Systemic Analytics

www.sa-journal.org

Syst. Anal. Vol. 3, No. 1 (2025) 8–19.

Paper Type: Original Article

Optimal Power Flow Analysis of Uyo Zone 002 IBB Distribution Feeder Line System Network Using Conventional Analytical Techniques

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Citation:

Received: 14 July 2024 *Revised: 09 September 2024* *Accepted: 12 November 2024*	Abia, E. S., Nworah, K., & Fischer, G. (2025). Optimal power flow analysis of uyo zone 002 IBB distribution feeder line system network using conventional analytical techniques. *Systemic Analytics*, 3(1), 8-19.

Abstract

The Optimal Power Flow (OPF) analysis is crucial for ensuring the efficient operation of power systems by optimising the generation and transmission of power while satisfying various operational constraints. This paper compares three different analytical methods, Gauss-Seidel, Newton-Raphson, and Fast Decoupled, to simulate and compute the OPT in Uyo Zone 002 IBB distribution feeder lines system network using the ETAP software. The study aimed to determine the most suitable method for achieving optimal regional power flow. Using the Gauss Siedel method, the load flow was analysed for a 44-bus system wh in bus 1, 2, and 4's transmission lines operate on 132,000 kVA lines. The power generated in bus two was observed at 0.014MW while Mvar was -0.076. The load flow in the buses varied between -0.007 and 0.014 MW, while the Mvar was between -0.03 and 0.076. The voltage magnitudes (% Mag) ranged between 100.000 and 100.497. Using the Newton-Raphsons method, the load flow was analysed for a 44-bus system where all the transmission lines on all the buses operate at 11 kVA. The voltage magnitude on buses 10 and 12 were 98.744% and 76.014%, respectively, while other buses worked at 100.497. Using the Fast Decoupled method, the 11kV transmission line accommodated all the buses and their voltages and power generation. The loads flowing through all the buses in the system had the same parametric values except for Umoh Obot Street s/s Bus 16, whose voltage magnitude dropped to 76.014% with Ang of -45.2%. Only the % Mag for UMOH OBOT S/S Bus 16 was 76.014%, and the rest were 100.497. The study results indicate that the three methods were quite effective in terms of convergence speed and accuracy. However, the Newton-Raphson method was able to quickly converge to a solution that satisfies all operational constraints while minimising generation costs. In contrast, the Gauss-Seidel method exhibited slower convergence and may require more iterations to reach a feasible solution. The fast decoupled method, although computationally efficient, may sacrifice accuracy for speed in certain scenarios.

Keywords: Optimal power flow, Gauss-seidel, Newton-raphson, Fast decoupled, ETAP software.

1 | Introduction

Modern power systems' increasing complexity and variability present challenges in maintaining optimal load flow in distribution feeder lines. Some of the primary issues facing the Uyo Zone 002 IBB distribution feeder lines include balancing the supply and demand of electricity in real time. As the electricity demand fluctuates

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10.31181/sa31202532

throughout the day, ensuring that the Uyo Zone 002 IBB distribution feeder lines can handle varying loads without causing disruptions or overloading the system is essential. Failure to maintain optimal load flow can result in voltage fluctuations, power outages, and equipment damage, leading to significant economic and social costs. Moreover, the ageing infrastructure of Uyo Zone 002 IBB distribution feeder lines poses a considerable challenge to the optimal load flow study. These distribution feeder lines were designed and built decades ago and may not be equipped to handle the increasing demands of modern power systems. As a result, these lines may be operating near their capacity, increasing the risk of overloads and equipment failures. Addressing the challenges posed by fluctuating demand, renewable energy integration, and ageing infrastructure ensures that efficient and reliable operation of the distribution feeder lines will ultimately benefit both utilities and end-users. Hussain et al. [1] used the Gauss-Seidel method for load flow analysis to calculate steady-state voltages, voltage angles, real and reactive power flows, line losses, and overall reactive and active power losses. The study revealed the steady-state conditions of the 5-bus power system. The calculated results include voltage magnitudes, angles, real and reactive power flows, line losses, and overall reactive and active power losses. The analysis also provided insights into the system's operating conditions and helped identify potential areas for improvement.

The Gauss-Seidel method effectively analyses small power systems, providing accurate results with minimal computational complexity. The study demonstrated the importance of load flow analysis in understanding power system behaviour and optimising system operations. The results highlight the significance of considering reactive power in power system analysis to ensure efficient energy transmission. Komolafe and Lawal [2] obtained results from Optimal Power Flow (OPF) analysis of the Nigerian 330-kV power system network, with Flexible Alternating Current Transmission System (FACTS) devices included. The Static Synchronous Compensator (STATCOM) and Unified Power Flow Controller (UPFC) data were incorporated into a Newton-based OPF algorithm. The algorithm was applied to solve the Nigerian 34-bus power system. The hydro units were assumed to have been optimally dispatched, while the OPF was used to dispatch the thermal plants. The OPF results without FACTS devices showed that the power network operated at a cheaper generation cost of 3,268,518.64N/h compared to the generation cost for the conventional power flow at 3,459,837.46N/h.

