Nigerian transmission network modelling and suggest their suitability in the future power system analysis and operational procedure follow-up of the Nigerian transmission Network.
This research have succeeded in exposing the stability of the Nigerian Transmission Network. The fact that the National Control Center (NCC) of the Transmission Company of Nigeria (TCN) do not perform system dynamics is evident in the epileptic power supply that Nigeria is currently battling at any careless disturbance. The dynamic models of the power plants helped to understand the behaviour of the critical network parameters and as such will help in understanding the effect of any contingency in the network.

The importance of these dynamic models implementation is far beyond this project as it serves as the platform for all other analysis and any electrical parameter investigation that maybe of interest to the system operators, the National Electricity Regulatory Commission (NERC), the National Control Center and/ the research Academia. These can include but are not limited to Modal Analysis, further transient analysis, Contingency Analysis, short circuit single or multiple fault analysis and other investigations. These analyses are important in the Nigerian context especially during the case of load shading, generators out of operation due to faults or maintenance, integration of renewable energy sources into the Grid etc.

APPENDIX A: Transmission Line Data

Line Name	Grid	Par. no.	Length	Max. Limiting Current
	kV		km	kA
Adiabor-Odukpani	330	1	18	1.36
Afam IV_V-Port Harcourt	330	2	45	2.72
Afam VI-Alaoji	330	2	25	2.72
Afam VI-Ikot Ekpene	330	2	90	2.72
Ahoada-Yenegoa	132	2	46	0.8
Aja-Alagbon	330	2	26	2.72
Aja-Egbin	330	2	14	2.72
Ajaokuta Benin	330	1	195	1.36
Ajaokuta-Geregu	330	2	5	2.72
Ajaokuta-Lokoja	330	2	38	2.72
Aladja-Delta	330	1	32	1.36
Aladja-Sapele NIPP	330	1	63	1.36
Alaoji G.S-Alaoji T.S	330	2	5	2.72
Alaoji-Ikot Ekpene	330	2	38	2.72
Alaoji-Onitsha	330	1	138	1.36
Alaoji-Owerri	330	2	60	2.72
Aliade Ugwuaji-Makurdi	330	2	50	2.72
Aliade-N/Haven South	330	2	150	2.72
Ayede-Ikeja West	330	1	137	1.36
Ayede-Osogbo	330	1	115	1.36
Azura-Benin	330	2	5	2.72
B'Kebbi-Kainji	330	1	310	1.36
Benin North- Ajaokuta	330	2	195	2.72
Benin North-Eyaen	330	2	5	2.72
Benin-Benin North	330	2	20	2.72
Benin-Delta	330	2	107	2.72
Benin-Egbin	330	2	218	2.72
Benin-Ikeja West	330	2	280	2.72
Benin-Omotosho	330	2	120	2.72
Benin-Onitsha	330	2	137	2.72
Benin-Osogbo	330	1	251	1.36
Benin-Sapele G.S	330	2	50	2.72
Calabar-Ikot Ekpene	330	2	72	2.72
Damaturu-Gombe	330	1	160	1.36
Damaturu-Maiduguri	330	1	260	1.36
Egbema-Omoku	330	2	30	2.72
Egbema-Owerri	330	2	30	2.72
Egbin-Erunkan	330	2	30	2.72
Egbin-Ikeja West	330	2	62	2.72
Erunkan-Ikeja West	330	1	32	1.36
Ganmo-Osogbo	330	1	87	1.36
Gbaran-Yenegoa	132	2	5	0.8
Gombe-Yola	330	2	217	2.72
Gwags-Katampe	330	2	30	2.72
Gwags-Lokoja	330	2	140	2.72
Gwags-Shiroro	330	2	114	2.72
Ibom-Ikot-Abasi	330	2	5	2.72
Ihovbor-Osogbo	330	1	5	1.36
Ikeja West-Akangba	330	1	18	1.36
Ikeja West-Omotosho	330	1	160	1.36
Ikeja West-Osogbo	330	1	252	1.36
Ikot_Abasi-Ikot Ekpene	330	2	75	2.72
Ikot Ekpene-N/Haven South	330	2	143	2.72
Jalingo-Yola	330	2	132	2.72
Jebba G.S-Jebba T.S	330	2	8	2.72
Jebba-Ganmo	330	1	70	1.36
Jebba-Kainji T.S	330	2	81	2.72
Jebba-Osogbo T.S	330	1	157	1.36
Jebba-Shiroro	330	2	244	2.72
Jos-Gombe	330	2	265	2.72
Jos-Makurdi	330	2	230	2.72
Kaduna-Kano	330	1	230	1.36
Kaduna-Shiroro	330	2	96	2.72
Kainji G.S-Kainji T.S	330	2	0.47	2.72
Katampe-Shiroro	330	2	144	2.72
N/Haven-N/Haven South	330	2	5	2.72
N/Haven-Onitsha	330	2	96	2.72
Odukpani-Ikot Ekpene	330	2	5	2.72
Okearo-Egbin	330	2	30	2.72
Okearo-Ikeja West	330	2	32	2.72
Okpai-Onitsha	330	2	80	2.72
Omoku-Port Harcourt	330	1	5	1.36
Onitsha-Owerri	330	2	137	2.72
Owerri 132kv-Ahoda	132	2	73	0.8
Papalanto-Ayede	330	1	60	1.36
Papalanto-Ikeja West	330	2	30	2.72
Paras Energy-Ikorodu	330	2	18	0.8
Rivers IPP-Port Harcourt	330	2	5	2.72
Sakete-Ikeja West	330	1	70	1.36
TransAmadi-Port-Harcourt	330	2	5	2.72

