Comparative Analysis of Load Flow Computational Methods Using MATLAB

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Abstract- **The power system analysis and design is generally done by Using Load flow analysis. The main information attained from this study includes the magnitudes and phase angles of load bus voltages, reactive powers at generator buses, real and reactive power flow on transmission lines. This information is essential for the continuous monitoring of the current state of the system, Planning, operation, economic scheduling and exchange of power between utilities.**

Different methods are used for load flow analysis. The objective of this study is to develop MATLAB programs for load flow study to calculate bus voltages, their phase angles, real power loss and reactive power loss in the power system, computational time, and number of iterations, accuracy and memory for IEEE 9, IEEE 14, IEEE 25 bus systems. The different methods of load flow study are analysed and compared with each other. Every method has advantages and disadvantages in different conditions. So, comparison of these methods can be useful to select the best method for a typical network. As a result, some suggestions are proposed to apply the methods.

Keywords-Load flow, An Approximate method, Gauss Seidel method, Newton Raphson method, Fast decoupled method.

I. INTRODUCTION

Load flow studies [9] are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. Load flow analysis is fundamental to the study of power systems. This analysis is at the heart of contingency analysis and the implementation of real-time monitoring systems. The study gives steady state solutions of the voltages at all the buses, for a particular load condition. Different steady state solutions can be obtained, for different operating conditions, to help in planning, design and operation of the power system. Thus the load flow problem consists of finding the power flows (real and reactive) and voltages of a network for given bus conditions. At each bus, there are four quantities of interest to be known for further analysis: the real and reactive power, the voltage magnitude and its phase angle.

II. LOAD FLOW ANALYSIS

The complex power (S_i) injected by the source into the i^{th} bus of a power system is:

$$S_i = P_i - jQ_i \qquad (1)$$

Where P_i is the real power and Q_i is injected power into the i^{th} bus.

$$P_i = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}|\cos(\theta_{ik} + \delta_k - \delta_i) \quad i=1, 2\ldots..n \qquad (2)$$

$$Q_i = -|V_i| \sum_{k=1}^{n} |V_k||Y_{ik}|\sin(\theta_{ik} + \delta_k - \delta_i) \quad i=1, 2\ldots..n \qquad (3)$$

Where V_i is the voltage at the ith bus, V_k is the voltage at the kth bus, Y_{ik} is the mutual admittance between nodes i and k, θ_{ik} is the angle of Y_{ik}, δ_k is the angle of V_k and δ_i is angle of V_i.

Bus Classification: A bus is a node at which one or many lines, one or many loads and generators are connected. In a power system each node or bus is associated with 4 quantities, such as magnitude of voltage, phage angle of voltage, active or true power and reactive power in load flow problem two out of these 4 quantities are specified and remaining 2 are required to be determined through the solution of equation. Depending on the quantities that have been specified, the buses are classified into 3 categories:

Load Buses: In these buses no generators are connected. At this type of bus, the net power P_i and Q_i are specified whereas $|V_i|$ and δ_i are unspecified.

Voltage Controlled Buses: These are the buses where generators are connected. At this type of bus, the net power P_{Gi} and $|V_i|$ are specified whereas Q_i and δ_i are unspecified.

Slack or Swing Buses: Usually this bus is numbered as 1.This bus is distinguished from other two types of buses by the fact that real and reactive powers at this bus are not specified. Instead, voltage magnitude and phase angle are specified.

III. APPROXIMATE (APPROX.) LOAD FLOW

In this method [7] following assumptions and approximations are made in the load flow equations:

- Line resistances being small are neglected i.e. P_L, the active power loss of the system is zero. Thus $\theta_{ik} \cong 90^0$ and $\theta_{ii} \cong -90^0$.
- ($\delta_i - \delta_k$) is small (< π/6) so that sin (δ_i- δ_k) ≅ (δ_i- δ_k).This is justified from considerations of stability.
- All buses other than the slack bus are PV buses i.e. voltage magnitudes at all the buses including the slack bus are specified.

