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Comparative Load Flow Analysis on a 33kv Distribution Network

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ABSTRACT

A power system's most important and fundamental tool is load flow analysis. Most commercial power systems are too complicated to solve manually. Likewise, because of the power stream condition which is nonlinear, more calculation time were required and become confounded as the quantity of transport expansion in transport frameworks. Power flow solution iterative methods simulation can be used to improvise this. Using the ETAP (Electrical Transient Analyzer Program) software, a simulated iterative algorithm for resolving power flow equations was created. The study's objectives are to discover the distribution network's load flow solution, or system losses; to compare the time elapsed, real power losses, power mismatch, reactive power losses and load flow analysis using Newton Raphson, Gauss-Seidel, and Fast Decoupled method. The Port Harcourt zone 4 distribution network was tested by three different methods based on the results from the three, Fast Decoupled method required less number of iterations compared to Newton Raphson and Gauss-Seidels methods. All three iterative algorithms were successful to give the load flow solution for the Distribution system.

Keywords: *load flow analysis, real power loss, power mismatch, reactive power loss, Newton Raphson, Gauss-Seidel, fast decoupled methods, ETAP*

INTRODUCTION

When looking into issues with the operation and planning of power systems, load flow analysis is the most important method. Load flow analysis is executed to find the sensitivity of feeder status with variation of power loading, conductor length, and total capacity of distribution transformers. The purpose of load flow studies is to guarantee that the grid system's transfer of electrical power from generators to consumers is stable, dependable, and cost-effective [10].

It is helpful in determining the best location for the proposed generating station, substation, and new lines as well as their maximum capacity. [2]. The importance of power flow studies in electrical power systems cannot be over-emphasized as both power system engineers and researchers depend on its outcome to know the true state of the system under investigation [12].

Fundamentally, load flow analysis involves determination or solution of the power network where the bus voltages, angles or power flows (real and reactive powers) are unknown or presumed to be unknown. Load flow solution is a solution of the network under steady state condition subject to certain inequality constraints under which the system operates such as, load nodal voltages, reactive power generation of the generators, tap setting of a tap changing transformer under load transformer [3].

There are two main types of buses, i.e., load and generator buses. A special type of generator bus is used as reference bus and

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is named as slack bus. For different types of buses, the constraints are different [7]. Load flow analysis is restricted to the bulk power transmission portion of the transmission system.

Load flow calculations are required as part of generation dispatch to ensure that lines are not overloaded. Optimal load flow calculation should take into account transmission and distribution system losses, so it is important to understand how electric power flows through wires, transmission lines, and other electrical components that make up an electrical power system. [11].

For distribution systems, the power flow analysis is a very important and fundamental tool. Its results play a major role during the operational stages of any system for its control and economic schedule, as well as during expansion and design stages. The purpose of any load flow analysis is to compute precise steady-state voltages and voltage angles of all buses in the network, the real and reactive power flows into every line and transformer, under the assumption of known generation and load [9].

Although we can easily calculate voltage and current through branches of small direct (D.C) circuits in terms of each other, even a small network of a handful of A.C. power sources and load defy our ability to write down formulas for the relationship. We can only get at a numerical answer through the process of successive approximation or iteration. To find out what the voltage or current at any given point will be, we must as a result simulate the entire system.

Historically, such simulations were accomplished through an actual miniature D.C model of power in use. Generators were represented by small D.C power supplies, loads by resistors, and transmission lines by approximately sized wires. The voltage and current can then be found by direct measurement to know how much current on line a will increase. The D.C model does not exactly match the behavior of the A.C. the system, but it gives an approximation that is close enough for practical use. In the age of computers there is no longer a need to build physical models anymore, but instead create them mathematically [5].

During the second half of the twentieth century, and after the large technological developments in the fields of digital computers and high-level programming languages, many methods for solving the load flow problem have been developed, such as Gauss-Seidel (bus impedance matrix), Newton-Raphson‘s (NR) and its decoupled versions.

Nowadays, many improvements have been added to all these methods involving assumptions and approximations of the transmission lines and bus data, based on real systems conditions. Load flow studies are important in the planning, operation, and future expansion of power systems. For a particular load condition, the study provides steady-state solutions to the voltages at all the buses.

For various operating conditions, various steady-state solutions can be obtained to aid in planning, design, and operation, economic scheduling, and exchange of power between utilities.

Load flow analysis is to find the magnitude and phase angle of voltage at each bus and real and reactive power in each transmission line.

The load flow problem consists of finding the power flow (real and reactive) and voltages of a network for a given bus condition. Because of the non-linearity of the algebraic equations, describing the

given power system, their solutions are obviously, based on the iterative methods only [9].

LITERATURE REVIEW

[10] Conducted load flow analysis using Newton Raphson method using a case study of South-West Nigeria 330KV Network Using the NR application in the MATLAB environment, the load flow of a small area with six bus-bars was carried out.

