Optimal Power Flow for 330 KV Transmission Network using Fast Decoupled Method

Mboutidem Pius Felix[1], Nseobong Ibanga Okpura[2], Kufre Michael Udofia[3], Kehinde Samuel Owoeye[4]
[1,2,3,4] Department of Electrical/Electronic and Computer Engineering, University of Uyo, Uyo, Nigeria
([1]dyvvne@gmail.com, [2]nseobongokpura@uniuyo.edu.ng, [3]kufremudofia@uniuyo.edu.ng, [4]kehindeowoeye24@gmail.com)

Abstract **— Voltage instability (voltage profile violation), high power losses, long transmission lines and nature of transmission lines, management of reactive power, and voltage control constitute parts of the major challenges in power system industry. The primary aim of this study was to perform an optimal power flow analysis using fast decoupled method to minimize system operating costs and obtain more capacity out of the existing system. This study examined optimization of bus voltages and transmission lines using the Nigerian 330 kV lines, 10-bus transmission network as a case study. The 10 buses are located at Delta, Okapi, Afam, Onitsha, Benin, Aladja, Alaoji, New Haven, Oshogbo, and Sapele while their data were obtained from the National Control Centre, Oshogbo. The Modelling of the 10-bus transmission line network was done using Power System Analytical Tool (PSAT) while power flow was determined using BX and XB fast decoupled algorithm. Power losses were determined from the outcomes generated from the BX and XB fast decoupled algorithm. Simulations were carried out using the buses and transmission lines parameters of the 10-bus transmission line network. The results showed an improvement in the voltage of the buses when the optimal power flow was performed. The bus voltage was normalized between 0.95 and 1.03 which is the appropriate voltage values for the buses.**

Keywords — Optimal Power Flow (OPF), Transmission network, Fast Decoupled, MATLAB.

I. INTRODUCTION

Due to exponential increase in the electricity demand and competition in energy market, the transmission system worldwide is undergoing continuous changes and restructuring. This led to the lines becoming heavily loaded and the power transmission systems have been facing many problems like voltage instability power losses and transmission line congestion. This may lead to reduction of the power system efficiency and loss of voltage. Due to continual increase in demand for electric energy with its associated problems if unmonitored and controlled may also led to overload of some lines located in some paths [1].

Technically, these problems can be removed by addition of new transmission capacity but the economic, political and environmental considerations in building new transmission facilities have made this option not desirable. Therefore, for efficient power delivery there is every need for power compensation of the existing 330kV Nigeria power system [2]. Utilization of reactive power to improve voltage profile and power factor and reduce power losses is known as compensation. Load compensation can also be referred to improving power qualities of which there are many ways to achieve that such as installation of new transmission lines, reconducting transmission line/terminal equipment replacements, voltage upgrade, and conversion from single circuit to double circuit, phase shifting and reactive power compensation [3].

In load flow study, the main objective is to determine the complex bus voltages, real and reactive power injected into the transmission system as well as real and reactive power at the slack bus with other parameters being specified. Load flow analysis usually finds its application during power network design and planning. It is also useful for obtaining the system behaviour during operation in order to predict the loading condition of transmission lines and under a balance condition such that the analysis can be carried -out using a balance three-phase representation [4].

II. RESEARCH METHODOLOGY

The primary material required for this research was a computer system that comprises of the following software installations;

Micro-soft office word which aides in proper explanation of the research embarked and

Mat Lab software that contains power system analytical toolbox (PSAT). This computer package enables application and performance of optimum power flow of a power system network.

A detailed research methodology was outlined in this study which includes the study cites, modelling procedures and procedure on implementing and simulating with power system analytical tool.

A. The Research Procedure

A carefully selected 330 kV power system network consisting of three TCN regions was used for this study. The network diagram with other relevant data required was obtained from the National control centre (NCC) Oshogbo in Osun State, Nigeria. From the power system line diagram acquired, ten buses where selected that represents three regions of the country.

A power flow analysis was performed on the selected network using fast decoupled algorithm (BX and XB fast decouple algorithm) to obtain the power flow analysis of the selected power system network using power system analytical toolbox. After wards, an o-optimal power flow was carried out to minimize the cost of generating power, improve system losses and improve voltage profile without an aid of a FACT device [5]. Optimal power flow was carried out on both active and reactive power dispatch to primarily minimize the rate of voltage collapse. The research procedure is outline in the flow diagram shown in Figure 1.

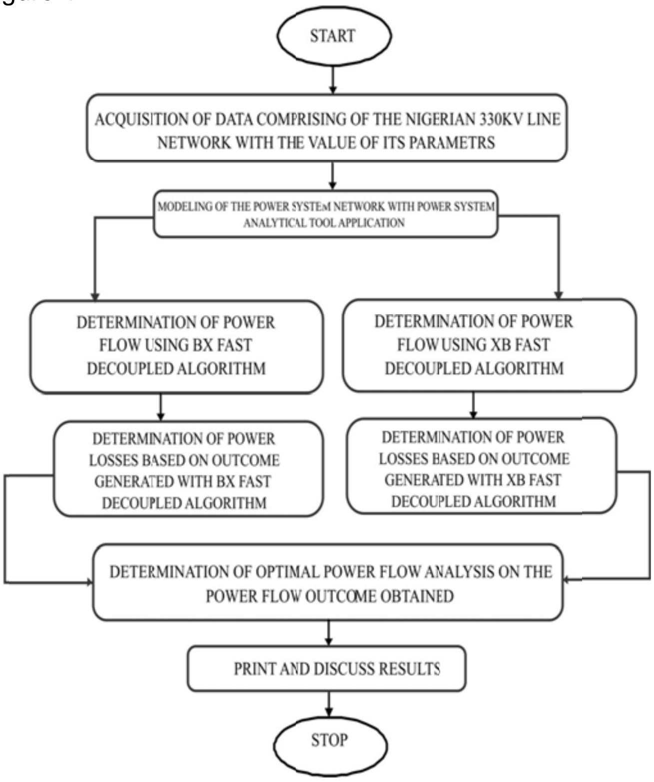

Fig. 1. Flow diagram for research.
Source: Developed by the researchers (2023)

B. Description of Case Study Site

The study area is the power system network of Nigeria. Currently, Nigeria has 6 regions with each having a significant number of generation stations, transmission stations and sub-transmission stations. The power system network system 330 kV which includes generation and load stations. The entire data was obtained in the national control centre located at Oshogbo in Osun state, south-western Nigeria, where all the generation and transmission stations are monitored and analysed. As at the time of obtaining the data needed, there were 72 stations (generation and transmission stations) in Nigeria under supervision and control. Due to the constant demand in load, it was observed how there occurs constant power outages and constant reduction voltage profile reduction [6].