Equations then reduce to

$$P_i = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}|(\delta_i - \delta_k); \quad (4)$$

i= 2, 3………n

$$Q_i = -|V_i| \sum_{\substack{k=1 \\ k\neq 1}}^{n} |V_k||Y_{ik}| cos(\delta_i - \delta_k) + |V_i|^2 |Y_{ii}|$$

i=2, 3……n (5)

Since $|V_i|$'s are specified Eq. (4) represents a set of linear algebraic equations in δi's which are (n-1) in number as δ_i is specified at the slack bus. The n^{th} equation corresponding to slack bus (n=1) is redundant as the real power injected at this bus is now fully specified as

$$P_i = \sum_{i=2}^{n} P_{Di} - \sum_{i=2}^{n} P_{Gi}$$

Equation (2) can be solved explicitly for δ_2, δ_3… δ_n when substituted in Eq. (5) yields Q_i's, in the reactive power bus injections.

IV. GAUSS SEIDEL (GS) LOAD FLOW

The GS method [4] is an iterative algorithm for solving nonlinear algebraic equations. An initial solution vector is assumed, chosen from past experiences, statistical data or from practical considerations. At all subsequent iteration, the solution is updated till convergence is reached.

Case (a): Systems with PQ buses only:

Initially assume all buses to be PQ type buses, except the slack bus.

$$S_i = V_i \sum_{k=1}^{n} Y_{ik}^* V_k^*$$

This can be written as

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

So that,

$$V_i = \frac{1}{Y_{ii}} \left[\frac{P_i - j\,Q_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq 1}}^{n} Y_{ik} V_k \right]$$

Whereas i = 2, 3,………..n (6)

Equation (6) is an implicit equation since the unknown variable, appears on both sides of the equation. Hence, it needs to be solved by an iterative technique. In Gauss Seidel method, the value of the updated voltages is used in the computation of subsequent voltages in the same iteration, thus speeding up convergence. Iterations are carried out till the magnitudes of all bus voltages do not change by more than the tolerance value.

Algorithm for GS method

Step1. Prepare data for the given system as required.
Step2. Formulate the bus admittance matrix Y_{BUS}. This is generally done by the rule of inspection.
Step3. Assume initial voltages for all buses =2, 3,… n. In practical power systems, the magnitude of the bus voltages is close to 1.0 p.u. Hence, the complex bus voltages at all (n-1) buses (except slack bus) are taken to be 1.0 $\angle 0^0$.This is normally refersed as the ***flat start*** solution.
Step4. Update the voltages. In any $(r+1)^n$ iteration, from (6) the voltages are given by

$$V_i^{(k+1)} = \frac{1}{Y_{ii}} \left[\frac{P_i - j\,Q_i}{(V_i^k)^*} - \sum_{k=1}^{i-1} Y_{ik} V_k^{(r+1)} - \sum_{k=i+1}^{n} Y_{ik} V_k^{(r)} \right] \quad (7)$$

Here note that when computation is carried out for bus-i, updated values are already available for buses 2, 3….(i-1) in the current *(r+1)^st* iteration. Hence these values are used. For buses *(i+1)…..n,* values from previous, r^{th} iteration are used.

Step5. Continue iterations till

$$|\Delta V_i^{(r+1)}| = |V_i^{(r+1)} - V_i^{(r)} < \varepsilon|$$

i = 2, 3…n. (8)

Where, ε is the tolerance value. Generally, it is customary to use a value of 0.0001 p.u.
Step6. Compute slack bus power after voltages have converged Using.

$$S_i^* = P_1 - jQ_1$$

[Assuming bus 1 is slack bus.]

$$= V_1^* \left(\sum_{j=1}^{n} Y_{1k} V_k \right) \quad (9)$$

Step7. Compute all line flows.

$$S_{ik} = V_i (V_i^* - V_k^*) Y_{ik}^* + V_i V_i^* Y_{ik0}^*$$

$$S_{ki} = V_k (V_k^* - V_i^*) Y_{ik}^* + V_k V_k^* Y_{ki0}^*$$

Step8. The complex power loss in the line is given by S_{ik} + S_{ki}. The total loss in the system is calculated by summing the loss over all the lines.