The results also showed that the incorporation of STATCOM and UPFC improved the overall system performance when compared with the solution with either of these devices on the network. Idoniboyeobu et al. [3] examined the existing electrical power network for the Ordinance area, Trans-Amadi Port Harcourt distribution network, which consists of four (4) 11kV distribution feeders, namely Waterworks, Fimie, Ndabros and Rivoc. The distribution network was modelled in the Electrical Transient Analyser Program (ETAP) using the Gauss-Seidel power flow equation. Power flow analysis was conducted for existing and modified networks using transformer tapping and capacitor bank optimisation methods. The results were analysed, and under-voltage buses, overloaded transformers and feeders were identified. Voltage below 95% was taken as under voltage, and transformer loading above 60% was taken as overloading. The reasons for the under-voltage and overloading were identified, and two (2) optimisation techniques were used to improve the network and to determine which of the methods was better. According to the simulation results, the effects of all bus voltages changed and improved above the acceptable range, which is 100%, because of varying the best condition of the tap ratio. When the capacitor bank under optimum value was installed at the weakest buses, the voltage of those buses was increased between 97.65% and 100.94%.

Idoniboyeobu and Ibeni [4] conducted research for Port Harcourt Town Zone 4, Rivers State power distribution network. The analysis was carried out to solve the problem of frequent power outages caused by heavy I2R losses in the line. Low voltages were experienced at the consumers' end, as well as poor power factor at the load end, over-loading of feeder transformers, and inadequate size of conductors at the consumer's end of the network in Port Harcourt Town, 33KV Distribution Network. A detailed survey was conducted on the Network, and the bus admittance matrix was formed. MATLAB programmable codes were written to solve the static load flow equations formulated using Fast decoupled and Newton Raphson algorithms based on the benefits of time and digital computer memory space. As a result, the bus voltages, phase angles, and network losses were reduced, and branch real and reactive power flow were obtained. Electrical Transient Analyzer Program (ETAP) software was used to model the network and carry out a simulation to compare the results. It was observed that both results obtained were similar. The total net power received was 130.412 MW and 84.28MVar using the Fast Decoupled Newton-Raphson load flow method in MATLAB Environment after injection of reactive power via Capacitor bank to the buses that were affected due to unacceptable voltage drop. The total net real and reactive power received using ETAP software was 126.7 MW and 93.8 MVar—the total line losses on the network reduced from 4.7512MW and 10.0517MVar to 3.5821MW and 7.5785MVar, respectively. A 24.6% reduction of the total real power losses was realised after injecting reactive power into the under-voltage buses; the bus voltage profiles were normalised, as observed in the results. The results obtained on each feeder will aid the system engineer during the operation and future network expansion under consideration.

Effiong et al. [5] exploited the use of the artificial neural network (ANN) to model and forecast the peak load demand in the Uyo metropolis using temperature, population and GDP as the explanatory variables. Particularly, sixteen (16) years (2000-2015) of data on annual peak-load demand, population, GDP, and temperature of Uyo were collected and then used to train and evaluate the ANN model. Furthermore, the ANN model was used to forecast the peak load demand in the Uyo metropolis from 2016 to 2025. The results of the error analysis of the ANN model gave a coefficient of determination value of 99.912 %, a squared error value of 1.102209, and a mean squared error value of 0.068888. The forecast results also showed that the peak load demand will be 63.14MW in 2025, an increment of 23.80% compared to the peak load in 2015. Essentially, compared to the power demand in 2015, an additional 23.80% of electric power needs to be produced to meet the peak load demand in the Uyo metropolis 2015.

2 | Methodology

The following iterative methods will investigate the optimal load flow study of the Uyo zone 002 IBB feeder line in the Uyo City metropolis. They are highlighted as follows:

I. Gauss-seidel method: the gauss-seidel method is one of the earliest and simplest techniques for load flow analysis. It iteratively solves the power flow equations for each bus in the system [6].

II. Newton-raphson method: the newton-raphson method is a more efficient iterative technique that uses the Jacobian matrix to converge to a solution faster than Gauss-Seidel. It is widely used for load flow analysis [7].

III. Fast decoupled load flow: this method simplifies the full newton-raphson equations by decoupling the real and reactive power equations, which can lead to faster convergence without significantly sacrificing accuracy [8].

Load flow data collection is a crucial step in power system analysis, as it provides valuable information about the flow of electrical power within a network. The first step in the load flow data collection process was identifying the different zones within the power system. These zones can be geographical areas, which in this case was Uyo, Akwa Ibom State, substations, or specific sections of the network that are of interest for analysis, presented in *Table 1*. Once the zones were identified, the next step was to gather relevant data for each zone. The data collection process typically involves collecting information on the electrical parameters of the network, such as line impedance, transformer ratings, and load profiles. This data was obtained from various sources, including utility records, equipment specifications, and field measurements. In this case, the network consists of no generator, 24 load points or sub-stations, 71 buses, 71 branches and one 132kv utility power grid coming in from Afam, which is being tied to Aloja 330kv transmission network. Hence, the bulk power from these sources is stepped down to the ratio of 132/33/11/0.415v, and a total generation capacity is obtained as 2.361MW with an installed load capacity of 1.161MW and losses of about 1.2mw. In the process, a simple load flow study was carried out to ascertain the state of the 11kv IBB Uyo feeder and from the above parameters, which indicated that out of the 2.361MW of power generated, 1.161MW was used to drive the load centres and approximately 1.2MW was being recorded as total losses within the distribution network.