The case study's data served as the system's input. The six buses' voltage profiles remain within acceptable limits, indicating that there is no divergence when employing the NR method in this instance. A reasonable loss coefficient matrix could also be found using the load flow solution.

[3] Conducted a study on the application of neuro-swarm intelligence techniques to load flow analysis. Test was conducted on the Diobu PHEDC 4-bus system using Neuro-Swarm algorithm and the result showed good performance with less computational time and divergence mostly in heavy loading conditions.

The results were validated by comparing them with that of Particle Swarm Optimization (PSO). The results showed better performance of N euro-Swarm Intelligence in terms of flexibility, number of control parameters, computational time and number of iterations.

[12] Proposed cascaded swarm intelligence algorithm for automated power flow studies. power flow in the steady state domain was well-thought-out with the goal of analyzing the state of a 4-bus 33kv distribution network. Results at various per unit base values proved automated with less computational time with better convergence.

[2] Carried out a study on power flow analysis using NR method. Three (3) bus system was analyzed by using NR method. The main objective of this study is to is to develop a MATLAB program to calculate voltages, active and reactive power and losses at each bus for 3 bus systems.

[7] conducted a study on result analysis on load flow by using Newton Raphson method the study reveals the electrical performance and power flows (real and reactive) for specified condition when the system is operating under steady state. It also gave an overview of different techniques used for load flow analysis results by using NR.

[4] Carried out a comparative study on the UNILAG distribution network, it proposed that for the Gauss Seidel method, the number of iterations increases directly as the number of buses of the network while that of Newton Raphson method is independent of the system size. It is finally concluded that for the large distribution network, the Newton Raphson method is faster and more reliable.

[13] Proposed a modified Gauss-Seidel method, by blending the implicit Zbus method and the Gauss-Seidel method to improve the computational efficiency. This technique which factorizes the three submatrices of the Y-framework rather than the entire Y-grid, works productively with outspread, pitifully fit and circled networks

[8] conducted load flow analysis using Gauss-Seidel method, it was concluded that Gauss-Seidel method can provide control of voltage magnitude and their angle. It can also be utilized to effectively increase power transfer capability of an existing power in transmission lines, reduce operational and investment costs.

[14] Demonstrated that the Newton-Raphson or the Gauss Seidel methods are conventional techniques for solving the load flow problem. With the load flow studies, the voltage magnitudes and phase angles can be ascertained at each bus in the steady state and can be computed within a specified limit.

[1] carried out analysis, design, and comparison of various load flow system solving methods, including the Newton-Raphson Method and the Gauss-Seidel Method, using MATLAB in the Power System. The analysis was done and observed, the desired result was achieved.

[9] carried and analysis for Electrical load flow studies in Port Harcourt, Nigeria, using Newton Raphson fast Decoupled Techniques. From the result obtained from the simulation on each feeder will aid the system engineer during operation and future expansion of the network under consideration.

MATERIALS AND METHODS

Materials used in this research work are; single line diagram of Port Harcourt Zone 4 33kV distribution network, ETAP software and a computer system. ETAP software is used for comparison/validation. The Port Harcourt Town 33KV Feeder. The network was modeled in Electrical Transient Analyzer program (ETAP software) for simulation purposes for comparison between the Newton-Raphson, Gauss Seidel and Fast decoupled methods.