C. Data Acquisition

The Nigerian 330 kV transmission power network is presented in Figure 2. The network diagram consists of the current voltage values and the values of power generated (for generation stations) with the expected power rating of each generation station. From the power system line diagram presented in Figure 2, the required power system network needed for this study was carefully mapped out and displayed. This was necessary to ensure that the region under review consist of power generation station and load station (the load station can either be the transmission station or transmission substation). The network mapped out from the main Nigerian 330 kV power system network was modelled with power system analytical tool where the power flow analysis will be seen if Figure 2 and Figure 3.

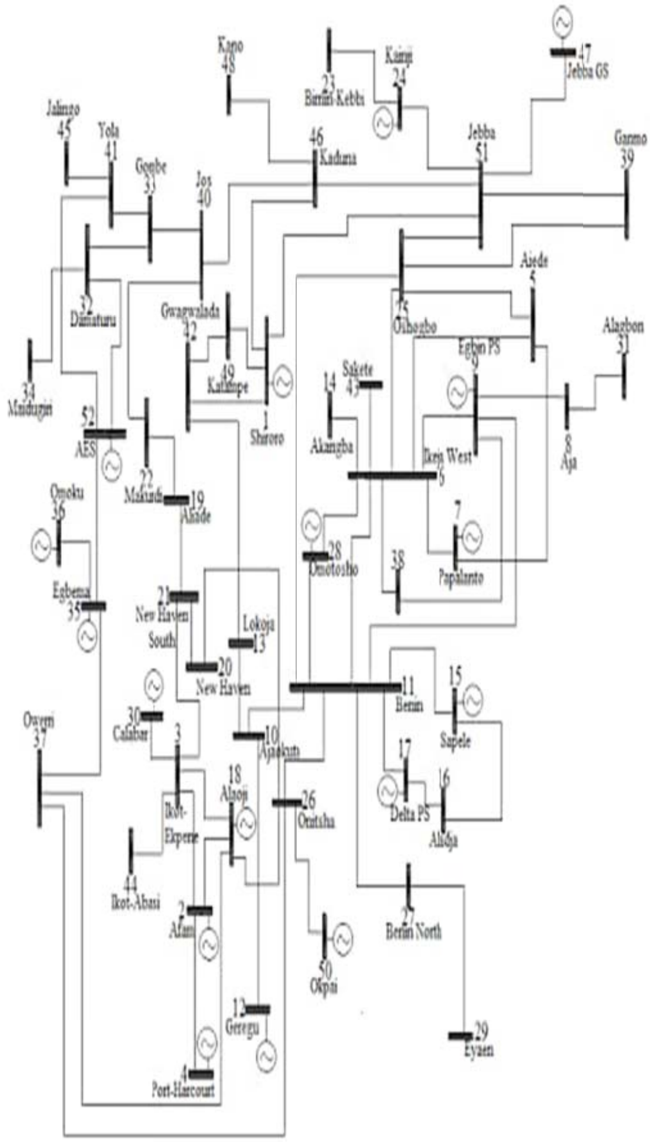

Fig. 2. Nigerian 330 kV Network.
Source: NCC Oshogbo

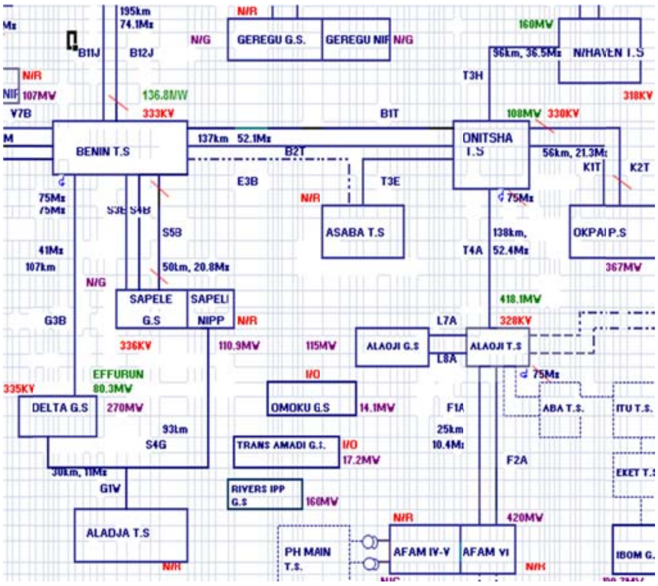

Fig. 3. Mapped out area of study.
Source: Developed by the researchers (2023)

The power system study area is shown in Figure 3. The locations with the power function are summarized in Table 1.

TABLE 1. POWER SYSTEM LOCATIONS AND TRANSMISSION LINE DATA

Bus Name From/To	Length	Shunt(pu)	$R_{1(pu)}$	$X_{1(pu)}$
Onitsha/New Heaven	96	0.035	0.0034	0.0292
Onitsha/Alaoji	138	0.524	0.0049	0.0419
Benin/Sapele	50	0.208	0.0018	0.0139
Alaoji/Afam	25	0.104	0.0090	0.0070
Sapele/Aladja	63	0.239	0.0023	0.0190
Delta/Aladja	30	0.171	0.0011	0.0088
Benin/Delta	107	0.239	0.0022	0.0190
Onitsha/Okpai	80	0.104	0.0090	0.0070
Oshogbo/Benin	251	0.954	0.0089	0.0763

TABLE 2. BUS DATA

Bus Name	Generation		Load		Volts V	Angle Degree	Remarks
	P(mw)	Q(mvar)	P(mw)	Q(mvar)			
Delta	55.00	28.160			1.00	0.000	PV Bus
Okapi	220.00	112.700			1.00	0.000	PV Bus
Sapele	75.00	38.420			1.00	0.000	PV Bus
Afam	479.00	245.310			1.00	0.000	PV Bus
Onitsha			130.510	66.860	1.00	0.000	Load Bus
Benin			160.560	82.240	1.00	0.000	Load Bus
Aladja			47.997	24.589	1.00	0.000	Load Bus
Alaoji			163.950	83.980	1.00	0.000	Load Bus
Newheaven			113.050	57.910	1.00	0.000	Load Bus
Oshogbo			120.370	61.650	1.00	0.000	Load Bus

Outline in Table 1 and Table 2 are the ten buses to be analysed with fast decoupled power flow analysis with performance of optimal power flow.

D. Fast Decoupled Power Flow Model

It has been observed that the convergence performance of fast decoupled power flow iteration is to a significant extent better than expected. This is due to the approximation introduced in the derivation of the primary models of the method. The two types (versions) of fast decoupled load flow analysis include; BX fast decouple and XB fast decouple [7].