After the data had been collected, the next step was to input it into a load flow analysis software program, which uses mathematical algorithms to calculate the power flow within the network and determine the voltage and current levels at different points in the system. To achieve this, ETAP analytical software employed the Gauss-Seidel method, Newton-Raphson Method, and Fast Decoupled Load Flow as the analytical tool, which simulated and computed the results for the load flow analysis. The results of the load flow analysis helped identify potential issues such as voltage drops, overloads, and power losses. One of the key advantages of using a load flow analysis software program is that it allows for the simulation of different scenarios and the evaluation of potential solutions. For example, the software can assess the impact of adding new generation capacity or upgrading existing equipment on the network's overall performance.

Table 1. Load flow data for various zones.

Zones	Date When Data Was Obtained	Core Loss	Efficiency
ABAK ROAD S/S2	02/02/2023	0.375	57.66
ABAK ROAD S/S6	02/02/2023	0.375	47.66
ABAK ROAD S/S	17/09/2023	0.375	67.66
ATIKU	17/09/2023	0.375	47.66
CITY CENTRE S/S2	04/02/2023	0.375	57.66
ESUENE STR S/S3	17/09/2023	0.062	47.77
ESUENE STR S/S	17/09/2023	0.375	67.66
ESUENE STR S/S2	17/09/2023	0.062	85.76
EXISTING 2X 11/33 INJ	30/01/2023	0.187	69.38
EXISTING 2X 11/33 INJ	30/01/2023	0.187	59.38
FAITH STREET S/S3	02/02/2023	0.375	97.66
FHE RD S/S	17/09/2023	0.062	67.77
IBB MAIN TRX INJ S/S2	17/09/2023	0.312	59.38
IBOKO STR S/S2	17/09/2023	0.375	67.66
INACTIVE	17/09/2023	0	87.66
INACTIVE T2	17/09/2023	0	67.66
INACTIVE 2	17/09/2023	0	57.66
MASK S/S	17/09/2023	0.062	97.66
MECHANIC VILLAGE S/S	17/09/2023	0.062	87.75
MKPONG STR. S/S3	04/02/2023	0.375	67.66
NEPA ROAD S/S2	17/09/2023	0.375	97.66
OLD RING ROAD S/S5	04/02/2023	0.625	67.66
PETER UBOH S/S4	17/09/2023	0.625	97.66
PORT HARCOURT STR S/S	17/09/2023	0.625	97.66
S/S4	17/09/2023	0.375	97.66
SILAS UDO S/S	30/01/2023	0.062	97.66
SLOT 10 S/S	17/09/2023	0.062	77.72
TANTALISER S/S	17/09/2023	0.062	67.72
UDO STR S/S 1	17/09/2023	0.062	87.77
UDO UDOETOR S/S	17/09/2023	0.375	67.66
UMOH OBOT S/S	17/09/2023	0	77.78
WATER BOARD S/S4	02/02/2023	0.375	47.66
WINNERS CHAPEL S/S	17/09/2023	0.375	97.66

3 | ETAP load flow

The algorithm flowchart for ETAP load flow analysis consists of several steps executed sequentially to determine the voltage magnitudes and phase angles at each bus in the power system. The algorithm starts with initialising the system parameters, such as the bus admittance matrix, the load data, and the generation data. Next, the algorithm iterates through each bus in the system and calculates the power injections and the voltage at each bus using the power flow equations. The fundamental power flow equations are based on Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL) and can be written as follows for a balanced three-phase system:

Nodal Equations (Polar Form): at each node (bus) 'i', the sum of the complex power injections equals the sum of the complex power withdrawals:

Where

$$\mathrm{Si} = \mathrm{Pi} + \mathrm{jQi} = \mathrm{Vi} * (\mathrm{Ii} * -\mathrm{Yi} * \mathrm{Vi}). \quad (1)$$

S_i Is the complex power injection at bus 'i', P_i and Q_i are the real and reactive power injections at bus 'i', V_i is the complex voltage magnitude at bus 'i', I_i is the complex current injection at bus 'i', YI is the complex admittance matrix for bus 'i', '*' denotes the complex conjugates.

$$S_i = P_i + jQi = V_i * (I_i * -Y_i * V_i). \quad (2)$$

where Si is the complex power injection at bus 'i', I_{ij} is the complex current flowing from bus 'i' to bus 'j', Y_{ij} is the complex admittance between bus 'i' and 'j', V_i and V_j are the complex voltage magnitudes at buses 'i' and 'j', respectively.