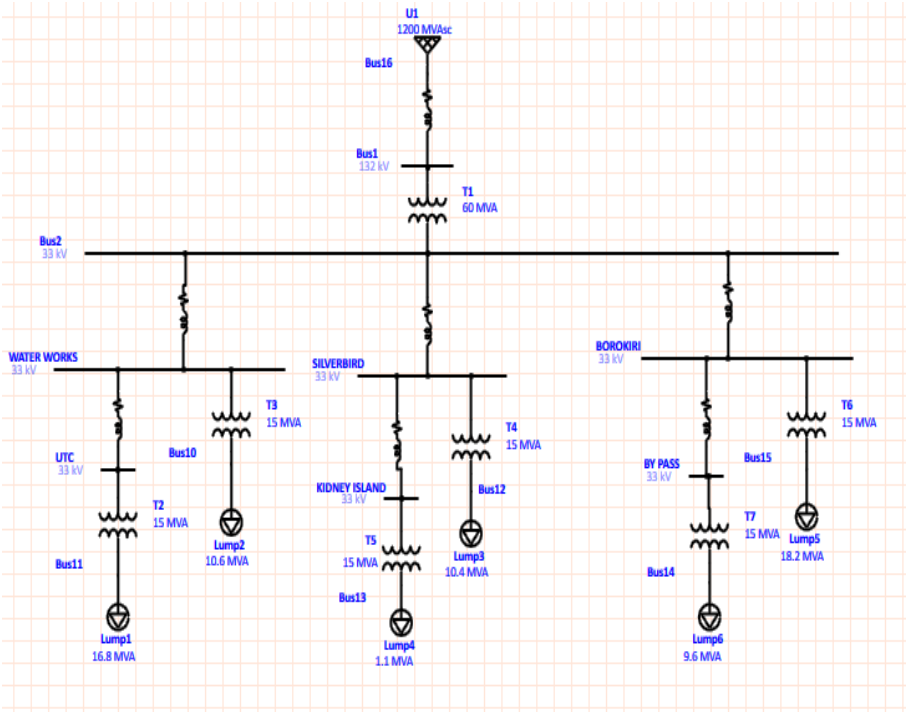


Fig. 1: *ETAP Presentation of PHEDC 33KV Network Schematic for Port Harcourt Zone 4.*

Methods of Load Flow Calculations

The most important load flow methods are categorized as: Gauss-Siedel method, Newton-Raphson method and Fast Decoupled method.

Newton-Raphson Method

Newton-Raphson method is an iterative method which approximates the set of non-linear equations using Taylor's series expansion and the terms are restricted to the first order approximation. This method is one of the most popular procedures for solving these power flow equations.

$$P_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \cos(\theta_{ki} + \delta_{ik}) \quad (1)$$
$$Q_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \sin(\theta_{ki} + \delta_{ik}) \quad (2)$$

Where:
n =total number of buses in the system
Pi and Qi =specified active and reactive demand at load bus i
Yik= element of line conductance
Vi = bus voltage at bus i
Vj = bus voltage at bus j
θi, θj = bus voltage angle
δij= load angle

Gauss Seidel Method
Gauss Seidel is another method of solving a non-linear equation. The principle of this method is rather simple. It is used for solving the equation of the form:

$$I_i = Y_{i1} V_1 + Y_{i2} V_2 + .. + Y_{ik} V_K \quad (3)$$

Also
$$I_i = \sum_{i,k=1}^{n} Y_{ik} V_k \quad (4)$$

Complex power injected into the ith bus is given as
$$S_i = V_i I_i^* = P_i + jQ_i \quad (5)$$

Substituting (3.2) into (3.3)
$$P_i - jQ_i = V_i^* \sum_{i,k=1}^{n} Y_{ik} V_k \quad (6)$$

Let V_k and V_{ik} be
$$V_k = V_K \angle \delta_k \quad \text{(voltage at the bus k)} \quad (7)$$
$$Y_{ik} = Y_{ik} \angle \theta_{ik} \quad \text{(admittance between bus i and bus k)} \quad (8)$$

Substitute equations (3.5) and (3.6) into equation (3.4)
$$P_i - jQ_i = V_i \sum_{k=1}^{n} V_{ik} V_i \angle(\delta_k + \theta_{ik} - \delta_i) \quad (9)$$
$$P_i - jQ_i = V_i \sum_{k=1}^{n} |V_{ik}||V_i||V_k|[\cos(\delta_k + \theta_{ik} - \delta_i) + \mathrm{j}\sin(\delta_k + \theta_{ik} - \delta_i)] \quad (10)$$

Separating the real and imaginary part
Real power
$$P_i - jQ_i = V_i \sum_{k=1}^{n} |V_{ik}||V_i||V_k|[\cos(\delta_k + \theta_{ik} - \delta_i)] \quad (11)$$

Reactive power
$$P_i - jQ_i = V_i \sum_{k=1}^{n} |V_{ik}||V_i||V_k|[\sin(\delta_k + \theta_{ik} - \delta_i)] \quad (12)$$

Fast Decoupled Method
In Fast Decoupled Load Flow method, the convergence is geometric, 2 to 5 iterations are normally required for practical accuracies, speed for iterations of the FDLF is nearly five times that of NR method or about two-thirds that of the GS method.

Here Bii -Imaginary part of diagonal elements of Ybus, Bij - Imaginary part of off-diagonal elements of Ybus, θii-Angle of Yii element of Ybus, B' -Imaginary part of Ybus of order (n-1) x (n-1), B''- Imaginary part of Ybus of order (n-1-npv) x (n-1-npv).