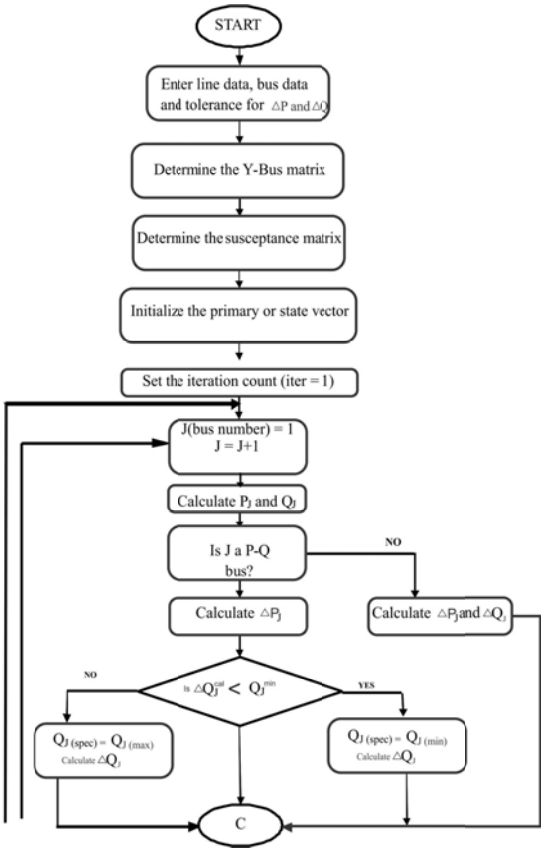

Fig. 4. Fast decoupled flow algorithm.
Source: Developed by the researchers (2023)

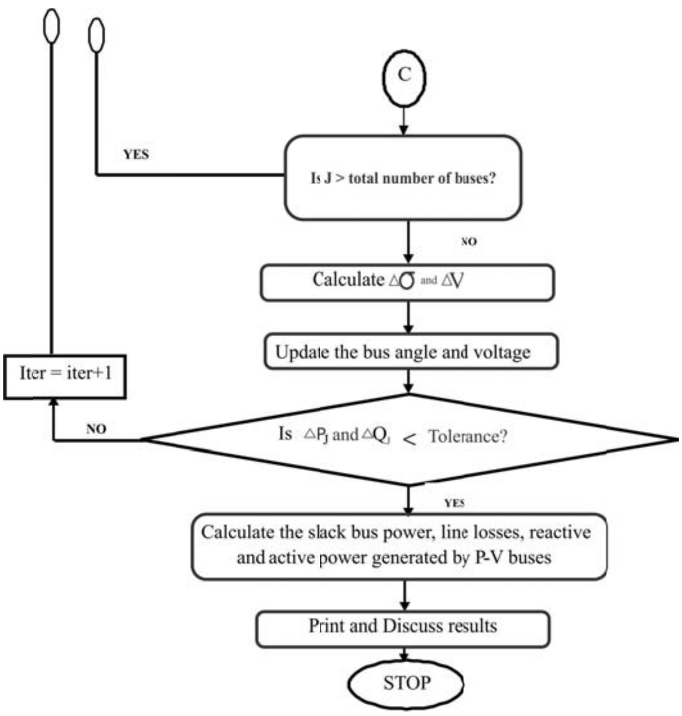

Fig. 4. Fast decoupled flow algorithm.
Source: Developed by the researchers (2023)

The flow diagram showing the procedure of utilizing fast decouple power flow algorithm is shown in Figure 4.

BX is the general purpose fast decoupled load flow while XB is the standard fast decoupled load flow algorithm iteration. It should be noted that XB and BX fast decoupled flow algorithm follows the same iteration pattern but produces different iteration results hence, one flow algorithm will be used in the representation [8].

To obtain the calculated active and reactive power, the equations are shown in Equations 1 and 2 respectively.

$$P_J^{calc} = \sum_{J=1}^{N} |V_J||Y_{Ji}||V_J| \cos(\sigma_J - \sigma_i) \quad (1)$$

$$Q_J^{calc} = \sum_{J=1}^{N} |V_J||Y_{Ji}||V_J| \sin(\sigma_J - \sigma_i) \quad (2)$$

Where P_J^{calc} is the calculated active power, Q_J^{calc} is the calculated reactive power, V_J is the voltage magnitude of the bus J and σ_J represents the angle.

The determine the change in phases and voltages of the buses, we have;

$$\Delta\sigma_J = inverse\ of - Z' \times \frac{\Delta P_J}{|V_J|} \quad (3)$$

$$\Delta V_J = inverse\ of - Z'' \times \frac{\Delta P_J}{|V_J|} \quad (4)$$

Where Z' is the susceptance matrix which comprises of the imaginary part of the Y-bus (Y) for all the buses with exception of the slack bus and Z'' is the imaginary part of the load buses.

To update the bus voltage;

$$newV = V + \Delta V_J \quad (5)$$

Where V is the voltage of bus J.

To obtain the change in active and reactive power (ΔP_J and ΔQ_J) respectively;

$$\Delta P_J = P_{J(spec)} - P_J^{cal} \quad (6)$$

$$\Delta Q_J = Q_{J(spec)} - Q_J^{cal} \quad (7)$$

Where $P_{J(spec)}$ the specified active is power of the buses and $Q_{J(spec)}$ is the specified reactive power of the buses.

E. Power system model with power system analytical tool (PSAT)

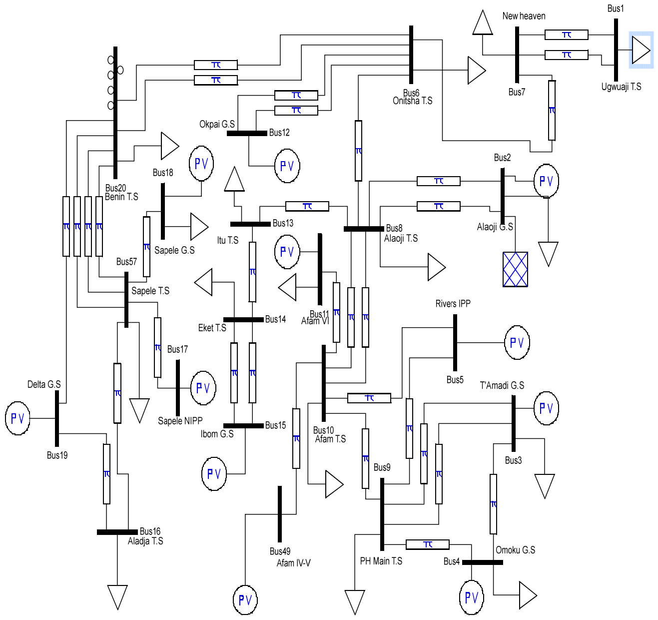

Fig. 5. Modelling of the selected power system network
Source: Developed by the researchers (2023)

