A Novel Comparison of Gauss–Seidel and Newton–Raphson Methods for Load Flow Analysis

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***Abstract*—All over the world, several methods of power flow analysis are used, namely Gauss-Seidel, Newton Raphson, Fast Decoupled Load Flow methods because power flow analysis is a critical factor for proper planning of power generating scheduling economically and calculation of power loss, bus voltage, angle. In this work, an operational comparison between Gauss-Seidel and Newton Raphson method is depicted using MATLAB simulation software for a 4–Bus system. By following the obtained values, it is prominent that Gauss Seidel follows the linear convergence whereas Newton Raphson exhibits the quadratic convergence. The selection of slack bus affects the Gauss-Seidel convergence adversely but for Newton-Raphson has minimal sensitivity towards this selection. While going through the simulation, it is lucid that Gauss-Seidel is comprehensible and reliable for small systems which are antithesis for Newton Raphson Method because repetitive computation of Jacobian makes it complicated.**

Keywords—steady state flow equations; Gauss–Seidel method; Newton–Raphson method; bus voltage magnitude; bus voltage angle; MATLAB simulation; mathematical computation

I. INTRODUCTION

In the present day, the power system network is extremely intricate comprising of hundreds of buses and transmission links. Hence, the load flow study necessitates considerable calculations. Power flow studies provide a schematic mathematical approach for determination of various bus voltages, their phase angles, active and reactive power flow through different branches, generators and loads under steady state conditions. For power flow study, some data has to be collected about the system which will aid to determine the possible future improvement of the system. So, for that some steps [1] are followed which are:

1) A single line diagram of the system is drawn.
2) Assuming a balanced three phase system, the transmission system is represented by its positive phase sequence network of linear lumped series and shunt branches. The line impedance and shunt admittance are then determined per unit values, including transformer impedances, shunt capacitor ratings and transformer tapping.
3) Using nodal analysis, node self and mutual admittances are resolved.
4) The shunt capacitance and per unit reactance and resistance between terminating buses of the lines are determined.
5) The operating conditions are chosen. The static operating state of the system is then specified by the constraints on power and/or voltage at the network buses.

Now the Load flow is needed to be run for the following cases:

1) In the power system designing;
2) In addition or outrage of transmission lines or other equipment;
3) When a new load center is built or when the network remains unaltered but load extends;

A complex power flow (or load flow) solution should have the following solution properties:

1) High computational speed;
2) Simplicity of the program;
3) Flexibility of the program;
4) Low computer storage;
5) Reliability of solution.

II. STEADY STATE LOAD FLOW

The objective of a load flow study is to acquire complete voltage angle and magnitude information for each bus in a power system for designated load and generator real power and voltage conditions. Due to the nonlinear nature of this problem, numerical methods are engaged to find a solution that is within a reasonable tolerance.

Now to interpret the power flow equations of a system with N buses and R generators, there will be 2 (N – 1) – (R – 1) unknowns [2]. In order to solve for the 2(N – 1) – (R – 1) unknowns, there must be 2(N – 1) – (R – 1) equations that do not include any new unknown variables. The possible equations to employ are power balance equations, which can be written for real and reactive power for each bus. The real power balance equation is,

$$0 = -P_i + \sum |V_i||V_k| \left(G_{ik} \cos\theta_{ik} + B_{ik} \sin\theta_{ik}\right) \quad (1)$$

Where the net power injected is expressed as P_i at bus i, the real part of the element in the bus admittance matrix Y_{BUS} is G_{ik} corresponding to the i^{th} row and k^{th} column, the imaginary part of the element is indicated as B_{ik} in the Y_{BUS} corresponding to the i^{th} row and k^{th} column and the difference in voltage angle

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between the i^{th} and k^{th} buses is symbolized as θ_{ik}. The reactive power balance equation is,

$$0 = -Q_i + \sum |V_i||V_k| \left(G_{ik} \cos\theta_{ik} + B_{ik} \sin\theta_{ik} \right) \quad (2)$$

Where the net reactive power injected is signified as Q_i at bus *i*.