$$P_i = \sum_{j=1}^{N} V_i V_i \left(G_{ij} COS(\theta_i - \theta_j) + B_{ij} Sin(\theta_i - \theta_j)\right). \quad (3)$$

where P_i is the real power injection or consumption at node I, V_i is the voltage magnitude at node I, θ_i is the phase angle of the voltage at node i, N is the total number of nodes in the system, G_{ij} is the real part of the admittance between nodes i and j (conductance), B_{ij} is the imaginary part of the admittance between nodes i and j (susceptance). This work aims to conduct a comprehensive load flow analysis using ETAP for the Uyo IBB feeder and advance knowledge in this area. Electric power systems are complex networks that require careful analysis to ensure efficient and reliable operation. Load flow analysis is a crucial tool in power system planning and operation, as it helps determine the steady-state operating conditions of the system [9]. One widely used software tool for load flow analysis was ETAP, which utilises algorithmic power flow equations to calculate power flow through the system. A detailed methodology must be adopted to apply the ETAP algorithmic power flow equations for load flow analysis. The following detailed procedure outlines how to use ETAP for load flow analysis effectively:

I. Data input: the first step in conducting the load flow analysis using ETAP was to input the necessary data into the software. This included information such as the system topology, equipment ratings, load profiles, and generation schedules. Ensuring the data input is accurate and complete is essential to obtain reliable results.

II. Network modelling: once the data was inputted, the next step was to create a detailed model of the power system network in ETAP. This involved defining the system's buses, branches, transformers, generators, and loads. The accuracy of the network model is crucial for obtaining accurate load flow results.

III. Initialisation: after the network model was created, the system was initialised to establish the initial conditions for the load flow analysis. This included setting the initial voltage magnitudes and phase angles at each bus in the system. Proper initialisation ensured convergence of the load flow solution.

IV. Load flow calculation: with the data inputted, network modelled, and system initialised, the load flow analysis was performed using the ETAP software. The algorithmic power flow equations were solved iteratively to calculate the voltage magnitudes and phase angles at each bus, as well as the power flows through the system's branches. The load flow solution provided valuable insights into the operating conditions of the power system.

V. Analysis of results: the results were analysed to assess the system's performance once the load flow calculation was complete. This included evaluating voltage profiles, power flows, line losses, and system stability. System optimisation identified and addressed any violations of operating limits or constraints.

The aforementioned steps were adopted and illustrated on the algorithm flowchart in *Fig. 1*. This included Calculation of the bus admittance matrix, which represents the impedance between each pair of buses in the system, and convergence criteria, which determines when the algorithm has reached a solution, where the algorithm iterates through the power flow equations until the difference between the calculated and the actual power injections at each bus is within a specified tolerance.