The test system configuration is based on the Nigeria 330 kV,10- bus system as shown in Figure 5. For the 330 kV Nigeria Power Network simulation and analysis, some MATLAB programs were developed. The algorithm used for the simulation and analysis of the case study was power system analytical toolbox (PSAT) and routines collection of m-files which comprises of three main algorithms namely, gauss-siedel Newton Raphson and decoupling method [8]. The input data for the power flow analysis include: the bus data for both the active and reactive power of the generator buses, the transmission line data, voltage and transformer/load data which were obtained from Power Holding Company of Nigeria [9]. Figure 7 is the implementation of the power system line in Figure 3. To ensure the clarity of the network model in PSAT, the model is divided into four sections with the snapshot of each section presented. It can be seen from Figure 5 that Alaoji generation station was selected as the slack bus due its constant voltage stability. The entire network is a 330 kV transmission network [10].

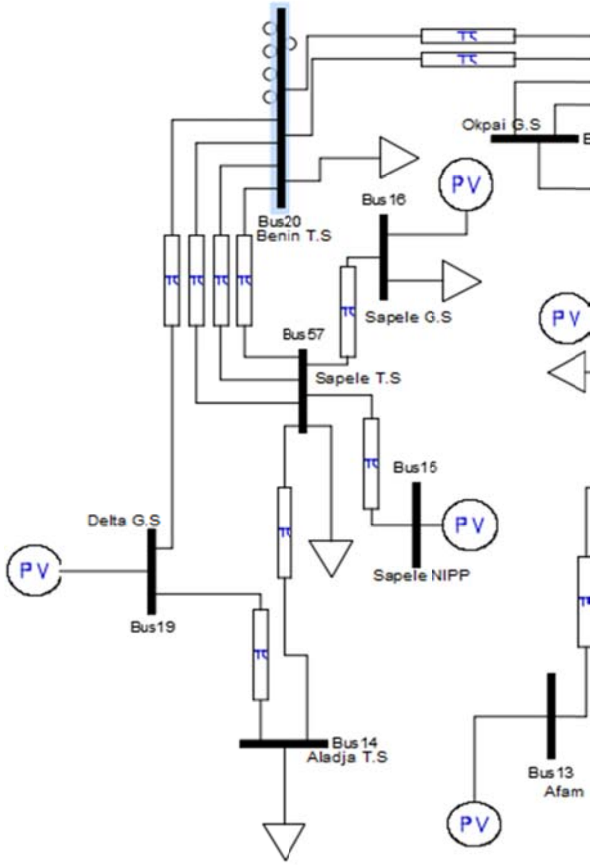

Fig. 6. First section of the selected region.
Source: Developed by the researchers (2023)

The first section of the model is shown in Figure 6. it shows delta generation station, Aladja transmission station, Afam generation station, Sapele generation station, Benin transmission station, and okapi generation station. The section is displayed in Figure 6.

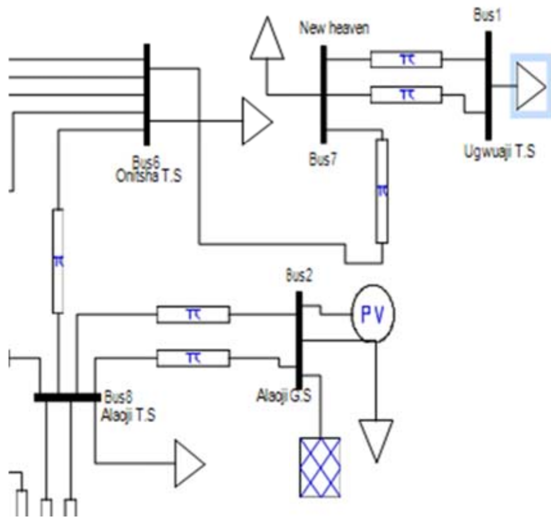

Fig. 7. Section two of power system model.
Source: developed by the researchers (2023)

The second section of the model is seen in Figure 7. This section comprises of generation and transmission station in Alaoji, (Alaoji generation station is the slack bus), new-heaven, Ugwuaji and Onitsha transmission stations. The third section is shown in Figure 7.

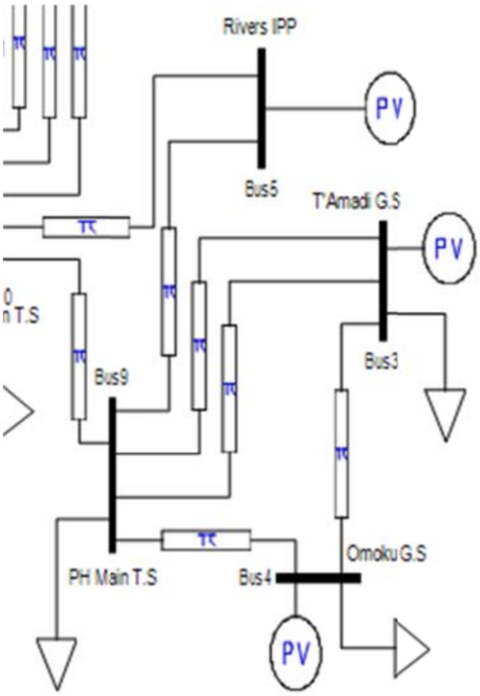

Fig. 8. Third Section of The Model.
Source: Developed by the researchers (2023)

This third section as shown in Figure 8 comprises of Port-Harcourt transmission station, Omoku and trans-amadi generation stations. The parameters for the slack bus were captured and displayed in Figure 9.

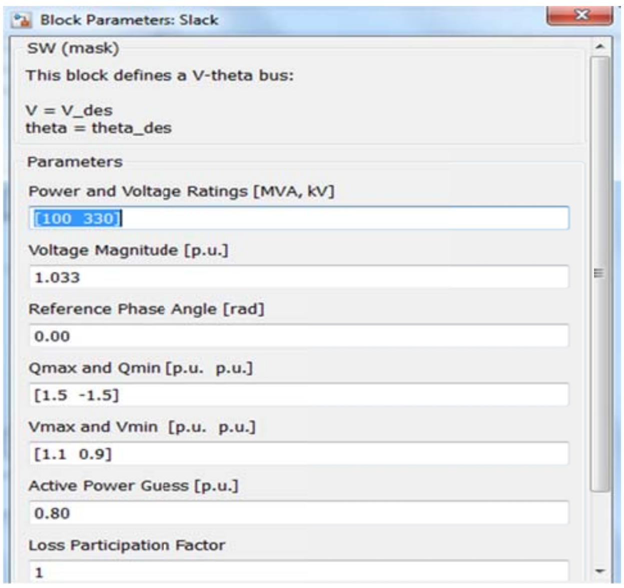

Fig. 9. Parameters for the slack bus.
Source: Developed by the researchers (2023)

The parameters for the P-V generation station for Afam is shown in Figure 10.