Now the complex power injected at bus i is given as [2],

$$S_i = V_i I_i^* \quad (3)$$

Here $V_i = |V_i| \angle \delta_i$

And $I_i = \sum_{k=1}^{N} Y_{ik} V_k$

I_i represents the net current injected into the network at bus i

$$= Y_{i1}V_1 + Y_{i2}V_2 + Y_{i3}V_3 + \cdots + Y_{iN}V_N$$

$$= \sum_{k=1}^{N} Y_{ik} V_k$$

Thus, it can be written as, $S_i = P_i + jQ_i$

Rewriting the complex power flow equation (3) as $S_i^* = V_i^* I$, it can be obtained that,

$$P_i - jQ_i = V_i^* \sum_{k=1}^{N} Y_{ik} V_k$$

$$= \sum_{k=1}^{N} |Y_{ik} V_k V_i| \angle(\theta_{ik} + \delta_k - \delta_i) \quad (4)$$

Separating equation (4) into real and imaginary parts, we can obtain,

$$P_i = \sum_{k=1}^{N} |Y_{ik} V_k V_i| \cos(\theta_{ik} + \delta_k - \delta_i) \quad (5)$$

$$Q_i = -\sum_{k=1}^{N} |Y_{ik} V_k V_i| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (6)$$

Where the network active bus power is P_i, the network reactive bus power is Q_i, the bus voltage is V_i, the voltage phase angle δ_i, the admittance matrix is Y and the total number of buses is N.

In solving the power flow problems, the bus type is first identified and at each bus, two of the four quantities $|V_i|$, δ_i, P_i and Q_i are specified and the remaining two are to be calculated. Such as for a PQ bus, P_i and Q_i are known and $|V_i|$ and δ_i are to be determined. In a PV bus, P_i and $|V_i|$ being known and hence it is required to obtain Q_i and δ_i. The real (P_L) and reactive (Q_L) power system losses can be obtained as follows [2],

$$P_L = \sum_{i=1}^{N} P_{g_i} - \sum_{i=1}^{N} P_{d_i} \quad (7)$$

$$= summation\ of\ real\ power\ flows$$

$$= \sum_{i=1}^{N} [\sum_{i=1}^{N} (P_{ik} + P_{ki})] \quad (8)$$

Similarly,

$$Q_L = \sum_{i=1}^{N} Q_{g_i} - \sum_{i=1}^{N} Q_{d_i} \quad (9)$$

$$= summation\ of\ reactive\ power\ flows$$

$$= \sum_{i=1}^{N} [\sum_{i=1}^{N} (Q_{ik} + Q_{ki})] \quad (10)$$

Here, the active and reactive generations are expressed as P_{gi} and Q_{gi} respectively. On the other hand, P_{di} and Q_{di} define the active and reactive demand respectively.

In any of the power flow techniques, initial voltage being specified to all the buses, for the first iteration, PQ bus voltage values are set to (1+j0) while PV bus voltages are set to (V+j0). Next [Y_{BUS}] matrix being formed, to update voltages and angles, iterative method is applied in order to persuade the specified conditions of load and generations.

TABLE I. SUMMARY OF POWER FLOW VARIABLES

Type Of Buses	No. Of Buses	Quantity Specified	No. Of Equations	No. Of δ_i, $\vert V_i \vert$ Variables
Slack (or swing bus)	One	$\vert V_i \vert$, δ_i	0	0
Voltage controlled (or PV) (bus ((M+1),(M+2),…., N))	(N – M – 1)	P_i, $\vert V_i \vert$	(N – M – 1)	(N – M – 1)
Load bus (or PQ bus)(2,3,…..,M)	(M – 1)	P_i, Q_i	2 (M – 1)	2 (M – 1)

The iterative cycle is discontinued when the bus voltages and angles are such that the specified condition of load and generation are fulfilled.

III. POWER FLOW METHODS

A. Gauss-Seidel

From equation (4), it can be written as [2],

$$P_i - jQ_i = V_i^* Y_{ii} V_i + V_i^* \sum_{\substack{k=1 \\ k\neq i}}^{N} Y_{ik} V_k$$

for i = 2,3,4,…,N

$$\text{Or, } V_i = \frac{1}{Y_{ii}} \left(\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{N} Y_{ik} V_k \right) \quad (11)$$

for i = 2,3,4,…,N

In G-S algorithm, equation (11) is utilized to find the final bus voltages using successive steps of iterations where,

$$V_i^{p+1} = \frac{1}{Y_{ii}} \left(\frac{P_i - jQ_i}{\left(V_i^p\right)^*} - \sum_{\substack{k=1 \\ k\neq i}}^{N} Y_{ik} V_k^p \right)$$

$$\text{i.e. } V_i^{p+1} = \frac{1}{Y_{ii}} \left(\frac{P_i - jQ_i}{\left(V_i^p\right)^*} - \sum_{k=1}^{i-1} Y_{ik} V_k^{p+1} - \sum_{k=i+1}^{N} Y_{ik} V_k^p \right) \quad (12)$$

for i = 2,3,4,…,N

G-S algorithm convergence is slower and it is conventional to use acceleration factor for speeding up the convergence process.