Kaduna-Jos	330	1	197	1.36

Typical 330 kV Transmission Line parameters used

R1	R0	X1	X0	B1	B0	Y1	Y0	C1	C0
Ω/km	Ω/km	Ω/km	Ω/km	µS/km	µS/km	µS/km	µS/km	µF/km	µF/km
0.0394	0.274	0.331	0.997	3.49	2.49	3.49	2.49	0.012134	0.0073052

Typical 132 kV Transmission Line parameters used:

R1	R0	X1	X0	B1	B0	Y1	Y0	C1	C0
Ω/km	Ω/km	Ω/km	Ω/km	µS/km	µS/km	µS/km	µS/km	µF/km	µF/km
0.123	0.315	0.392	1.349	2.993	1.79	2.993	1.79	0.0010853	0.0017783

APPENDIX B: Generator Basic Data

Name	Grid kV	TypeSym	Plant Category
AES GT1 Plant	330	AES Plant	Gas
AES GT2 Plant	330	AES Plant	Gas
Afam I-III 1	330	Afam I-III Plant	Gas
Afam I-III 2	330	Afam I-III Plant	Gas
Afam I-III 3	330	Afam I-III Plant	Gas
Afam IV-VIGT1	330	Afam IV-VI Plant	Gas
Afam IV-VI GT2	330	Afam IV-VI Plant	Gas
Afam IV-VIGT3	330	Afam IV-VI Plant	Gas
Afam IV-VIGT4	330	Afam IV-VI Plant	Gas
Alaoji NIPP GT1	330	Alaoji Plant	Gas
Alaoji NIPP GT2	330	Alaoji Plant	Gas
Alaoji NIPP GT3	330	Alaoji Plant	Gas
Asco Plant	330kV	Asco Plant	Gas
Azura IPP GT1	330	Azura IPP Plant	Gas
Azura IPP GT2	330	Azura IPP Plant	Gas
Azura IPP GT3	330	Azura IPP Plant	Gas
Azura IPP GT4	330	Azura IPP Plant	Gas
Egbin ST1	330	Egbin Plant	Steam
Egbin ST2	330	Egbin Plant	Steam
Egbin ST3	330	Egbin Plant	Steam
Egbin ST4	330	Egbin Plant	Steam
Egbin ST5	330	Egbin Plant	Steam
Egbin ST6	330	Egbin Plant	Steam
Gbaran Plant	330	Gbaran Plant	Gas
Geregu GT1	330	Geregu-GT1-GT3 Plant	Gas
Geregu GT2	330	Geregu-GT1-GT3 Plant	Gas
Geregu GT3	330	Geregu-GT1-GT3 Plant	Gas
Geregu NIPP 1	330	Geregu NIPP Plant	Gas
Geregu NIPP 2	330	Geregu NIPP Plant	Gas
Geregu NIPP 3	330	Geregu NIPP Plant	Gas
Geregu NIPP 4	330	Geregu NIPP Plant	Gas
Ibom Power	330	Ibom Power Plant	Gas
Ihovbor NIPP GT1	330	Ihovbor NIPP Plant	Gas
Ihovbor NIPP GT2	330	Ihovbor NIPP Plant	Gas
Ihovbor NIPP GT3	330	Ihovbor NIPP Plant	Gas
Ihovbor NIPP GT4	330	Ihovbor NIPP Plant	Gas
Jebba 2G1	330	Jebba Plant	Hydro
Jebba 2G2	330	Jebba Plant	Hydro
Jebba 2G3	330	Jebba Plant	Hydro
Jebba 2G4	330	Jebba Plant	Hydro
Jebba 2G5	330	Jebba Plant	Hydro
Jebba 2G6	330	Jebba Plant	Hydro
Kainji 1G10	330	Kainji Plant	Hydro
Kainji 1G11	330	Kainji Plant	Hydro
Kainji 1G12	330	Kainji Plant	Hydro
Kainji 1G5	330	Kainji Plant	Hydro
Kainji 1G6	330	Kainji Plant	Hydro
Kainji 1G7	330	Kainji Plant	Hydro
Kainji 1G8	330	Kainji Plant	Hydro
Kainji 1G9	330	Kainji Plant	Hydro
Odukpani GT1	330	Odukpani Plant	Gas
Odukpani GT2	330	Odukpani Plant	Gas
Odukpani GT3	330	Odukpani Plant	Gas
Odukpani GT4	330	Odukpani Plant	Gas
Odukpani GT5	330	Odukpani Plant	Gas
Okpai GT1	330	Okpai GT1-GT3	Gas
Okpai GT2	330	Okpai GT1-GT3	Gas
Okpai GT3	330	Okpai GT1-GT3	Gas