Case (b): Systems with PV buses also present: At PV buses, the magnitude of voltage and not the reactive power is specified. Hence it is needed to first make an estimate of Qi to be used in (7). From (0) we have

$$Q_i = -Im \left\{ V_i^* \sum_{k=1}^{n} Y_{ik} V_k \right\}$$

Where, *Im* stands for the imaginary part. At any *(r+1)^st* iteration, at the PV bus-*i*,

$$Q_i^{(r+1)} = -Im \left\{ (V_i^{(r)})^* \sum_{k=1}^{i-1} Y_{ik}^{(r+1)} V_i^{(r+1)} + (V_i^k)^* \sum_{k=1}^{n} Y_{ik} V_k^{(r)} \right\}$$

(10)

The steps for i^{th} PV bus are as follows:

1. Compute $Q_i^{(r+1)}$ Using (10).
2. Calculate V_i Using (7) with Qi = $Q_i^{(r+1)}$
3. Since $|V_i|$ is specified at the PV bus, the magnitude of V_i obtained in step 2 has to be modified and set to the specified value $|V_{i,sp}|$. Therefore,

$$V_i^{(r+1)} = |V_{i,sp}| \angle \delta_i^{(r+1)} \quad (11)$$

The voltage computation for PQ buses does not change.

Case (c): Systems with PV buses with reactive power generation limits specified: In the previous algorithm if the Q limit at the voltage controlled bus is violated during any iteration, i.e. $Q_i^{(r+1)}$is *computed* Using (10) is either less than Qi_{min} or greater than Qi_{max}, it means that the voltage cannot be maintained at the specified value due to lack of reactive power support. This bus is then treated as a PQ bus in the *(r+1)^th^* iteration and the voltage is calculated with the value of Q_i set as follows:

If $Q_i < Q_{i,min}$ Then $Q_i = Q_{i,min}$.
If $Q_i > Q_{i,max}$ Then $Q_i = Q_{i,max}$.

(12)

If in the subsequent iteration, if Q_i falls within the limits, then the bus can be switched back to PV status.

Acceleration of convergence

It is found that in GS method of load flow, the number of iterations increases with increase in the size of the system. The number of iterations required can be reduced if the correction in voltage at each bus is accelerated, by multiplying with a *constant α, called the acceleration factor*. In the $(r+1)^{th}$ iteration we can let

$$V_i^{(r+1)}(accelerated) = V_i^r + \alpha\left(V_i^{(r+1)} - V_i^{(r)}\right) \quad (13)$$

Where α is a real number. When α =1, the value of $V_i^{(r+1)}$ is the computed value. If 1 < α < 2, then the value computed is extrapolated. Generally α is taken between 1.2 to 1.6, for GS load flow procedure.

V. NEWTON RAPHSON (NR) LOAD FLOW

Newton Raphson (NR) [7] method is used to solve a system of nonlinear algebraic equations of the form f(x) =0. Consider a set of *n* nonlinear algebraic equations given by

$$f_i(x_1, x_2 \dots\dots\dots\dots x_n) = 0$$
$$i = 1,2 \dots\dots n \quad (14)$$

Let $x_1^0, x_2^0 \dots\dots\dots\dots x_n^0$ be the initial guess of unknown variables and $\Delta x_1^0, \Delta x_2^0 \dots\dots\dots\dots \Delta x_n^0$ be the respective corrections. Therefore,

$$f_i(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2^0, x_n^0 + \Delta x_n^0) = 0 \quad (15)$$

The above equation can be expanded Using Taylor's series to give

$$f_i(x_1^0, x_2^0 \dots\dots\dots x_n^0) + \left[\left(\frac{\partial f_i}{\partial x_1}\right)^{\circ}\Delta x_1^0 + \left(\frac{\partial f_i}{\partial x_2}\right)^{\circ}\Delta x_2^0 + \dots\dots\dots + \left(\frac{\partial f_i}{\partial x_n}\right)^{\circ}\Delta x_n^0\right]$$

+Higher order terms = 0.