However, if it increases too much, the system may diverge. The acceleration factor is introduced in the algorithm in the iteration test as follows:

$$x^{p+1} = x^p + \alpha \Delta x$$

Where α is an acceleration factor. In general, for best convergence, the acceleration factor is chosen as 1.4 or 1.6.

Some superiorities of Gauss-Seidel method are as follows:

1. It is one of the simplest and elementary iterative methods in power flow studies since early days of digital power analysis.
2. Because of its simplicity, G-S method does have a definite tutorial value, particularly for the beginners.
3. G-S method can be conveniently used for load flow studies in small power systems.
4. G-S method may be used for even large systems to obtain first approximate solution, which can then be

method.

However, the convergence of the G-S method becomes increasingly slower as the system size expands and hence it is not very much common to employ for practical load flow studies or for general research implications involving power flows in complex networks.

B. Newton-Raphson

Newton – Raphson (N – R) method is basically an iterative process for solving a set of simultaneous non-linear equation with an equal number of unknowns.

Let the set of simultaneous non-linear equations be written as,

$$f_m(x_n) = 0 \text{ for m = 1,2,3,..,N and n = 1,2,3,…,N} \quad (13)$$

The basic philosophy of N-R method of solution is that at each step of iteration process, the non-linear problem is approximated by linear matrix equation.

Let us show the linearizing approximation in case of a single variable problem.

Let x^p be an approximation to the solution of the single variable equation while it possesses an error Δx^p at the p^{th}process of iteration (Fig. 1). We can then write [2],

$$f(x^p + \Delta x^p) = 0 \quad (14)$$

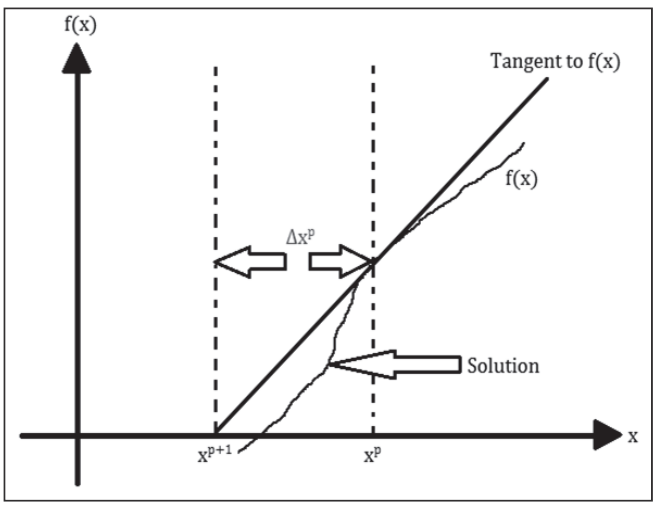

Fig. 1. Linear approximation of a single variable equation

After expanding with Taylor series and simplification, we can rewrite equation (14) as,

$$f(x^p) + J\Delta x^p = 0$$

$$\text{Or, } f(x^p) = -J\Delta x^p \quad (15)$$

The method of solving the single variable problem can easily be extended to the set of N equations having N numbers of unknowns. J becomes the square Jacobian matrix of first order partial differentials of $f_m(x_n)$ function. Any element of J being represented by,

$$J_{mn} = \frac{\partial f_m}{\partial x_n}$$

J_{mn} represents the slopes of the tangent hyper planes that approximate the function $f_m(x_n)$ at each step of iteration.

Though N – R method is a powerful method in power flow study, it does have some difficulties with certain type of functions.

1. If $f(x)$ has multiple roots, it is difficult to predict which root would be acquired.
2. If the starting value is very close to desired root, the procedure may converge to a more distinct root.
3. If x^p is near to a function maximum or minimum, Δx can be quiet large ($\Delta x \geq \Delta x_{max}$), causing x^{p+1} to be supplanted far from the solution and adding more iterations.
4. With large number of iterations ($p \geq p_{max}$), the computation becomes uneconomical.
5. Thus, in practical systems, if ($\Delta x \geq \Delta x_{max}$) or if ($p \geq p_{max}$) the program is abruptly terminated.

In power flow problems, since we are conversant with the problem, the starting values are usually correct and N – R method provides easy convergence. Newton Raphson method provides wide variety of system optimization calculations, sensitivity analysis, and outage-assessment calculations but for pursuing the formal incorporation of single-criterion controls, Newton-Raphson method does not appear to be strong [3].