Olorunsogo NIPP GT1	330	Olorunsogo NIPP Plant	Gas
Olorunsogo NIPP GT2	330	Olorunsogo NIPP Plant	Gas
Olorunsogo NIPP GT3	330	Olorunsogo NIPP Plant	Gas
Olorunsogo NIPP GT4	330	Olorunsogo NIPP Plant	Gas
Olorunsogo NIPP GT5	330	Olorunsogo NIPP Plant	Gas
Omoku Unit 1 GT1-GT3	330	Omoku Plant	Gas
Omoku Unit 2 GT1-3	330	Omoku Plant	Gas
Omotosho GT1	330	Omotosho Plant	Gas
Omotosho GT2	330	Omotosho Plant	Gas
Omotosho GT3	330	Omotosho Plant	Gas
Omotosho NIPP GT1	330	Omotosho NIPP Plant	Gas
Omotosho NIPP GT2	330	Omotosho NIPP Plant	Gas
Omotosho NIPP GT3	330	Omotosho NIPP Plant	Gas
Omotosho NIPP GT4	330	Omotosho NIPP Plant	Gas
Omotosho NIPP GT5	330	Omotosho NIPP Plant	Gas
Papal/Olorunsogo PH1 G1	330	Papalanto/Olorunsogo Plant	Gas
Papal/Olorunsogo PH1 G2	330	Papalanto/Olorunsogo Plant	Gas
Papal/Olorunsogo PH1 G3	330	Papalanto/Olorunsogo Plant	Gas
Papal/Olorunsogo PH1 G4	330	Papalanto/Olorunsogo Plant	Gas
Papal/Olorunsogo PH1 G5	330	Papalanto/Olorunsogo Plant	Gas
Papal/Olorunsogo PH1 G6	330	Papalanto/Olorunsogo Plant	Gas
Papal/Olorunsogo PH1 G7	330	Papalanto/Olorunsogo Plant	Gas
Papal/Olorunsogo PH1 G8	330	Papalanto/Olorunsogo Plant	Gas
Paras-Energy Plant	330	Paras-Energy Plant	Gas
Rivers IPP GT1	330	Rivers IPP Plant	Gas
Rivers IPP GT2	330	Rivers IPP Plant	Gas
Sapele Gas GT1	330	Sapele Gas Plant	Gas
Sapele Gas GT2	330	Sapele Gas Plant	Gas
Sapele Gas GT3	330	Sapele Gas Plant	Gas
Sapele Gas GT4	330	Sapele Gas Plant	Gas
Sapele Gas GT5	330	Sapele Gas Plant	Gas
Sapele Steam ST1	330	Sapele Steam Plant	Steam
Sapele Steam ST2	330	Sapele Steam Plant	Steam
Sapele Steam ST3	330	Sapele Steam Plant	Steam
Sapele Steam ST4	330	Sapele Steam Plant	Steam
Sapele Steam ST5	330	Sapele Steam Plant	Steam
Sapele Steam ST6	330	Sapele Steam Plant	Steam
Shiroro 411G1	330	Shiroro Plant	Hydro
Shiroro 411G2	330	Shiroro Plant	Hydro
Shiroro 411G3	330	Shiroro Plant	Hydro
Shiroro 411G4	330	Shiroro Plant	Hydro
Trans-Amadi Plant	330	Trans-Amadi Plant	Gas
Transcorp Delta I-III Plant 1	330	Transcorp Delta Plant 1	Gas
Transcorp GT15 Plant 2	330	Transcorp Plant 2	Gas
Transcorp GT16 Plant 2	330	Transcorp Plant 2	Gas
Transcorp GT17 Plant 2	330	Transcorp Plant 2	Gas
Transcorp GT18 Plant 2	330	Transcorp Plant 2	Gas
Transcorp GT20 Plant 2	330	Transcorp Plant 2	Gas