Where *i* = 1, 2...... *n* (16)

Where, $\left(\frac{\partial f_i}{\partial x_1}\right)^0, \left(\frac{\partial f_i}{\partial x_2}\right)^0, \dots\dots\dots, \left(\frac{\partial f_i}{\partial x_n}\right)^0$ are the partial derivatives of *fi* with respect to $(x_1, x_2, \dots\dots\dots x_n)$ respectively, evaluated at $(x_1^0), x_2^0, \dots\dots\dots x_n^0$). If the higher order terms are neglected, then (16) can be written in matrix form as

$$\begin{bmatrix} f_1^0 \\ f_2^0 \\ \vdots \\ f_n^0 \end{bmatrix} + \begin{bmatrix} \left(\frac{\partial f_1}{\partial x_1}\right)^0 & \left(\frac{\partial f_1}{\partial x_2}\right)^0 & \left(\frac{\partial f_1}{\partial x_n}\right)^0 \\ \left(\frac{\partial f_2}{\partial x_1}\right)^0 & \left(\frac{\partial f_2}{\partial x_2}\right)^0 & \left(\frac{\partial f_2}{\partial x_n}\right)^0 \\ \vdots & \vdots & \vdots \\ \left(\frac{\partial f_n}{\partial x_1}\right)^0 & \left(\frac{\partial f_n}{\partial x_2}\right)^0 \dots\dots & \left(\frac{\partial f_n}{\partial x_n}\right)^0 \end{bmatrix} \begin{bmatrix} \Delta x_1^0 \\ \Delta x_2^0 \\ \vdots \\ \Delta x_n^0 \end{bmatrix}$$

$$= 0 \quad (17)$$

In vector form (17) can be written as

$$f^0 + j^0 \Delta x^0 \cong 0 \quad (18)$$

j^0 is known as the Jacobian matrix equation (18) can be written as

$$f^0 \cong [-j^0]\Delta x^0 \quad (19)$$

Approximate values of corrections Δx^0 can be obtained from equation (19).These being a set of linear algebraic equations can be solved efficiently by triangularisation and back substitution. Updated values of x are then

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

Or in general, form the $(r+1)^{th}$ iteration

$$x^{(r+1)} = x^r + \Delta x^r \quad (20)$$

Iterations are continued till equation (14) is satisfied to any desired accuracy i.e.

$$|f_i(x^{(r)})| < \varepsilon$$

Where i=1, 2…..n.

NEWTON RAPHSON Algorithm

First, assume that all buses are PQ buses. At any PQ bus the load flow solution must satisfy the following non-linear algebraic equations

$$f_{iP}(|V|, \delta) = P_i(specified) - P_i = 0 \quad (21a)$$

$$f_{iQ}(|V|, \delta) = Q_i(specified) - Q_i = 0 \quad (21b)$$

Where expressions for Pi and Qi are given in equations. For a trial set of variables $|V_i|, \delta_i$ the vector of residuals f^O of equation (18) corresponds to

$$f_{iP} = P_i(specified) - P_i(cal) = \Delta P_i \quad (22a)$$

$f_{iQ} = Q_i(specified) - Q_i(cal) = \Delta Q_i$ (22b)