The equations relating power mismatch to the voltage and power angle changes ($\Delta|V|$ and $\Delta\delta$) can be represented in N –R method as,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} [J_1] & [J_2] \\ [J_3] & [J_4] \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \frac{\Delta|V|}{|V|} \end{bmatrix} \quad (16)$$

The Jacobian [J] here is 2(N – 1)*2(N – 1) for power injection specified at (N – 1) buses. Each quadrant of Jacobian is (N – 1)*(N – 1). The Jacobian is usually non-singular due to diagonal dominance in each quadrant.

C. Algorithm for Solving the Power Flow Problem of A 4-Bus System Using Newton – Raphson Method in Polar Form

Step 1:Guess values of δ_i and V_i at first iteration i.e. δ_i^0, V_i^0 for the state variables.

Step 2:Use δ_i^0 and V_i^0 to calculate P_i^0 *and* Q_i^0 and then mismatches ΔP_i^0 *and* ΔQ_i^0 including the elements of Jacobian.

Step 3:Obtain $\Delta\delta_i^0$ and $\frac{\Delta|V_i^0|}{|V_i^0|}$ solving the system Jacobian related vector matrix equation,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} [J_1] & [J_2] \\ [J_3] & [J_4] \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \frac{\Delta|V|}{|V|} \end{bmatrix}$$

Step 4: Find the new values of δ_i and V_i,

$$\delta_i^1 = \delta_i^0 + \Delta\delta_i^0$$

$$|V_i|^1 = |V_i|^0 + \Delta|V_i|^0 = |V_i|^0 \left[1 + \frac{\Delta|V_i|^0}{|V_i|^0}\right]$$

Step 5:Use the new values of δ_i^1 and $|V_i|^1$ as starting values of next iteration and continue till the problem converges by maintaining change in bus powers within a given tolerance.

The algorithm for N – R method, applicable for polar expression of equations of load flow, can be further simplified by dividing each $\Delta|V_i|^p$ by $|V_i|^p$ does not numerically affect the algorithm, but only simplifies some of the Jacobian terms. $\Delta\delta^p$ is the correction to PQ and PV buses while $\frac{\Delta|V_i|^p}{|V_i|^p}$ is the correction to PQ buses.

In computational aspects for rectangular version, the polar coordinate representation of successive equations and computations are preferable when N – R method is included. The equations for reactive power mismatch are required only for load buses where the equations for real power mismatch are adjacent for all buses only except for the clack bus.

The crucial information to be remembered is that the starting voltage has to be stringently chosen. Otherwise rapid convergence or brisk divergence may occur in the Newton-Raphson procedure and the outcome of which can be wrong solution. The enforcement of the limits on the Δδ and ΔV size correction at each step is the method for the solution of these problems. By providing the good and optimized starting V and δ values a good method can be achieved with a good output. So, following the usual practice, for load buses, the bus voltage is set to (1+j0) per unit (p.u.) as the staring voltage and for controlled buses the starting voltage is set to (V+j0) p.u. But, there are always some contradictions which lead to poor choice of starting points. There is one different procedure which uses one iteration of D.C. load flow, providing rational voltage angle estimation. The succeeding step is one more interation to obtain the voltage magnitudes.

D. Analytical comparison between the different methods of solving the load flow problems

The oldest load flow solution procedure is the Gauss – Seidel Method. It is the most uncomplicated, authentic, and normally tolerant to poor voltages and to the conditions of the reactive power. However, the system size and the computational time are proportional to each other that is when the size of the system increases the computational time also increases rapidly and briskly. But, this procedure leads to poor convergence rate and explicitly shows the convergence problems for an emphasized system with high level active power transfer.

The convergence rate of the Newton – Raphson method is very high and it is quadratic. The relation between the convergence time and the system size is linear only. The problem arises when there is a significant difference between the initial voltages and their true values. Hence, for this method starting with the flat voltage is suitable.

The Newton-Raphson method has a convergence of quadratic type while that for the Gauss-Seidel method is completely linear. With properly chosen starting values of V and δ, researchers report that the better method is the one with quadratic convergence. A present day common technique is accommodated where, if the values are particularly mentioned, the voltage magnitudes are set to given values; otherwise the slack bus magnitudes are set as the voltage magnitudes. The Newton-Raphson Method may not be faster than the Gauss-Seidel method, though it consists of lesser numbers of iterations.

The storage requirement is the other drawback for N-R method. In comparison with the Gauss – Seidel method, Newton – Raphson method engages significant amount of computer space. The quadratic type of convergence results precise accuracy near the exact solution within few number of iterations. The Jacobian Matrix is the function of the voltages and the power angle variables and each of these values alters with every iteration. But, still after few iterations, the coefficients of the Newton – Raphson method lead towards the constant values.