The diagonal element of J_1.

$$\frac{\partial \delta_i}{\partial \delta_i} \sum_{j=1}^{n} |V_i||V_J||V_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) - |V_i|^2|Y_{ii}|sin\theta_{ii} \quad (13)$$

$$\frac{\partial \delta_i}{\partial \delta_i} = -Q_i - |V_i|^2|Y_{ii}| \sin\theta_{ii} \quad (14)$$

$$\frac{\partial \delta_i}{\partial \delta_i} = -Q_i - |V_i|^2 B_{ii} \quad (15)$$

$$B_{ii} >> Q_i \; and \; |V_i|^2 \approx |V_{ii}| \quad (16)$$

$$\frac{\partial \delta_i}{\partial \delta_i} = -|V_i|B_{ii} \quad (17)$$

Similarly the diagonal elements of j4 is represented

$$\frac{\partial \delta_i}{\partial \delta_i} \sum_{j=1}^{n} |V_i||V_J||V_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) - |V_i||Y_{ii}|sin\theta_{ii} \quad (18)$$

$$\frac{\partial \delta_i}{\partial \delta_i} = Q_i - |V_i||Y_{ii}| \sin\theta_{ii} \quad (19)$$

Since $B_{ii} = |Y_{ii}|sin\theta_{ii} >> Q_i$

$$\frac{\partial \delta_i}{\partial \delta_i} = -|V_i|B_{ii} \quad (20)$$

Equation 3.19 can be represented as

$$\frac{\partial \delta_i}{\partial |V_j|} = -|V_i|B_{ij} \quad (21)$$

With these assumptions the equation becomes

$$\frac{\Delta P}{|V_i|} = -B'\Delta\delta \quad (22)$$

$$\frac{\Delta Q}{|V_i|} = -B'\Delta|V| \quad (23)$$

The value of the voltage angle $(\Delta\delta)\; and\; \Delta|V|$ is obtained by

$$\Delta\delta = -[B']\frac{\Delta P}{|V|} \quad (24)$$

$$\Delta|V| = -[B']\frac{\Delta Q}{|V|} \quad (25)$$

RESULTS

This provides a comparative study on Load flow Analysis Methods, all the results after conducting a power flow analysis simulation.

According to that Gauss Seidel, Newton Raphson, and Depending on the type of testing, the maximum power mismatch, the time elapsed, and line losses for real power (MW) and reactive power (MVar) were examples of fast decoupled methods.

The various buses are shown in Table-1. It shows the voltage and load demand from all three Load Flow Analysis methods.

Table 1: *Bus and Load Results.*

			Fast Decoupled			Newton Raphson			Gauss Seidel		
S/N	BUS ID	kV	Voltage	Load		Voltage	Load		Voltage	Load	
			%	kW	kvar	%	kW	kvar	%	kW	kvar
	Borokiri	33kV	92.63	22691.7	16326.6	92.63	22691.4	16326.6	92.81	22717.5	16332.1
	By Pass	33kV	92.55	7868.2	5352.5	92.55	7868.1	5352.5	92.72	7873.4	5357.2
	Kideny Island	33kV	92.94	908.8	569.2	92.94	908.8	569.2	92.95	916.3	569.2
	Silver Bird	33kV	92.95	9440.4	6413.1	92.95	9440.4	6413.1	92.96	9448.4	6412.6
	UTC	33kV	92.64	13694.3	9995.6	92.64	13694.1	9995.6	92.65	13702.1	9995.7
	Water Works	33kV	92.8	22401.3	15986.1	92.8	22401.1	15986.1	92.81	22409.5	15985.7