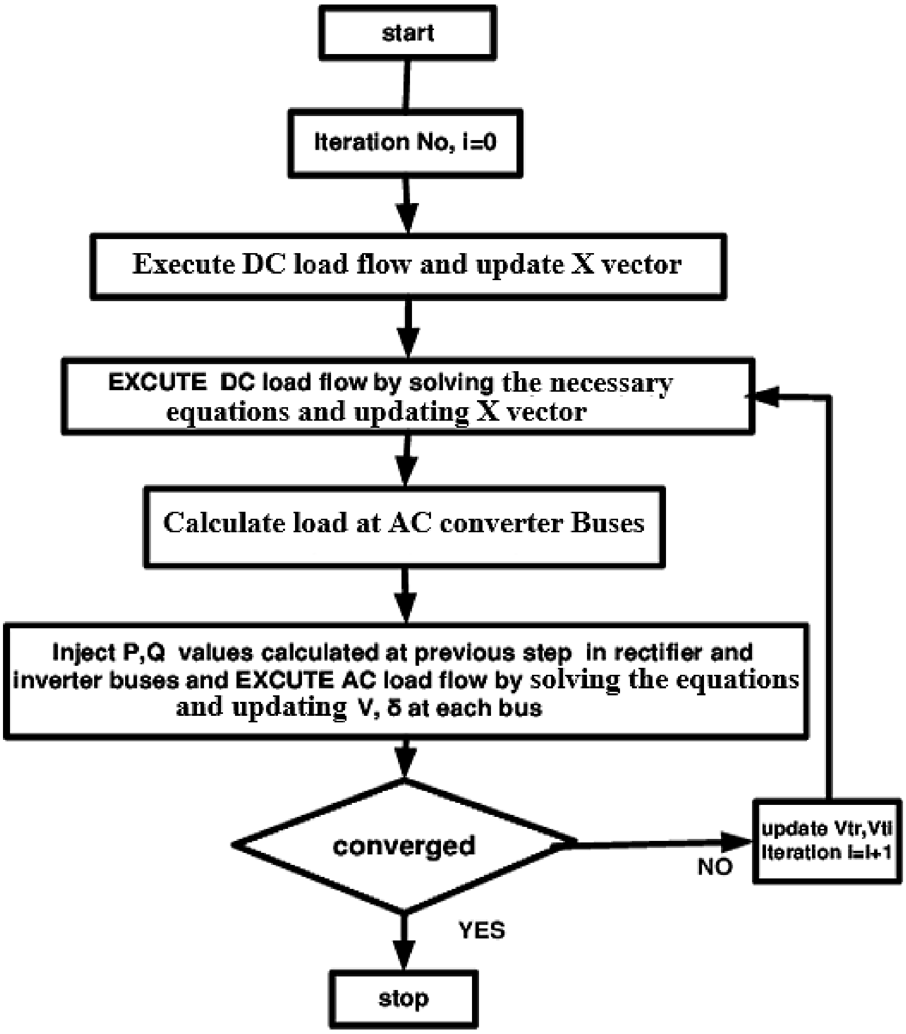
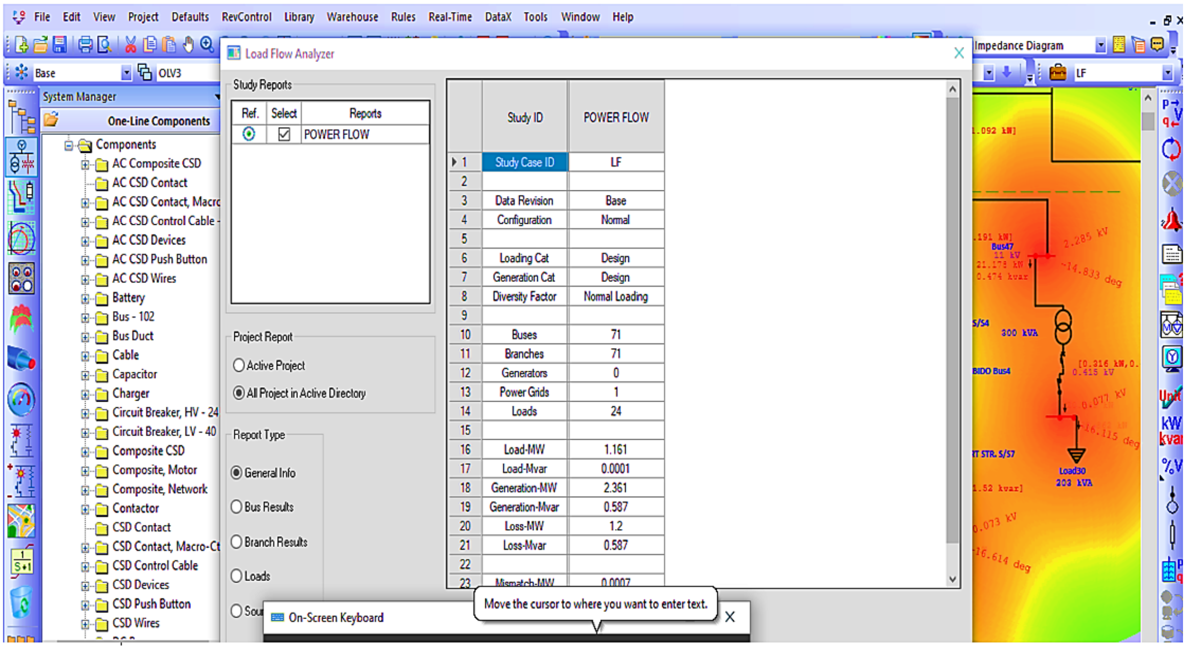


Fig. 1. Algorithm flowchart for ETAP load flow analysis.

The ETAP load flow program features an advanced graphical interface that presents results with precision. This includes calculations for voltage drop, load terminal voltage, branch losses, and transformer LTC settings [10]. Effortlessly and precisely generate and verify system models using ETAP's load flow analysis software. Simultaneously compute power flow for three-phase, single-phase, panel, and UPS systems. Key features of the load flow software include analysis of voltage loss and power flow. Power factor correction refers to improving an electrical system's power factor. Automated device assessment Automated temperature adjustment Actions of Load Tap Changer (LTC) in two-winding and three-winding transformers Actions of an automatic voltage regulator Power losses due to both resistance and reactance Comprehensive notifications and documentation of violations [11]. Analyse the results of a power flow analysis using many reports. Perform Load Flow analysis automatically in response to system modifications. A toolbar that allows for effortless changing and displaying of result units with a single click. Capabilities of Load Flow Software Simulation of power flow under various loading and generation situations. Automatically modify the transformer tap and LTC/voltage regulator configurations. Convergence parameters for load flow calculations modified by the user utilise the load flow result analyser to compare and evaluate numerous reports. Incorporate the impact of phase-shifting transformers. Visualise power flow results visually. Analyse instances of critical and marginal limit breaches. ETAP load flow profile employed in the load flow analysis



in this study is presented in *Fig. 2.*

Fig. 2. ETAP load flow profile

The purpose of the OPF problem is to maximise the steady state performance of a power system by optimising an objective function while ensuring that several equality and inequality constraints are met [12]. The OPF problem may be mathematically expressed in the following manner.