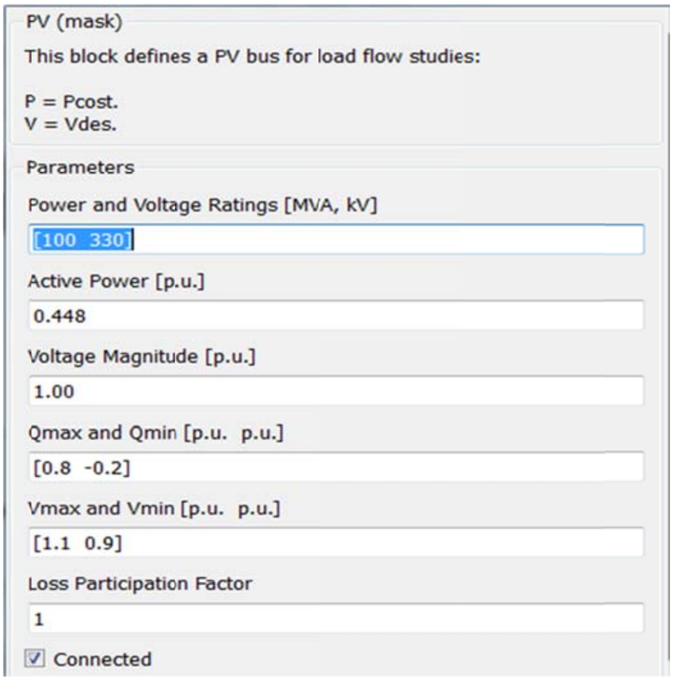

Fig. 10. Parameters for the PV generation bus.
Source: Developed by the researchers (2023

The parameters for the load bus are shown in Figure 11.

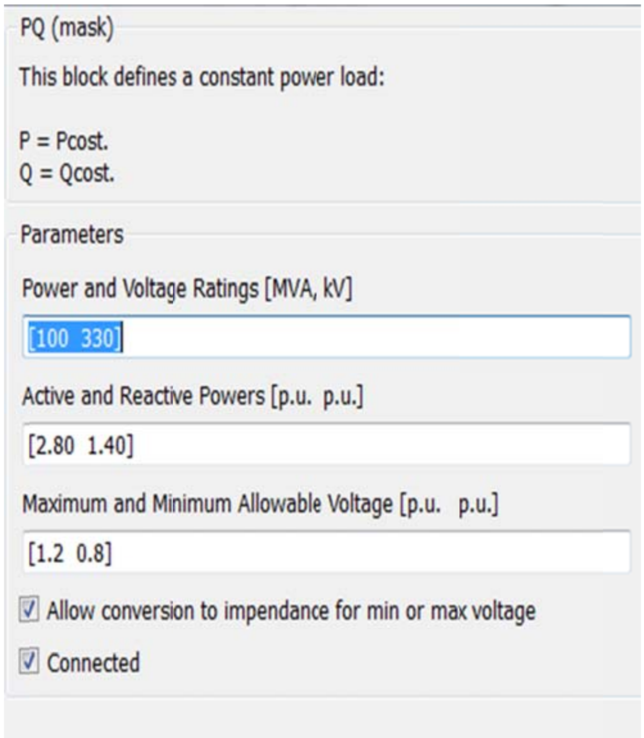

Fig. 11. Load bus for PHTS.
Source: Developed by the researchers (2023)

F. MATLAB

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation (MATLAB USER MANUAL and Documentation,2020b). Typical uses as stated in MATLAB User Manual and Documentation (2020b) and by anonymous (2012) include:

Math and Computation
Algorithm development
Modelling, simulation and prototyping
Data analysis, exploration and visualization
Scientific and engineering graphics
Application development, including Graphical User interface building.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows one to solve many technical computing problems, especially those with matrix and vector formulation, in a fraction of the time it would take to a program in a scalar non-interactive language such as C or Fortran notation (MATLAB User Manual and Documentation, 2020b). The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state of the art in software for matrix computation. MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering and science. In industry, MATLAB is the tool of choice for high-productivity research, development and analysis.

MATLAB features a family of application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collection of MATLAB function (M-file) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neutral network, fuzzy logic, wavelet, simulation and many others (MATLAB User Manual and Documentation 2020b).

G. PSAT

The power system analysis toolbox for electric power system analysis and simulation. The command line version of PSAT is also GNU Octave compatible [11]. All operations can be assessed by means of graphical user interfaces (GUIS) and a Simulink based library provides a user-friendly tool for network design. The main features of PSAT are; power flow, continuation power flow, optimal power flow, small signal stability analysis, time domain simulation, complete graphical user interface, user defined models, FACTS models, wind turbine models, Conversion of data files from several formats, export results to EPS, plain text.MS excel and Latex files, Interfaces for Gams and UWPFLOW programs, Command usage and GNU octave compatibility [11].

The PSAT environment that houses the optimal power flow is shown in Figure 11. Once the model data is loaded to the environment, the XB and the BX fast decoupled power flow analysis was first performed. The come dynamic components (icons) for determination of optimal parameters were added to the existing power system model in modelling environment of PSAT. Without these components, simulation of optimal power flow will not be possible. The PSAT library with the optimal power flow blocks to be inserted into the model environment is shown.

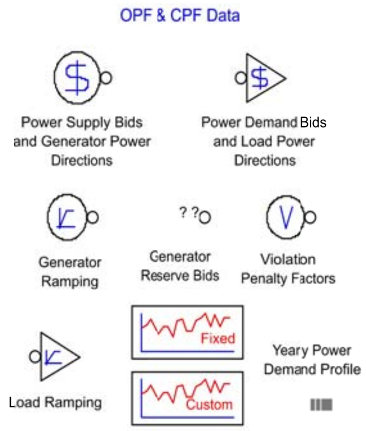

Fig. 12. Optimal power flow block models.
Source: Developed by the researchers (2023)

The first block was inserted to all the power generation buses including the slack bus while the second block was inserted in the load buses. The environment for activating the power flow is shown in Figure 12.