While the vector of corrections Δx^0 corresponds to $\Delta|V_i|, \delta_i$ Equation (18) for obtaining the approximate corrections vector can be written for the load flow case as

$$\begin{bmatrix}\Delta P_i \\ \Delta Q_i\end{bmatrix} = \begin{bmatrix} H_{im} & N_{im} \\ J_{im} & L_{im}\end{bmatrix}\begin{bmatrix}\Delta\delta_m \\ \Delta|V_m|\end{bmatrix} \quad (23)$$

i^{th} bus m^{th} bus m^{th} bus

Whereas,

$$H_{im} = \frac{\partial P_i}{\partial \delta_m}, N_{im} = \frac{\partial P_i}{\partial |V_m|}, J_{im} = \frac{\partial Q_i}{\partial \delta_m}, L_{im} = \frac{\partial Q_i}{\partial |V_m|}$$

It is to be observed that the jacobian elements corresponding to the i^{th} bus residuals and m^{th} bus corrections are 2*2 matrix enclosed in the box in equation (21a) where i and m are both PQ buses. Since at the slack bus P_1 and Q_1 are unspecified and $|V_i|$ and δ_i are fixed. Consider now the presence of PV buses. If the i^{th} bus is a PV bus, Q_i is unspecified so that there is no equation corresponding to equation (21b). Therefore the jacobian elements are

$$\Delta P_i = \begin{bmatrix} H_{im} & N_{im}\end{bmatrix}\begin{bmatrix}\Delta\delta_m \\ \Delta|V_m|\end{bmatrix}$$

i^{th} bus m^{th} bus m^{th} bus

If the m^{th} bus is also a PV bus $|V_m|$ becomes fixed so that $\Delta|V_m| = 0$ and jacobian elements are

$$\Delta P_i = [H_{im}][\Delta\delta_m]$$

i^{th} bus m^{th} bus m^{th} bus

If the i^{th} bus is a PQ bus while m^{th} bus is a PV bus, then elements are

$$\begin{bmatrix}\Delta P_i \\ \Delta Q_i\end{bmatrix} = \begin{bmatrix} H_{im} \\ J_{im}\end{bmatrix}[\Delta\delta_m]$$

i^{th} bus m^{th} bus m^{th} bus

It is convenient for numerical solution to normalize the voltage corrections

$$\frac{\Delta|V|_m}{|V|_m}$$

As a consequence of which, the corresponding jacobian elements become

$$N_{im} = \frac{\delta P_i}{\delta|V_m|}|V_m|, L_{im} = \frac{\delta Q_i}{\delta|V_m|}|V_m|$$

VI. FAST DECOUPLED LOAD FLOW

If the coefficient matrices are constant, the need to update the Jacobian at every iteration is eliminated. This has resulted in development of *Fast Decoupled Load Flow* (FDLF) [7].Memory requirement of Newton-Raphson is reduced by this method. The property of weak coupling between P-δ and Q-V variables gave the necessary motivation in developing the fast decoupled load flow method. In which P-δ and Q-V problems are solved separately. The elements are to be neglected are submatrices [N] and [J]

$$[\Delta P] = [H][\Delta\delta] \quad (24)$$

$$[\Delta Q] = [L]\left[\frac{\Delta|V|}{|V|}\right] \quad (25)$$

Here, certain assumptions, the entries of the [H] and [L] submatrices will become considerably simplified

$$H_{ij} = L_{ij} = -|V_i||V_j|B_{ij} \quad \text{for } i \neq j$$

$$H_{ii} = L_{ii} = -B_{ii}|V_i|^2 \quad \text{for } i=j$$

Matrices [H] and [L] are square matrices with dimension $(n_{PQ} + n_{PV})$ and n_{PQ} respectively. Equations (24) and (25) can now be written as

$$[\Delta P] = [|V_i||V_j|B'_{ij}][\Delta\delta] \quad (26)$$

$$[\Delta Q] = [|V_i||V_j|B''_{ij}]\frac{\Delta|V|}{|V|} \quad (27)$$

Where B'_{ij}, B''_{ij} are elements of [-B] matrix.

Fast decoupled load flow algorithm

Step1. Omitting from [B′] the representation of those network elements that predominantly affect reactive power flows.