G – S and N – R methods are the general purpose approaches to solve most of the linear systems. The Newton – Raphson method takes more amount of time because of the recalculation of the Jacobian Matrix. So, for betterment they have shown that use of Dist-Flow method in load flow determination for reconfigurable network achieve superior optimization [4].

If the starting point approximation is good, the N-R method is very much desirable and definitive procedure. N – R method aids to solve heavily loaded systems. N – R method may not be even distributed by poor system and the location or selection of slack bus is simple. The convergence attributes of Newton-Raphson methods gives complementary to those properties of Gauss-Seidel method. For this reason, to solve the load flow problems both of these procedures are applied. As a result the staring of the solution may be Gauss-Seidel, whereas there occurs a switching in between the procedures to derive a well-converged and rapid solution with the Newton-Raphson ending of the procedure.

The Fast Decoupled Load Flow (FDLF) Methods are derived from the estimation to the Newton – Raphson (N – R) method. In the N – R method, there is a requirement for the Jacobian because of the computation of Δδ and ΔV. Due to this reason, the convergence of the iterative programme gets affected by the Jacobian, but it does not have any direct impact on the final solution. In the Fast Decoupled Load Flow (FDLF) method, some assumptions and approximations are made which results as the increment of the iteration numbers. However, as there no need to recalculate and refactor the Jacobian matrix, the computational effort reduces significantly. So, subsequently the requirement of enormous computer memory decreases in this method. In comparison to the quadratic convergence rate of the N – R method, the convergence rate of the fast decoupled load flow (FDLF) methods is linear.

The initial voltage and reactive power conditions affect the fast decoupled load flow (FDLF) methods in a minor way than the N – R method [1] that is this method is less sensitive to these factors. The systems with high R/X ratio cannot be solved using fast decoupled XB method; the BX method is convenient and suitable for such systems. Rapid solutions with good accuracy are provided by the fast decoupled load flow (FDLF) methods, for most system conditions. A comparison between several non-linear approaches for load flow analysis with voltage profile, line losses and run time values has been shown in [5] and a conclusion can be drawn that fast decoupled load flow improves the voltage profile and line losses. However, full N – R formulation may be required in the case of system conditions with very large angles across lines and with special control devices that strongly impact active and reactive power flows.

The reason behind longer investment and low computational time requirement for Gauss-Seidel in comparison to other methods like Newton-Raphson and Fast-decoupled method have been explained in [6]. It has been explained that the Gauss-Seidel technique increments in number juggling movement, Newton-Raphson increments in quadratic progression while the quick decouple increments in geometric movement. Due to good computational characteristic, Gauss-Seidel method is useful for small system with less computational complexity whereas Newton Raphson method is the most effective and reliable one for its fast convergence and accuracy. Gauss – Seidel, Newton – Raphson and Fast Decoupled Power Flow methods can be very much helpful in short circuit analysis, calculation of symmetric faults, location and type of the faults etc. [7].

IV. Mathematical Calculation of Load Flow Analysis

In this analysis, a 4 – BUS system (Fig. 2) has been considered for all the calculations. A large 30 bus system has employed for load flow analysis using Newton – Raphson method and the metrics are captured in the Appendix. This analysis can be extended for N – BUS system also. The distribution of load flow methods for committed loads has been developed in [8]. In load flow equations, active power generations are normally specified and the generator bus voltage magnitudes are normally maintained as a specified level (by AVR and machine excitation). The loads are usually specified as constant power type with real and reactive components being given. During normal steady state operation, the loads are assumed to be unaffected by small variation of voltage and frequency. The exclusion of slack bus from the load flow iteration restricts many analyses to make. A method of including slack bus into the Jacobians for N–R load flow study is developed which involves formulating the loss equation and then devising the formula for the terms to be included with the elements of the Jacobian matrix [9].