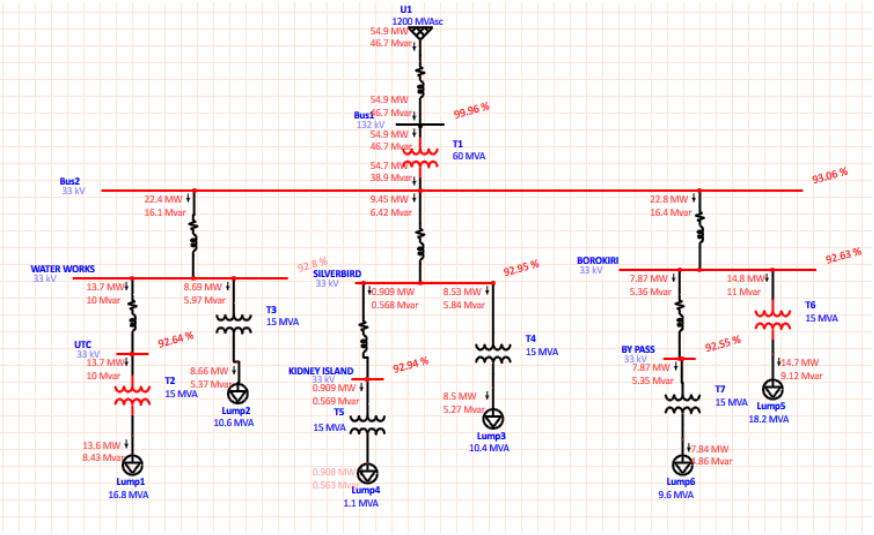


Fig. 2: *Newton Raphson Load Flow Analysis.*

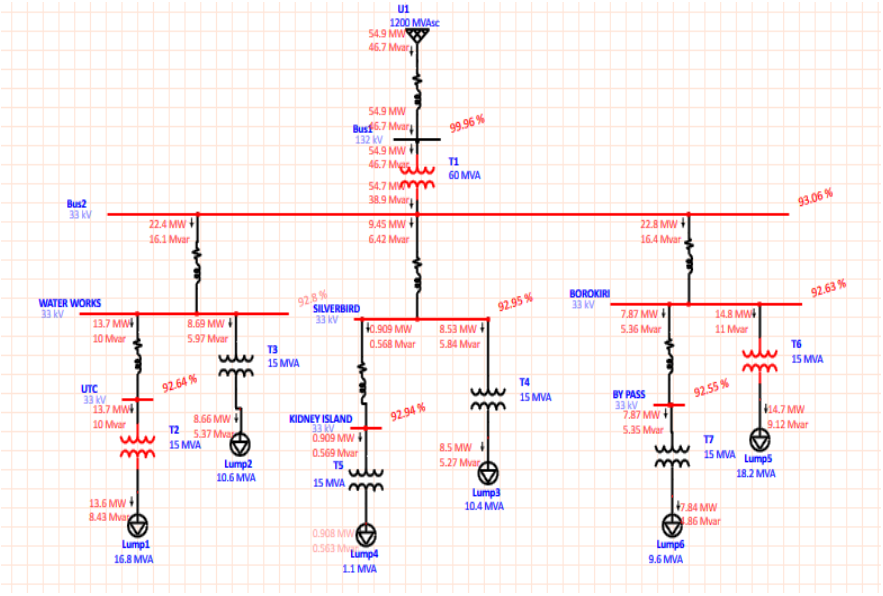


Fig. 3: *Fast Decoupled Load Flow Analysis.*

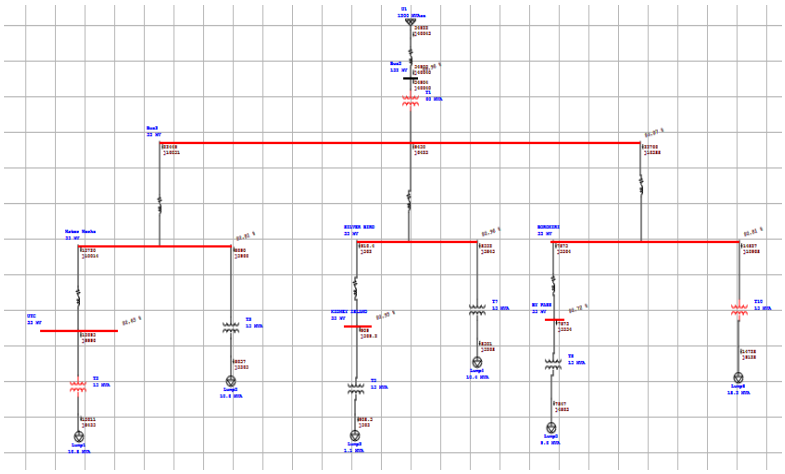


Fig. 4: *Gauss Seidel Load Flow Analysis.*

Comparative Results of the Three Load Flow Analysis Methods

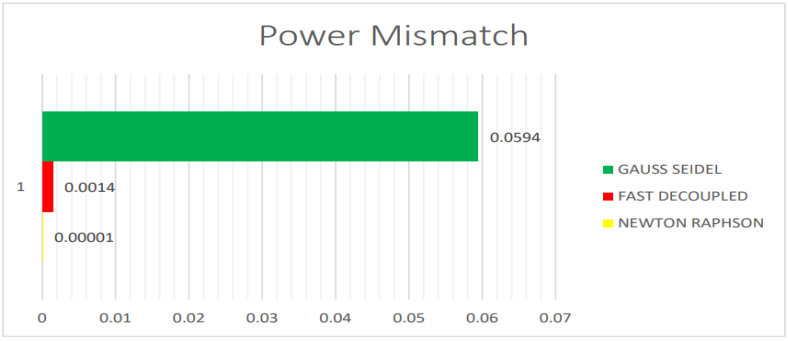


Fig. 5: *Comparison between Power Mismatch.*

Fig-5 shows the maximum power mismatch for the Port Harcourt Zone 4 system using three different methods. Based on graph illustration related to the experiment result shows that the Newton Raphson method is more sufficient to diminish the power mismatch when compare with Gauss Seidel and Fast Decoupled methods, this situation arises due to the impedance mismatch in output.