$$\mathrm{Min} J(x, u), \quad (4)$$

$$\text{Subject to: } g(x, u) = 0 h(x, u) \le 0. \quad (5)$$

Where x is the vector of dependent variables consisting of slack bus power P_{G1}, load bus voltage V_L, generator reactive power output Q_G and transmission line loading S_L

Hence, x can be expressed as

$$X^T = [P_{G1}, VL_1 \dots \dots V_{LNL}, Q_{G1} \dots \dots . Q_{GNG}, S_1. \quad (6)$$

The quick decoupled load flow approach involves dividing the vector of state variables into two separate parts:

$$X = [Vm\, ;\, Va]. \quad (7)$$

Where Vm is a vector of voltage magnitudes, and Va is a vector of voltage angles. The load flow equations are also split into two parts:

$$F(X) = [Fm(Vm, Va);\ Fa(Vm, Va)]. \quad (8)$$

Where $Fm(Vm, Va)$ is a vector of nonlinear equations representing the power balance equations for voltage magnitudes, and $Fa(Vm, Va)$ is a vector of nonlinear equations representing the power balance equations for voltage angles.

To linearise the equations, the method uses the Jacobian matrices, which are defined as the matrix of partial derivatives of the load flow equations with respect to the state variables:

$$Jm = \partial Fm(Vm, Va) / \partial X, \quad (9)$$

$$Ja = \partial Fa(Vm, Va) / \partial X. \quad (10)$$

Where Jm is the Jacobian matrix for voltage magnitude equations, and Ja is the Jacobian matrix for voltage angle equations.

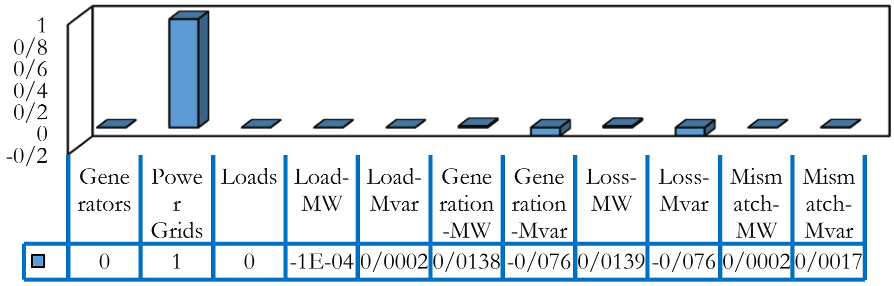
3.1 | Results and Discussion

One of the tools commonly used for power flow analysis is the ETAP, which provides detailed line diagrams to visualise the power flow in a system. A system operating under a no-load condition means no external load is connected to the system. The power flow analysis helps determine the system's voltage levels, current flows, and power losses in this scenario. The ETAP line diagram for IBB feeder lines provided a graphical representation of the system components, such as generators, transformers, transmission lines, and loads, along with the associated parameters. The IBB feeder lines of the ETAP line diagram for power flow analysis on a no-load condition provide valuable insights into the performance of the zone's electrical system.

Table 2. Parameters for power flow simulation analysis on no load condition.

Study Case ID	LF
Data Revision	Base
Configuration	Normal
Loading Cat	Design
Generation Cat	Design
Diversity Factor	Normal loading

ETAP software was used to analyse the power flow in a no-load condition. Using ETAP software, a simple power system with generators, transformers, and transmission lines was modelled. A power flow analysis was performed on the system under a no-load condition. The results showed the system's voltage profile, power losses, and reactive power flow. From the power flow simulation analysis in *Table 3*, 0.0139 Loss in Mega Watt was experienced, -0.076 Loss-Mvar, with a 0.0002 Mismatch in MW and 0.0017 Mismatch in Mvar were also obtained.



Simulation parameters

Fig. 3. Simulated result of power flow analysis on no load condition.

Table 4 shows the no-load condition of 0% at different voltage levels of the buses in the IBB Feeder Lines, Uyo Metropolis. The simulated results provided valuable insights into the behaviour of the power system under no-load conditions. The simulation process identified areas of high voltage drop, which could indicate potential issues in the system. The reactive power flow, essential for maintaining system stability, was also analysed. Overall, the power flow analysis on a no-load condition using ETAP software was a valuable exercise in understanding the behaviour of a power system. The simulated results provided valuable insights that can be used to optimise the system for better efficiency and reliability.

Table 4. Simulated results of load flow on no load condition in IBB feeder lines uyo metropolis.