APPENDIX C: Generator Data used

Name	Active Power	Reactiv Power	Appar. Power	Power Factor
	MW	Mvar	MVA	
AES-GT1 Plant	147	110.25	183.75	0.8
AES-GT2 Plant	147	110.25	183.75	0.8
Afam I-III 1	117	87.75	146.25	0.8
Afam I-III 2	117	87.75	146.25	0.8
Afam I-III 3	117	87.75	146.25	0.8
Afam-IV-VI GT1	162.503	100.710 3	191.18	0.85
Afam-IV-VI GT2	162.503	100.710 3	191.18	0.85
Afam-IV-VI GT3	162.503	100.710 3	191.18	0.85
Afam-IV-VI GT4	162.503	100.710 3	191.18	0.85
Alaoji-NIPP GT1	166.668	103.291 5	196.08	0.85
Alaoji-NIPP GT2	166.668	103.291 5	196.08	0.85

Alaoji-NIPP GT3	166.668	103.2915	196.08	0.85
Asco Plant	110.0325	68.192	129.45	0.85
Azura-IPP GT1	114.75	55.57596	127.5	0.9
Azura-IPP GT2	114.75	55.57596	127.5	0.9
Azura-IPP GT3	114.75	55.57596	127.5	0.9
Azura-IPP GT4	114.75	55.57596	127.5	0.9
Egbin ST1	219.996	106.5490	244.45	0.9
Egbin ST2	219.996	106.5489	244.44	0.9
Egbin ST3	219.996	106.5489	244.44	0.9
Egbin ST4	219.996	106.5489	244.44	0.9
Egbin ST5	219.996	106.5489	244.44	0.9
Egbin ST6	219.996	106.5489	244.44	0.9
Gbaran Plant	120	90	150	0.8
Geregu GT1	138	85.52476	162.353	0.85
Geregu GT2	138	85.52476	162.353	0.85
Geregu GT3	138	85.52476	162.353	0.85
Geregu NIPP 1	112.5	36.97696	118.4211	0.95
Geregu NIPP 2	112.5	36.97695	118.4211	0.95
Geregu NIPP 3	112.5	36.97695	118.4211	0.95
Geregu NIPP 4	112.5	36.97696	118.4211	0.95
Ibom Power	155	116.25	193.75	0.8
Ihovbor NIPP GT1	125	93.75	156.25	0.8
Ihovbor NIPP GT2	125	93.75	156.25	0.8
Ihovbor NIPP GT3	125	93.75	156.25	0.8
Ihovbor NIPP GT4	125	93.75	156.25	0.8
Jebba 2G1	96.407	59.74769	113.42	0.85
Jebba 2G2	96.407	59.74769	113.42	0.85
Jebba 2G3	96.407	59.74769	113.42	0.85
Jebba 2G4	96.407	59.74769	113.42	0.85
Jebba 2G5	96.407	59.74769	113.42	0.85
Jebba 2G6	96.407	59.74769	113.42	0.85
Kainji 1G10	95	31.22499	100	0.95
Kainji 1G11	95	31.22499	100	0.95
Kainji 1G12	95	31.2249	100	0.95
Kainji 1G5	95	31.22499	100	0.95
Kainji 1G6	95	31.22499	100	0.95
Kainji 1G7	95	31.22499	100	0.95
Kainji 1G8	95	31.22499	100	0.95
Kainji 1G9	95	31.22499	100	0.95
Odukpani GT1	125.001	77.46866	147.06	0.85
Odukpani GT2	125.001	77.46866	147.06	0.85
Odukpani GT3	125.001	77.46866	147.06	0.85
Odukpani GT4	125.001	77.46866	147.06	0.85
Odukpani GT5	125.001	77.46866	147.06	0.85
Okpai GT1	160.0805	99.20899	188.33	0.85
Okpai GT2	160.0805	99.20899	188.33	0.85
Okpai GT3	160.0805	99.20899	188.33	0.85
Olorunsogo NIPP GT1	150.0012	72.64892	166.668	0.9
Olorunsogo NIPP GT2	150.0012	72.64892	166.668	0.9
Olorunsogo NIPP GT3	150.0012	72.64892	166.668	0.9
Olorunsogo NIPP GT4	150.0012	72.64892	166.668	0.9
Olorunsogo NIPP GT5	150.0012	72.64892	166.668	0.9
Omoku Unit 1 GT1-GT3	75	56.25	93.75	0.8
Omoku Unit 2 GT1-3	75	56.25	93.75	0.8
Omotosho GT1	111.6672	83.7504	139.584	0.8
Omotosho GT2	111.6672	83.7504	139.584	0.8
Omotosho GT3	111.6672	83.7504	139.584	0.8
Omotosho NIPP GT1	100	75	125	0.8
Omotosho	100	75	125	0.8