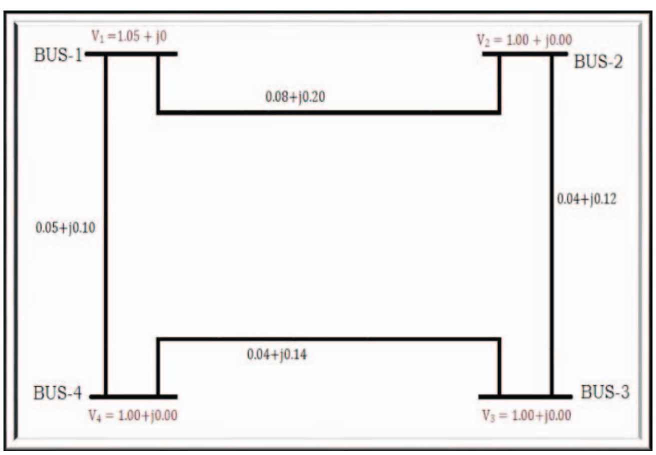

Fig. 2. A four bus, four line system

TABLE II. BUS DATA

Bus No.		1	2	3	4
Bus Code or Bus Type		1 (Slack Bus/ Reference Bus)	3 (PV Bus)	3	3
Voltage Magnitude		1.05	1.00	1.00	1.00
Voltage Angle		0	0	0	0
Load	Real (P_d)	0	– 0.45	– 0.51	– 0.60
	Reactive (Q_d)	0	– 0.15	– 0.25	– 0.30
Generation	Real (P_g)	0	0	0	0
	Reactive (Q_g)	0	0	0	0
Reactive Power Load (RPL)	Q_{min}	0	0	0	0
	Q_{max}	0	0	0	0
Reactive Power Injection (RPI)		0	0	0	0

TABLE III. LINE DATA

Bus Number	1	2	3	4
From Bus	1	1	2	3
To Bus	2	4	3	4
Resistance (R)	0.08	0.05	0.04	0.04
Reactance (X)	0.20	0.10	0.12	0.14
Susceptance (1/2B)	0	0	0	0
Tap Setting Value	1 (i.e. no tap setting is done)	1	1	1

TABLE IV. CALCULATION OF CONDUCTANCE (G) AND SUSCEPTANCE (B)

Line, Bus To Bus	R, pu	X, pu
1 – 2	0.08	0.20
1 – 4	0.05	0.10
2 – 3	0.04	0.12
3 – 4	0.04	0.14
Line	**G, pu**	**B, pu**
1 – 2	1.724	-4.31
1 – 4	4	-8
2 – 3	2.5	-7.5
3 – 4	1.887	-6.6038

V. Simulation Results

The complete comparison of the values obtained by mathematical calculation and MATLAB simulation for both the methods i.e. Gauss – Seidel and Newton – Raphson is provided. As we can see the values are quiet indistinguishable with each other. There are nominal fractional dissimilarities between them.

TABLE V. COMPARISON BETWEEN MATLAB AND THEORETICAL CALCULATIONS

		Gauss – Seidel		Newton – Raphson	
		MATLAB	Theo-retical	MATLAB	Theo-retical
Voltage Magnitude	V_1	1.05	1.05	1.05	1.05
	V_2	1.1360	1.042276	1.1119	1.160
	V_3	1.1540	1.0494249	1.1243	1.180
	V_4	1.1268	1.084325	1.1379	1.148
Voltage Angle	δ_1	0.00	0.00	0.00	0.00
	δ_2	4.8486°	1.67349°	0.1136°	0.097°
	δ_3	5.4874°	2.4401638°	0.1310°	0.112°
	δ_4	3.5680°	2.51973°	0.0744°	0.069°

The programming methods may be non-identical, but there should be resemblance between the results. This is because of the same concept on which the programming is based on. In [10], a user friendly software based MATLAB programming has been originated which advances the accomplishment of the execution of the power flow analysis, line loss determination more efficiently and with lesser time consumption according to the requirement.

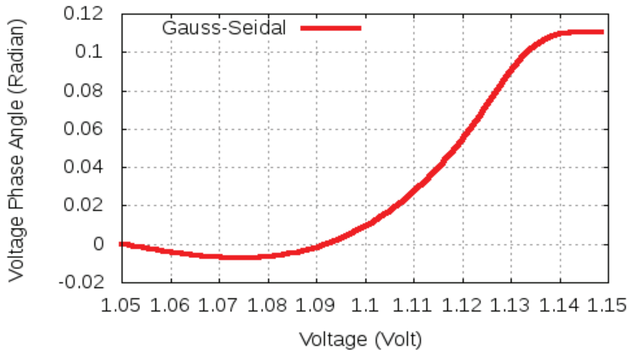

Fig. 3. MATLAB simulation variation in Gauss – Seidel

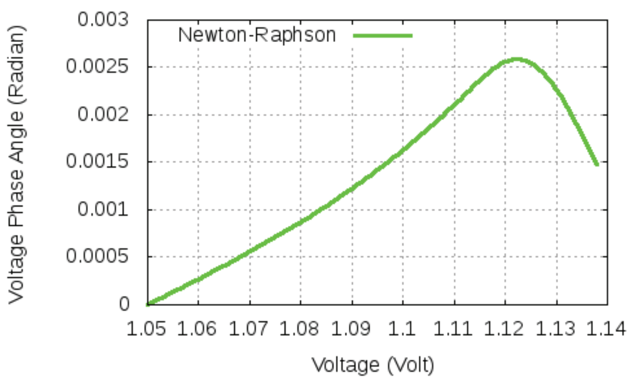

Fig. 4. MATLAB simulation variation in Newton – Raphson

From these two graphs (Fig. 3 and Fig. 4), it is noticeable that the Newton-Raphson Method follows a particular sequence while incrementing and that is why it is linear, which is not observable for Gauss-Seidel analysis. But for Gauss Seidel method the computational characteristics is better than the Newton Raphson Method. In Table VI., active and reactive power for the line and bus obtained by both Gauss – Seidel and Newton – Raphson has been presented.