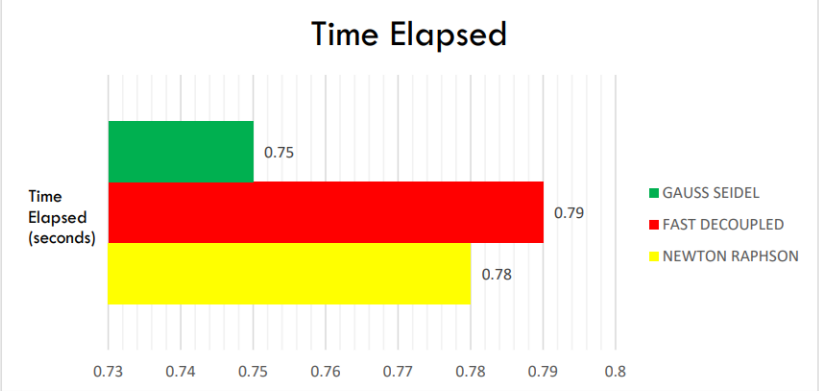


Fig. 6: *Comparison between Time Elapsed.*

Fig-6 shows the time taken to complete the process of formulation to get the output by using three different numerical methods respectively using the Port Harcourt zone 4 system. Based on the analysis the graph shows that the Gauss Seidels method processes faster at 0.75s to develop the output solution. Compare to the Fast Decoupled methods slight delay of 0.78s. Moreover, Newton Raphson method takes slightly more time 0.79s than Gauss Seidel and Fast Decoupled methods to develop the total process of simulation.

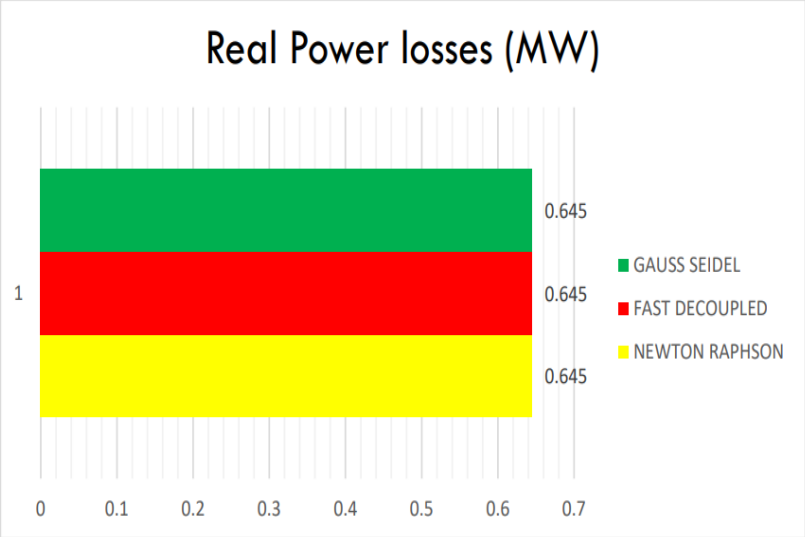


Fig. 7: *Comparison of Real Power losses (MW).*

Fig-7 shows the real power losses of the Port Harcourt zone 4 system, based on the graph the three different numerical methods which are Gauss Seidel, Newton Raphson and Fast Decoupled Method as shown in the graph all approximately effectively ascertains the losses in the system.

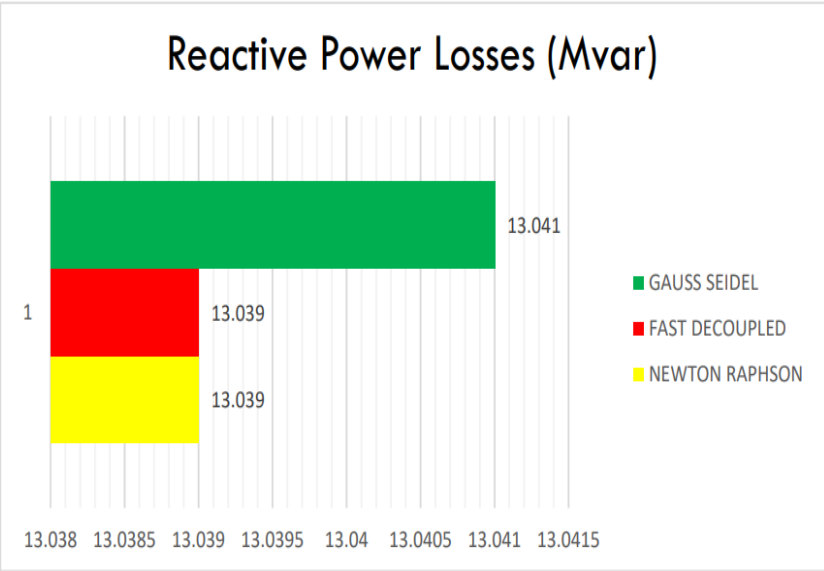


Fig. 8: *Comparative between Reactive Power losses (MVar).*

Fig-8 shows the total reactive power (MVar) losses for the the Port Harcourt zone 4 system. The outcome shows that the Gauss Seidels method is more effective to bring out the precise reactive power losses. Moreover, the Fast Decoupled and Newton Raphson methods were slightly less effective and had a different of 0.002 MVar. Comprehensively the Gauss Seidels method appropriately and effectively ascertain the losses in the system.