Bus ID	Nominal kV	Voltage	MW Loading	% Loading
ABAK ROAD Bus46	11	100.5	0	0
ABAK ROAD FEED LINE Bus40	11	100.5	0	0
ATIKU	11	100.5	0	0
ATIKU Bus34	11	100.5	0	0
Bus1	132	100	0.0138	0
Bus2	132	100	0.0138	0
Bus3	11	100.51	0.0133	0
Bus4	132	100	0.0138	0
Bus5	33	100.03	0.0138	0
Bus6	11	100.06	0.0069	0
Bus8	11	100.06	0.0138	0
Bus9	11	100.5	0.0133	0
Bus10	11	98.74	0	0
Bus11	11	100.5	0	0
Bus12	11	76.01	0	0
Bus16	11	100.5	0	0
Bus18	11	100.5	0	0
Bus20	11	100.5	0	0
Bus21	11	100.5	0	0
Bus24	11	100.5	0	0
Bus25	11	100.5	0	0
Bus26	11	100.5	0	0
Bus27	11	100.5	0	0
Bus34	11	100.5	0	0
Bus36	11	100.5	0	0
Bus37	11	100.5	0	0
Bus38	11	100.5	0	0
Bus44	11	100.5	0	0
Bus47	11	100.5	0	0
Bus49	11	100.5	0	0
OLD RING ROAD Bus40	11	100.5	0	0
PETER UBOH Bus5	11	100.5	0	0
UDO UDOETOR BUS	11	100.5	0	0
UMOH OBOT S/S	11	76.01	0	0

The Gauss-Seidel method is an iterative technique used to solve a system of linear equations. The power flow equations are a set of nonlinear equations that represent the balance of power in the system, taking into account the power generation, transmission, and consumption. The Gauss-Seidel method works by iteratively updating the values of the unknown variables in the system until a convergence criterion is met [13]. The method is based on the principle of successive approximation, where each iteration brings the solution closer to the actual solution. *Table 5* shows iteratively the load flow analysis using the Gauss Siedel method on a 44-bus system where the transmission lines in buses 1, 2 and 4 operate on 132,000 kVA lines. The power generated in bus 2 stands at 0.014MW while Mvar was -0.076. The load flow in the buses varied between -0.007 and 0.014 MW, while the Mvar was between -0.03 and 0.076. The Gauss-Seidel method modelled the feeder line as a network of nodes and branches. The nodes represent the buses in the system, while the branches represent the transmission lines and transformers. The power flow equations were then formulated based on Kirchhoff's laws and the power balance equations at each node. The acronyms KV, % mag, Ang, MW, Mvar, AMP and %PM represent Kilovolt, voltage magnitude, Amperes, Megawatts, Megavolts, Amperes and power factor.

Table 5. Simulation result for Gauss Siedel method on a bus network systems.

ID	KV	% Mag	Ang	MW	Mvar	AMP	%PF
ABAK ROAD Bus 17	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
ABAK ROAD FEED LINE	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
ATIKU	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
ATIKU Bus 18	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
Bus 1	132.000	100.000	0.0	-0.014	0.076	0.3	-17.9
Bus 2	132.000	100.000	0.0	0.014	-0.076	0.3	-17.9
Bus 3	11.000	100.513	-0.4	0.01	-0.03	1.6	-31.8
Bus 4	132.000	100.030	0.0	-0.013	0.072	3.8	-18.2
Bus 5	33.000	100.497	-0.4	0.003	-0.042	2.2	-7.7
Bus 6	132.000	100.000	0.0	0.014	-0.076	0.3	-17.9
Bus 7	33.000	100.030	0.0	0.007	-0.038	0.7	-17.9
Bus 8	132.000	100.055	0.0	0.007	-0.038	0.7	-17.9
Bus 9	11.000	100.030	-0.4	-0.014	0.076	1.3	-17.9
Bus 10	11.000	100.055	0.0	-0.007	0.038	1.9	-17.9
Bus 11	33.000	100.496	-0.4	0.007	-0.038	1.8	-17.9
Bus 12	11.000	100.055	0.0	0.014	-0.076	3.8	-17.9
Bus 13	33.000	100.496	0.0	-0.007	0.038	1.9	-17.9
Bus 14	132.000	100.030	-0.4	-0.007	0.038	1.9	-17.9
Bus 15	11.000	100.496	-0.4	-0.013	0.073	3.8	-17.9
Bus 16	33.000	100.055	-0.4	0.013	-0.073	3.7	-18.1

The Newton-Raphson method is a widely used numerical technique for solving load flow equations in power systems. The Newton-Raphson method is an iterative technique used to solve nonlinear equations. These equations are typically nonlinear and involve complex relationships between voltage magnitudes, phase angles, and power injections at various nodes in the system. This method iteratively updates the voltage magnitudes and phase angles at each node in the system until a set of equations is satisfied within a specified tolerance. Table 6 shows the load flow analysis iteratively using the Newton Raphsons method on a 44-bus system where all the transmission lines on all the buses operate 11 kVA lines. The voltage magnitude on buses 10 and 12 were 98.744% and 76.014%, respectively, while other buses worked at 100.497. This iterative process allowed the analysis of different operating conditions and identified potential issues in the power distribution feeder line of the IBB Uyo zone. The Newton-Raphson method accurately modelled the flow of power in the IBB Uyo feeder line, optimised its operation and ensured the reliability of the power system. Applying the Newton-Raphson method in load flow analysis was essential for maintaining the stability and efficiency of power distribution systems.

Table 6. Simulation result for Newton Raphson method on a bus network systems.