TABLE VI. OBTAINED POWER FOR BUS AND LINE

Gauss – Seidel		**Newton – Raphson**	
Active Power (MW)	**Reactive Power (MVar)**	**Active Power (MW)**	**Reactive Power (MVar)**
– 137.2545	– 50.3982	– 24.4207	– 61.5517
45.1151	10.1870	13.0207	21.5517
50.6586	17.7774	4.4000	0.0000
59.3020	23.5398	24.4000	40.0000

The first negative value in each column in Table VI can be ignored since it represents the power of the reference bus.

A. *Data for Power Loss in Gauss – Seidel Method*

The matrix for total power loss is given as,

$$\begin{bmatrix} 0 & -0.0275-0.0687i & 0 & -0.0419-0.0838i \\ 0 & 0 & -0.0012-0.0036i & 0 \\ 0 & 0 & 0 & -0.0042-0.0145i \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Delta P = \begin{bmatrix} 0 & -0.0275 & 0 & -0.0419 \\ 0 & 0 & -0.0012 & 0 \\ 0 & 0 & 0 & -0.0042 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Delta Q = \begin{bmatrix} 0 & -0.0687 & 0 & -0.0838 \\ 0 & 0 & -0.0036 & 0 \\ 0 & 0 & 0 & -0.0145 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

B. *Data for Power Loss in Newton – Raphson Method*

The matrix for total power loss is given as,

$$\begin{bmatrix} 0 & -0.0043-0.0108i & 0 & -0.0100-0.0200i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Delta P = \begin{bmatrix} 0 & -0.0043 & 0 & -0.0100 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Delta Q = \begin{bmatrix} 0 & -0.0108 & 0 & -0.0200 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

VI. CONCLUSION

In this report, the power flow investigation has exhibit a substantial enhancement over the power system like load flow, voltage magnitude, voltage angles and power loss calculation. The simulation of the system with MATLAB escalates the rate of the procedure and thus it consumes less amount of time. As in this paper, it is noticeable that Newton – Raphson method is more functional and efficacious with respect to the Gauss – Seidel procedure. With the customization and improvement the accuracy of the output gets enhanced.

With growing number of buses, the precision, authenticity, accessibility and effectiveness of the Newton – Raphson method is prominently observable. Hence, without depending on the number of buses, accurate calculation of the load line losses in a certain bus system is feasible with the support of bus data, line data and a simulation program in MATLAB.

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APPENDIX

A. Data for a 30 bus system using Newton – Raphson method

1) Simulation results of voltage magnitude and voltage angle

TABLE VII. VOLTAGE MAGNITUDE AND VOLTAGE ANGLE

Magnitude (V)	Angle (°)	Magnitude (V)	Angle (°)	Magnitude (V)	Angle (°)
1.0600	0	1.0820	-9.3568	1.0563	-12.5373
1.0430	-3.1857	1.0670	-10.9739	1.0569	-12.5321
1.0269	-5.7075	1.0710	-10.1316	1.0453	-12.6101
1.0189	-6.8584	1.0543	-11.8914	1.0454	-12.9969
1.0100	-10.6497	1.0515	-12.0681	1.0352	-12.6859
1.0167	-8.1781	1.0604	-11.7208	1.0179	-13.0910
1.0062	-9.7192	1.0607	-12.1804	1.0373	-12.2479
1.0100	-8.5893	1.0455	-12.7478	1.0154	-8.7438
1.0640	-10.3931	1.0450	-12.9655	1.0178	-13.4440
1.0684	-12.0878	1.0501	-12.8028	1.0065	-14.3018

2) Simulation results of active and reactive power

TABLE VIII. POWER FOR BUS AND LINE

Active Power (MW)	Reactive Power (MVar)	Active Power (MW)	Reactive Power (MVar)	Active Power (MW)	Reactive Power (MVar)
44.8047	38.5312	32.4600	8.6443	24.8117	-14.9635
34.9192	6.4575	40.1489	3.1555	32.4849	0.1132
33.2367	-0.6578	32.1300	2.8655	30.1623	-2.4669
21.3913	-18.1904	30.4815	-3.3464	29.8987	-2.1282
28.6167	-15.8674	28.3931	-5.4427	31.4228	0.0373
33.2553	-15.7205	30.4921	-2.8449	28.4598	-3.1315
25.5150	-16.2007	28.9397	-7.7112	35.5978	5.5214
25.6005	-19.5379	30.4492	-1.9210	30.6584	-5.3569
31.9206	-0.8833	28.3278	-6.2047	29.6435	-1.7187
47.5959	41.9685	31.2357	-1.3323	27.1496	-5.9201