III. SIMULATION, RESULTS AND DISCUSSION

A. Results

Presented in this section are the results of the power flow analysis of the power system network with XB and BX fast decoupled algorithm. Comparative analysis was carried out based on voltage stability and power loss generated by the power flow algorithms considered. Optimal power flow was applied to the best fast decouple model to normalize the voltage profile and power loss reduction. This was done with power system analytical toolbox.

B. XB fast Decoupled power flow

The first iteration of voltage profile and the power flows with PSAT is shown in Table 3.

TABLE 3. FIRST ITERATION OF BX FAST DECOUPLED POWER FLOW IN PSAT

Bus	**Vm**	**Va**	**P**	**Q**
Bus 1	1	-0.18517	-1.75	-1.31
Bus 10	0.985	-0.19522	-7.2	-4.12
Bus 11	1.003	-0.18414	1.12	3.8161
Bus 12	1.003	0	4.66	3.7003
Bus 13	0.98176	-0.19994	0.54	-5.7397
Bus 14	1	-0.24772	-2.1	-1.58
Bus 15	1	-0.24815	1.111	1.0403
Bus 16	1	-0.23992	0.27	0.06369
Bus 19	0.9836	-0.19897	3.41	3.251
Bus 2	0.96468	-0.20303	10.001	3.2218
Bus 20	0.84655	-0.32419	-1.44	-1.08
Bus 3	0.97487	-0.20598	0.2	2.279
Bus 4	0.99201	-0.24716	0.052	1.1548

Vm represents the voltage magnitude in pu, Va is the angular bus voltages in radians, P is the active power in pu and Q is the reactive power in pu. The bar chart for the voltage magnitude values generated is shown in Figure 14.

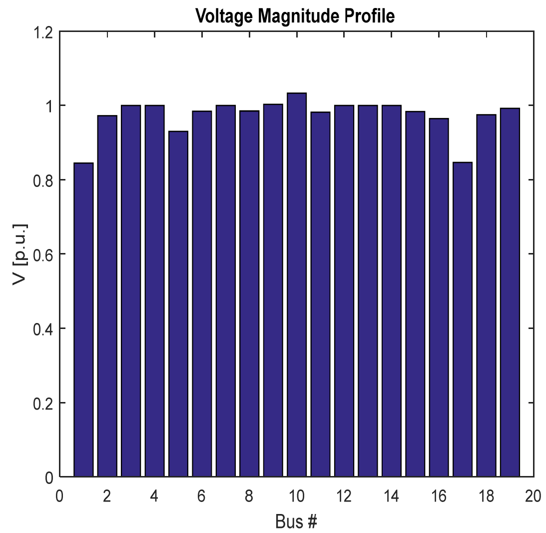

Fig. 13. Bar chart of voltage magnitude with PSAT.
Source: Developed by the researchers (2023)

From the bar chart presented in Figure 13, bus 1 had the highest voltage profile abnormality of 0.84478pu. Based on the tolerance voltage profile deviation of ±0.5, the power flow analysis had acceptable voltage profile stability with XB fast decoupled iterative method [12].

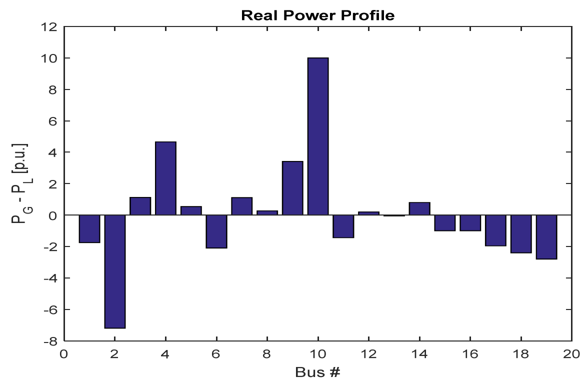

Fig. 14. Power flow for real power profile.
Source: Developed by the researchers (2023)

In Figure 14, P_G represents generated power and P_L represents load power. The figure for the reactive power is shown in Figure 15.

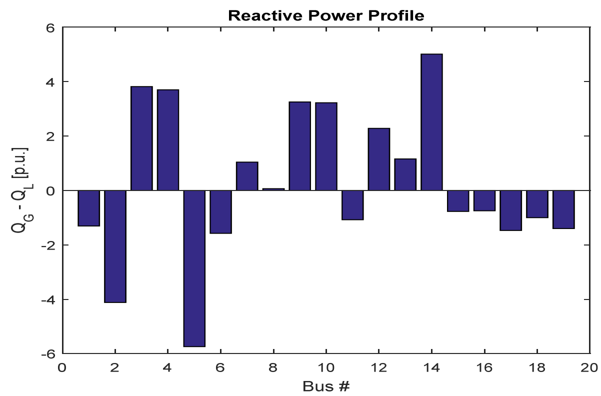

Fig. 15. Reactive Power Profile.
Source: Developed by the researchers (2023)

The reactive power profile is shown in Figure 15. Q_G represents reactive power generated and Q_L reactive load. Series of iteration carried out with XB fast decoupled algorithm is shown below.

C. *XB Fast De coupled Method*

Single slack bus model
Iteration = 1 Maximum convergence Error = 15.2194
Iteration = 2 Maximum convergence Error = 0.2419
Iteration = 3 Maximum convergence Error = 0.034974
Iteration = 4 Maximum convergence Error = 0.00559029
Iteration = 5 Maximum convergence Error = 0.0010928
Iteration = 6 Maximum Convergence Error = 0.00019972
Iteration = 7 Maximum convergence Error =3.6041e-05
Iteration = 8 Maximum convergence Error = 6.4349e-06
Power flow completed in 0.3945

A convergence error of 6.4349×10^{-6} was achieved at the eighth iteration leading to the convergence of the power system. The results presented in Table 4 represent the system at the first convergence (with convergence error of 15.1974 as shown in Figure 16) The voltage profile with the power flow of the power system at the final iteration point for the XB fast decoupled system is shown in Table 4.