ID	kV	% Mag.	Ang.	MW	Mvar	AMP	%PF
Bus 10	11.000	98.744	-0.4	0.000	0.000	0.0	0.0
Bus 11	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
Bus 12	11.000	76.014	-45.2	0.000	0.000	0.0	0.0
Bus 13	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
Bus 16	11.000	100.496	-0.4	-0.014	0.076	0.4	-17.9
Bus 17	11.000	100.496	-0.4	0.014	-0.072	0.5	-17.9
Bus 18	11.000	100.496	-0.4	0.01	-0.03	1.9	-31.8
Bus 20	11.000	100.496	-0.4	-0.013	0.074	3.7	-18.2
Bus 21	11.000	100.497	-0.4	0.003	-0.048	2.3	-7.7
Bus 24	11.000	100.496	-0.4	0.014	-0.076	0.3	-17.9
Bus 25	11.000	100.497	-0.4	0.007	-0.038	0.8	-17.9

Table 6. Contiued.

ID	kV	% Mag.	Ang.	MW	Mvar	AMP	%PF
Bus 26	11.000	100.496	-0.4	0.007	-0.038	0.7	-18.3
Bus 27	11.000	100.496	-0.4	-0.014	0.076	1.5	-17.9
Bus 34	11.000	100.497	-0.4	-0.007	0.038	2.2	-17.7
Bus 35	11.000	100.497	-0.4	0.007	-0.038	2.4	-17.9
Bus 36	11.000	100.497	-0.4	0.014	-0.076	3.7	-17.9
Bus 37	11.000	100.497	-0.4	-0.007	0.038	2.1	-18.1

One of the methods used for load flow analysis is the fast decouple method, which is known for its efficiency and accuracy in solving power flow equations for distribution feeder lines. The fast decoupling method is based on decoupling the power flow equations into two sets of equations: real power flow equations and reactive power flow equations. By decoupling these equations, the computational complexity of solving the power flow equations is significantly reduced, leading to faster convergence and improved computational efficiency. As shown in *Table 7*, the 11kV transmission lines run all the buses, and their voltages, power generation, load, and load flows of all the buses in the system had the same parametric values except for Umoh Obot street s/s Bus 16, whose voltage magnitude dropped to 76.014% with Ang of -45.2%. One key advantage of the fast decoupling method is its ability to handle unbalanced systems, common in distribution feeder lines due to single-phase loads and unbalanced distribution transformers. The process can accurately model the unbalanced nature of the system and provide accurate results for both balanced and unbalanced conditions.

Table 7. Simulation result for fast decouple method on a bus network system.

ID	kV	% Mag.	Ang.	MW	Mvar	AMP	%PF
Bus 38	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
Bus 39	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
Bus 41	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
Bus 44	11.000	100.497	-0.4	0.000	0.000	0.0	0.0
Bus 45	11.000	100.497	-0.4	-0.014	0.076	0.3	-17.7
Bus 47	11.000	100.497	-0.4	0.014	-0.076	0.3	-17.9
Bus 49	11.000	100.497	-0.4	0.01	-0.03	1.6	-31.8
Bus 54	11.000	100.497	-0.4	-0.013	0.072	3.8	-18.2
IBOKO Bus 54	11.000	100.497	-0.4	0.003	-0.042	2.2	-7.7
OLD RING ROAD Bus 40	11.000	100.497	-0.4	0.014	-0.076	0.3	-17.7
PETER UBOH Bus 5	11.000	100.497	-0.4	0.007	-0.038	0.7	-18.2
UDO UDOETOR BUS	11.000	100.497	-0.4	0.007	-0.038	0.7	-18.1
UMOH OBOT S/S Bus 16	11.000	76.014	-45.2	-0.014	0.076	1.3	-17.9
WATER BOARD	11.000	100.497	-0.4	-0.007	0.038	2	-17.5
WINNERS CHAPEL 47	11.000	100.497	-0.4	0.007	-0.038	2	-17.9

4 | Conclusion

The OPF analysis of Uyo Zone 002 using the Gauss-Seidel method, Newton-Raphson method, and fast decoupled method in ETAP software has provided valuable insights into the region's power system operation and management. The Gauss-Seidel method, although computationally less intensive, may converge slowly and may not always guarantee convergence. On the other hand, the Newton-Raphson method is more robust and converges faster. Still, it requires the calculation of Jacobian matrices, which can be computationally expensive for large power systems. The fast decoupled method balances computational efficiency and accuracy, making it a popular real-time power system analysis choice. It simplifies the power flow equations by neglecting specific terms, which may lead to some loss of accuracy but significantly reduces computational burden. However, the choice of method for OPF analysis in Uyo Zone 002 will depend on the specific requirements of the study, such as computational resources, accuracy, and convergence speed. Researchers and practitioners in power system analysis should carefully consider these factors when selecting an appropriate study method. Further research could focus on comparing the performance of these methods in other power system scenarios or exploring hybrid approaches that combine the strengths of multiple methods. The efficient and reliable operation of power systems in Uyo Zone 002 can be ensured by continuously improving and refining conventional analytical techniques.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest regarding the publications of this paper.

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