CONCLUSION

The key aspect discussed an analysis of numerical methods which is done by, the use of the Port Harcourt zone 4 bus network to compare the performance which execute from the simulation. Based on that, in term number of iterations that took to converge, Fast decoupled method shows an exceptional output, because it needs fewer iterations to accomplish load flow analysis when compared other two methods.

Comparatively, the time taken to process the simulation for each method shows, the Gauss Seidels is more effective to execute the output of the Port Harcourt zone 4 bus network faster than the other methods discussed in this paper. It is also shown that Gauss Seidels method is more effective in showing reactive power losses, while all three methods according to the research can effectively show real power losses.

APPENDIX 1

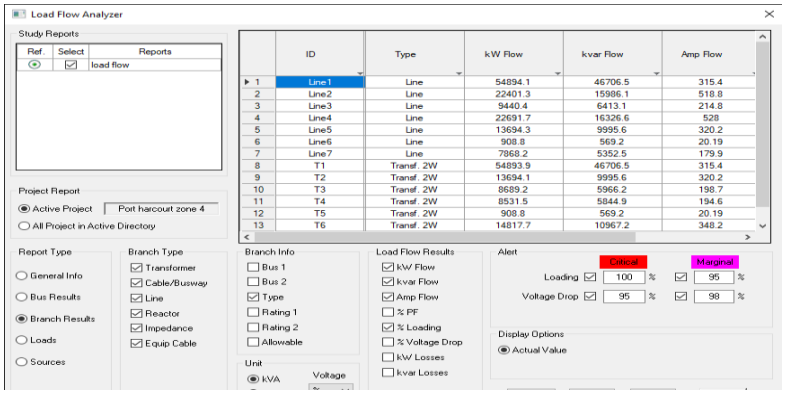


Fig. 9: *Newton Raphson Branch Flow Results.*

The efficiency of the Newton Raphson method is tested on the Port Harcourt power distribution network. Fig-9. The essence of this is to provide information that would help in identifying the points at which losses compensation would be required.

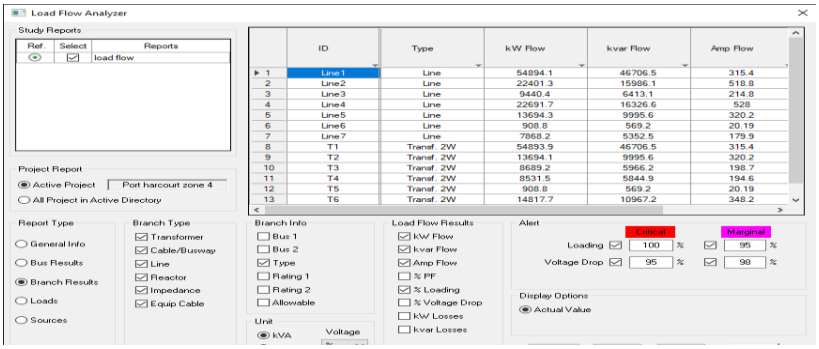


Fig. 10: *Fast Decoupled Branch Flow Results.*

From Fig-10 it is evident that the Fast-Decoupled branch flow results are the same with the Newton Raphson results.

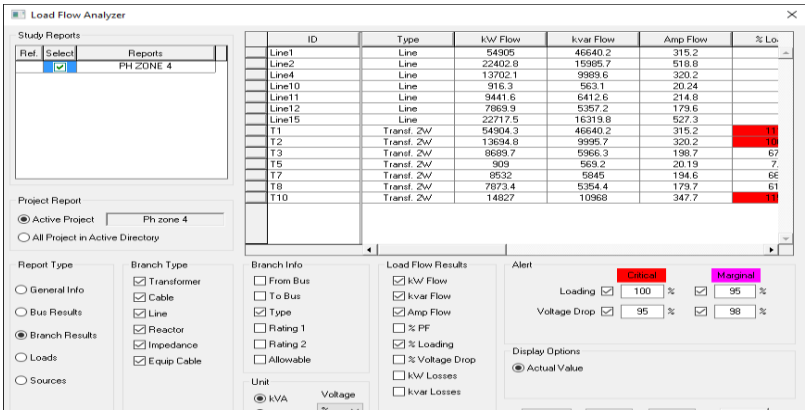


Fig. 11: *Gauss Seidel Branch Flow Results.*

From Fig-11, it is shown that the Gauss Seidel branch flow results are different from the Newton Raphson and Fast Decoupled results.