TABLE 4. POWER FLOW ANALYSIS

Bus No	Voltage(pu)	Phase(rad)	P_{gen} (pu)	Q_{gen}(pu)	P_{load} (pu)	Q_{load}(pu)
Bus1	0.844777	-0.3263	6.07E-06	4.72E-07	1.75	1.31
Bus10	0.972449	-0.2335	6.81E-08	2.55E-09	7.2	4.12
Bus11	1	-0.2291	6.46	7.826078	5.34	4.01
Bus12	1	-0.1668	4.660001	3.700289	0	0
Bus13	0.93	-0.2237	0.54	-5.73968	0	0
Bus14	0.984396	-0.2016	6.39E-09	3.75E-09	2.1	1.58
Bus15	1	-0.1852	1.111	1.040286	0	0
Bus16	0.985	-0.1952	0.67	0.243693	0.4	0.18
Bus19	1.003	-0.1841	3.41	3.251035	0	0
Bus2	1.033	0	12.27104	4.921781	2.27	1.7
Bus20	0.981755	-0.1999	4.41E-08	1.38E-08	1.44	1.08
Bus3	1	-0.2477	1	2.519016	0.8	0.24
Bus4	1	-0.2481	0.448	1.254834	0.5	0.1
Bus5	1	-0.2399	0.8	5.011337	0	0
Bus17	0.983605	-0.1989	1.3E-08	5.53E-09	1	0.77
Bus6	0.964678	-0.2030	-2.9E-06	1.21E-07	1	0.75
Bus7	0.84655	-0.3242	-4.9E-06	6.62E-07	1.96	1.47
Bus8	0.974871	-0.2059	5.99E-08	6.43E-09	2.4	1
Bus9	0.992008	-0.2471	1.21E-08	6.4E-11	2.8	1.4

D. *BX fast Decoupled power flow*

The first iteration of voltage profile and the power flows with PSAT for BX fast decouple is shown in Table 5.

TABLE 5. FIRST ITERATION OF THE BX FAST DECOUPLED POWER FLOW IN PSAT

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V_m represents the voltage magnitude in pu, V_a is the angular bus voltages in radians, P is the active power in pu and Q is the reactive power in pu. The bar chart for the voltage magnitude values generated is shown in Figure 16.

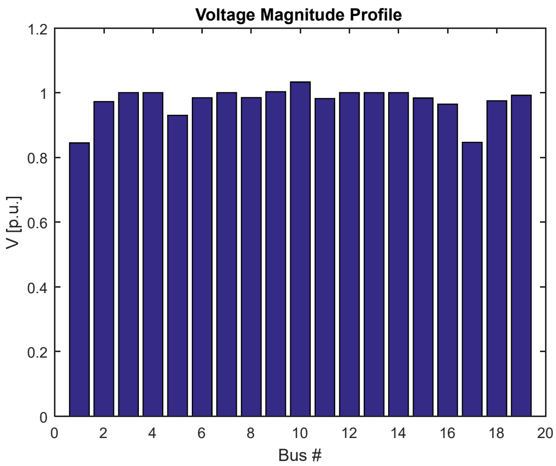

Fig. 16. Bar chart of voltage magnitude with PSAT.
Source: Developed by the researchers (2023)

From the bar chart presented in Figure 16 bus 1 had the highest voltage profile abnormality of 0.84478pu. Based on the tolerance voltage profile deviation of ±0.5, the power flow analysis had acceptable voltage profile stability with BX fast decoupled iterative method. The active and reactive power flows for each of the buses is shown in Figure 17 and Figure 18 respectively.

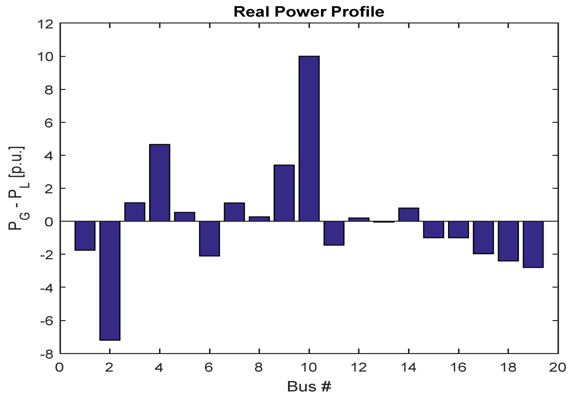

Fig. 17. Power flow for real power profile.
Source: Developed by the researchers (2023)

In Figure 17, P_G represents generated power and P_L represents load power. The figure for the reactive power is shown in Figure 18.

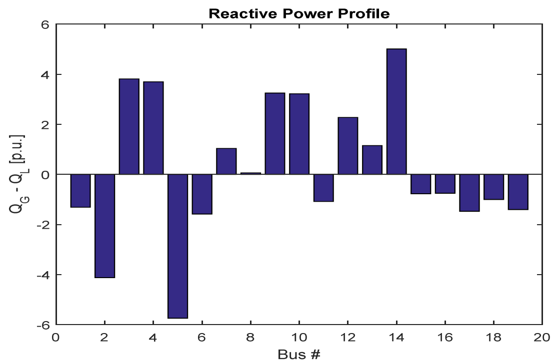

Fig. 18. Reactive power profile.
Source; developed by the researchers (2023)

The reactive power profile is shown in Figure 18. Q_G represents reactive power generated and Q_L reactive load.
Series of iteration carried out with BX fast decoupled algorithm is shown below.

E. BX Fast Decoupled Method

Single slack bus model

Iteration = 1 Maximum Convergence Error = 15.2194
Iteration = 2 Maximum Convergence Error = 0.25166
Iteration = 3 Maximum Convergence Error = 0.039254
Iteration = 4 Maximum Convergence Error = 0.0068085
Iteration = 5 Maximum Convergence Error = 0.0012866
Iteration = 6 Maximum convergence Error = 0.00023931
Iteration = 7 Maximum convergence Error = 4.3881e-05

Iteration = 8 Maximum convergence Error = 7.9583e-06

A convergence error of 7.9583×10^{-6} was achieved at the eighth iteration leading to the convergence of the power system. The results presented in Table 6 represent the system at the first convergence (with convergence error of 15.2194 as shown in Figure 19).

When compared with the XB fast decoupled method of power flow, it can be seen that BX fast decoupled method had a higher convergence error than XB fast decoupled method. The voltage profile with the power flow of the power system at the final iteration point for the BX fast decoupled system is shown in Table 6.