NIPP GT2				
Omotosho NIPP GT3	100	75	125	0.8
Omotosho NIPP GT4	100	75	125	0.8
Omotosho NIPP GT5	100	75	125	0.8
Papal/Olorun PH1 G1	41.88	31.41	52.35	0.8
Papal/Olorun PH1 G2	41.88	31.41	52.35	0.8
Papal/Olorun PH1 G3	41.88	31.41	52.35	0.8
Papal/Olorun PH1 G4	41.88	31.41	52.35	0.8
Papal/Olorun PH1 G5	41.88	31.41	52.35	0.8
Papal/Olorun PH1 G6	41.88	31.41	52.35	0.8
Papal/Olorun PH1 G7	41.88	31.41	52.35	0.8
Papal/Olorun PH1 G8	41.88	31.41	52.35	0.8
Paras-Energy Plant	72	34.87119	80	0.9
Rivers_IPP GT1	90.00225	55.77839	105.885	0.85
Rivers-IPP GT2	90.00225	55.77839	105.885	0.85
Sapele-Gas GT1	100	75	125	0.8
Sapele-Gas GT2	100	75	125	0.8
Sapele-Gas GT3	100	75	125	0.8
Sapele-Gas GT4	100	75	125	0.8
Sapele-Gas GT5	100	75	125	0.8
Sapele Steam ST1	120.006	58.12156	133.34	0.9
Sapele Steam ST2	120.006	58.12156	133.34	0.9
Sapele Steam ST3	120.006	58.12156	133.34	0.9
Sapele Steam ST4	120.006	58.12156	133.34	0.9
Sapele Steam ST5	120.006	58.12156	133.34	0.9
Sapele Steam ST6	120.006	58.12156	133.34	0.9
Shiroro 411G1	150.025	92.97716	176.5	0.85
Shiroro 411G2	150.025	92.97713	176.5	0.85
Shiroro 411G3	150.025	92.97713	176.5	0.85
Shiroro 411G4	150.025	92.97713	176.5	0.85
Trans-Amadi Plant	100	48.43222	111.1111	0.9
Transcorp Delta_I-III Plant 1	335	251.25	418.75	0.8
Transcorp GT15 Plant 2	113.0007	70.03155	132.942	0.85
Transcorp GT16 Plant 2	113.0007	70.03155	132.942	0.85
Transcorp GT17 Plant 2	113.0007	70.03155	132.942	0.85
Transcorp GT18 Plant 2	113.0007	70.03155	132.942	0.85
Transcorp GT20 Plant 2	113.0007	70.03155	132.942	0.85

APPENDIX D: Compensators in the Network

Bus Name	Grid	Qmax
	kV	**Mvar**
Ajaokuta	330	75
Alaoji	330	75
B'Kebbi	330	30
Benin	330	2 x 75
Gombe	330	2 x 50
Ikeja West	330	2 x 75
Jebba G.S	330	2 x 75
Jos	330	75
Kaduna	330	75
Kano	330	75
Katampe	330	75
Lokoja	330	75
Makurdi	330	75
Ncc Osogbo	330	75
Okearo	330	75
Onitsha	330	75
Yola	330	2 x 30

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