3) Simulation results of total power loss, ΔP and ΔQ

TABLE IX. POWER LOSS SUMMARY

Total Power Loss	ΔP	ΔQ
(1,2) -0.0015 - 0.0045i	(1,2) -0.0015	(1,2) -0.0045
(1,3) -0.0014 - 0.0056i	(1,3) -0.0014	(1,3) -0.0056
(2,4) -0.0010 - 0.0030i	(2,4) -0.0010	(2,4) -0.0030
(3,4) -0.0005 - 0.0015i	(3,4) -0.0005	(3,4) -0.0015
(2,5) -0.0012 - 0.0052i	(2,5) -0.0012	(2,5) -0.0052
(2,6) -0.0012 - 0.0035i	(2,6) -0.0012	(2,6) -0.0035
(4,6) -0.0000 - 0.0001i	(4,6) -0.0000	(4,6) -0.0001
(5,7) -0.0000 - 0.0001i	(5,7) -0.0000	(5,7) -0.0001
(6,7) -0.0004 - 0.0012i	(6,7) -0.0004	(6,7) -0.0012
(6,8) -0.0003 - 0.0010i	(6,8) -0.0003	(6,8) -0.0010
(6,9) 0 - 0.0110i	(12,14) -0.0002	(6,9) -0.0110
(6,10) 0 - 0.0050i	(12,15) -0.0007	(6,10) -0.0050
(9,10) 0 - 0.0002i	(14,15) -0.0000	(9,10) -0.0002
(9,11) 0 - 0.0016i	(12,16) -0.0001	(9,11) -0.0016
(4,12) 0 - 0.0097i	(10,17) -0.0002	(4,12) -0.0097
(12,13) 0 - 0.0001i	(16,17) -0.0000	(12,13) -0.0001
(12,14) -0.0002 - 0.0005i	(15,18) -0.0001	(12,14) -0.0005
(12,15) -0.0007 - 0.0015i	(18,19) -0.0000	(12,15) -0.0015
(14,15) -0.0000 - 0.0000i	(10,20) -0.0006	(14,15) -0.0000
(12,16) -0.0001 - 0.0002i	(19,20) -0.0002	(12,16) -0.0002
(10,17) -0.0002 - 0.0006i	(10,21) -0.0007	(10,17) -0.0006
(16,17) -0.0000 - 0.0000i	(10,22) -0.0003	(16,17) -0.0000
(15,18) -0.0001 - 0.0001i	(21,22) -0.0000	(15,18) -0.0001
(18,19) -0.0000 - 0.0000i	(15,23) -0.0001	(18,19) -0.0000
(10,20) -0.0006 - 0.0013i	(22,24) -0.0003	(10,20) -0.0013
(19,20) -0.0002 - 0.0003i	(23,24) -0.0000	(19,20) -0.0003
(10,21) -0.0007 - 0.0016i	(24,25) -0.0001	(10,21) -0.0016
(10,22) -0.0003 - 0.0007i	(25,26) -0.0004	(10,22) -0.0007
(21,22) -0.0000 - 0.0000i	(25,27) -0.0000	(21,22) -0.0000
(15,23) -0.0001 - 0.0002i	(6,28) -0.0000	(15,23) -0.0002
(22,24) -0.0003 - 0.0005i	(8,28) -0.0000	(22,24) -0.0005
(23,24) -0.0000 - 0.0000i	(27,29) -0.0004	(23,24) -0.0000
(24,25) -0.0001 - 0.0002i	(27,30) -0.0007	(24,25) -0.0002
(25,26) -0.0004 - 0.0005i	(29,30) -0.0001	(25,26) -0.0005
(25,27) -0.0000 - 0.0000i		(25,27) -0.0000
(28,27) 0 - 0.0013i		(28,27) -0.0013
(6,28) -0.0000 - 0.000i		(6,28) -0.0000
(8,28) -0.0000 - 0.0001i		(8,28) -0.0001
(27,29) -0.0004 - 0.0007i		(27,29) -0.0007
(27,30) -0.0007 - 0.0012i		(27,30) -0.0012
(29,30) -0.0001 - 0.0002i		(29,30) -0.0002