TABLE 6. POWER FLOW ANALYSIS

Bus No	Voltage (pu)	Phase (rad)	P_{gen} (pu)	Q_{gen}(pu)	P_{load} (pu)	Q_{load}(pu)
Bus1	0.844777	-0.3263	5.66E-06	7.99E-07	1.75	1.31
Bus10	0.972449	-0.2335	8.94E-08	6.38E-09	7.2	4.12
Bus11	1	-0.2291	6.46	7.826078	5.34	4.01
Bus12	1	-0.1668	4.660001	3.700288	0	0
Bus13	0.93	-0.2237	0.54	-5.73968	0	0
Bus14	0.984396	-0.2016	8.11E-09	5.99E-09	2.1	1.58
Bus15	1	-0.1852	1.111	1.040286	0	0
Bus16	0.985	-0.1952	0.67	0.243692	0.4	0.18
Bus19	1.003	-0.1841	3.41	3.251035	0	0
Bus2	1.033	0	12.27104	4.921781	2.27	1.7
Bus20	0.981755	-0.1999	4.85E-08	2.7E-08	1.44	1.08
Bus3	1	-0.2477	1	2.519016	0.8	0.24
Bus4	1	-0.2481	0.448	1.254834	0.5	0.1
Bus5	1	-0.2399	0.8	5.011337	0	0
Bus17	0.983605	-0.1989	1.5E-08	7.95E-09	1	0.77
Bus6	0.964678	-0.2030	-3.5E-06	1.95E-07	1	0.75
Bus7	0.84655	-0.3242	-4.2E-06	9.72E-07	1.96	1.47
Bus8	0.974871	-0.2059	2.5E-08	1.28E-08	2.4	1
Bus9	0.992008	-0.2471	1.49E-08	3.85E-10	2.8	1.4

TABLE 7. LINE FLOWS FOR THE TRANSMISSION LINE

From Bus	To Bus	Line	P flow	P loss	Q loss
Bus9	Bus4	1	0.008676	0.001192	0.008175
Bus10	Bus5	2	-0.36386	0.014671	0.111852
Bus7	Bus6	3	3.814108	0.103263	0.875594
Bus7	Bus1	4	-0.875	0.000423	0.002545
Bus7	Bus1	5	-0.875	0.000423	0.002545
Bus20	Bus6	6	-0.11528	0.000839	0.006175
Bus20	Bus6	7	-0.11528	0.000839	0.006175
Bus12	Bus6	8	-2.31078	0.01922	0.146842
Bus12	Bus6	9	-2.31078	0.01922	0.146842
Bus20	Bus57	10	0.082533	3.97E-05	-0.00066
Bus20	Bus57	11	0.082533	3.97E-05	-0.00066
Bus20	Bus57	12	0.082533	3.97E-05	-0.00066
Bus16	Bus57	13	-0.26986	0.000144	0.000136
Bus57	Bus15	14	1.111	0.004192	0.031258
Bus20	Bus19	15	1.431264	0.006501	0.054195
Bus19	Bus14	16	-1.97098	0.007756	0.064839
Bus17	Bus14	17	-0.12902	4.61E-05	-0.00058
Bus6	Bus8	18	-0.0377	0.000311	0.001695
Bus8	Bus2	19	5.068493	0.127321	1.079573
Bus8	Bus2	20	4.932547	0.012907	1.094422
Bus11	Bus10	21	-1.10569	0.01431	0.109074
Bus10	Bus13	22	0.54	0.034752	0.26635
Bus8	Bus10	23	-3.73587	0.013387	0.102004
Bus8	Bus10	24	-3.73587	0.013387	0.102004
Bus10	Bus9	25	-1.49384	0.010303	0.078272
Bus5	Bus9	26	-1.16173	0.002132	0.015406
Bus3	Bus9	27	-0.06926	0.001197	0.008147
Bus3	Bus9	28	-0.06768	0.00118	0.008082
Bus3	Bus4	29	-0.06068	3.39E-06	-0.00097

Due to a near similar convergence error value (7.9583×10^{-6} for BX fast decouple and 6.4349×10^{-6} for XB fast decouple), XB fast decoupled was selected for optimal power flow because of its low convergence error.

F. Optimal Power Flow

Optimal power flow of the power system was performed with XB fast decoupled power flow method. The voltage profile of the power system for optimal power flow analysis is shown in Table 8.

TABLE 8. VOLTAGE PROFILE FOR OPTIMAL POWER FLOW

Bus number	Voltage (pu)
Bus1	0.9722
Bus10	0.952449
Bus11	0.960
Bus12	0.952
Bus13	0.9503
Bus14	0.984396
Bus15	0.97
Bus16	0.985
Bus19	1.003
Bus2	1.033
Bus20	0.961755
Bus3	0.9700
Bus4	0.9750
Bus5	0.9505
Bus17	0.963605
Bus6	0.964678
Bus7	0.93655
Bus8	0.974871
Bus9	0.972008

The optimal power flow with XB fast decouple method is shown in Table 4 for the voltage profile. It was observed that the power flows for the optimal power flow results is the same with the results generated by the XB fast decoupled power flow method but differs in voltage profile values.

G. Discussion

The XB and BX fast decoupled method of power flow analysis was utilized in determining the voltage profile and the power flow of the buses and the transmission lines (Table 7). The XB fast decouple method of power flow had a better convergence leading to more accurate power flow results when compared to the BX fast decoupled power flow hence, it was utilized in the determination of the optimal power shown in Table 4. The comparative plot of the voltage profile of the XB fast decoupled power flow model with and without optimal power analysis is shown in Figure 19.

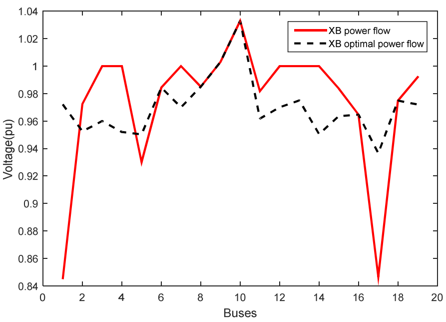

Figure 19: Comparative analysis of the voltage profile of the power system with and without optimal power flow analysis with XB power flow method.
Source: develop by the researchers (2023)

The comparative performance of the system with and without optimal power flow analysis is shown in Figure 19. it can be seen that there was an improvement in the voltage of the buses when the optimal power flow was performed. The bus voltages were almost normalized at between 0.95 and 1.03 which is the appropriate voltage values for the buses. To achieve this, more power should be generated from the generation stations as suggested by the power flow outcome shown in Table 4 and Table 6.

TABLE 9. COMPARATIVE STUDY WITH RELATED LITERATURE

Source		Results Accuracy
[13]		97%
[10]		92%
[5]		82%
[14]		90%
[15]		94%
This study		98%

From the results presented in Table 9, it can be seen that optimization of the power system without FACTS devices had a higher accuracy when compared with related studies. Hence, this model should be implemented to aid in prompt and accurate report in power system network.

IV. CONCLUSION

The primary aim of this study was to perform an optimal power flow using fast decoupled method on the Nigerian 330 kV lines to minimize system operating costs and obtain more capacity out of existing system. To achieve this, a 10 bus network data was obtained and simulated with power system analytical toolbox (PSAT) in carrying out the power flow analysis. On carrying out comparative load flow analysis on the system with and without optimal power flow, it was observed that there was an improvement in the voltage of the buses when the optimal power flow was performed. The bus voltages were normalized at 0.95pu and 1.03pu which is the appropriate voltages values for the buses.

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