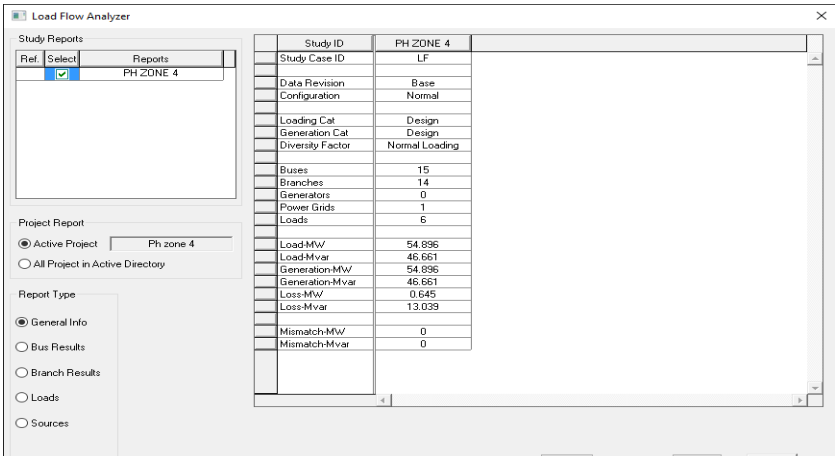


Fig. 12: *Newton Rapson Load Flow Analysis Result.*

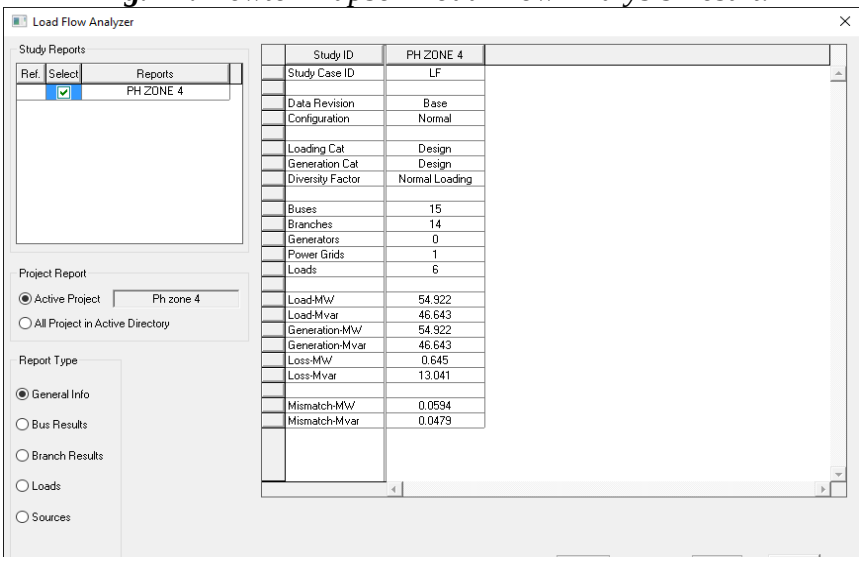


Fig. 13: *Gauss Seidel Load Flow Analysis Results.*

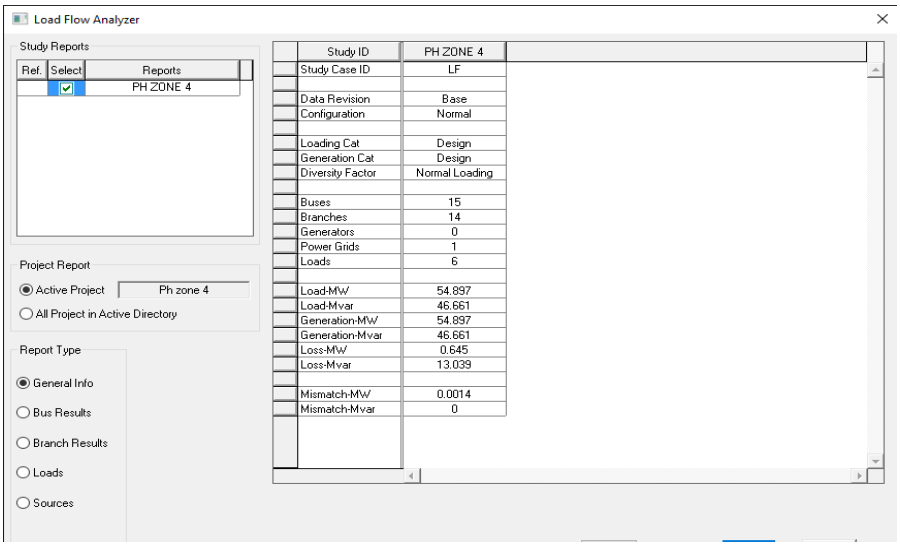


Fig. 14: *Fast Decoupled Load Flow Analysis Results.*

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