Step2. Neglecting from [B″] the angle shifting effects of phase shifters

Step3. Dividing each of the equation (26) and (27) by $|V_i|$ and setting $|V_j| = 1$ p.u in the equations.

Step4. Ignoring series resistance in calculating the elements of [B′] which then becomes the dc approximation power flow matrix.

With above modifications, the resultant simplified FDLF equations become

$$\left[\frac{\Delta P}{|V|}\right] = [B'][\Delta\delta] \quad (28)$$

$$\left[\frac{\Delta Q}{|V|}\right] = [B''][\Delta|V|] \quad (29)$$

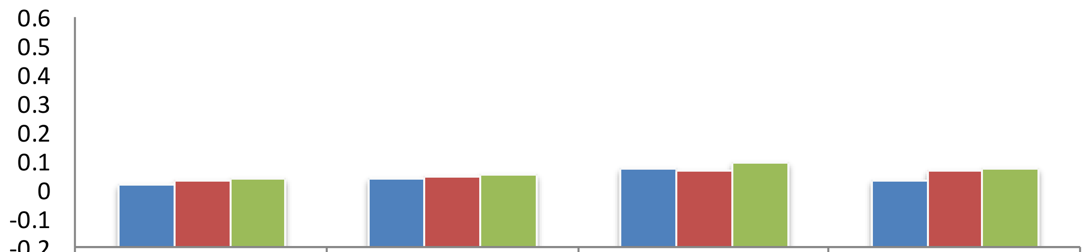
In Equation (28) and (29) both [B′] and [B″] are real, sparse and have the structures of [H] and [L] respectively. Since they haves contained only admittances. Equations (28) and (29) are solved alternatively always employing the most recent voltage value. Single iteration implies one solution for [Δδ] to update [δ] and then one solution for [Δ|V|] to update [|V|] to be called 1-δ and 1-V iteration. Separate convergence tests are applied for the real and reactive power mismatches as follows: max $[\Delta P] \leq \varepsilon_P$; max $[\Delta Q] \leq \varepsilon_Q$.

Where ε_P and ε_Q are the tolerances.

VII. RESULTS AND DISCUSSION

Above discussed load flow methods have been implemented by using MATLAB on sample test systems of IEEE 9-Bus System, 14- Bus System and 25- Bus power System. Performance of these methods have been studied in terms of number of iterations taken for a given accuracy, computational time, convergence obtained, requirement of computer storage memory etc. As discussed in the following sections.

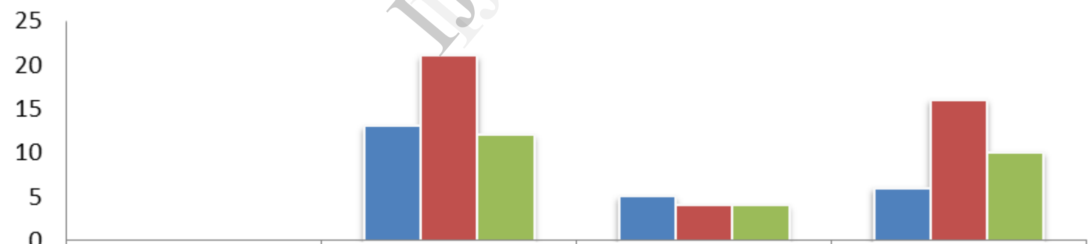
Computational Time (in seconds)
From Fig. 1 it is clear that the time per iteration in An Approximate, Gauss Seidel and Newton Raphson methods increases almost directly as the number of buses of the system while the elapsed time of the Fast Decoupled is less than the Newton Raphson method. But as accuracy increase from 0.01 to 0.000001 computational time of Newton Raphson method is quite less than other methods.



	APPROX.	GS	NR	FDLF
9 BUS	0.019591	0.036654	0.071281	0.031335
14 BUS	0.028978	0.042215	0.06869	0.068463
25 BUS	0.041169	0.050388	0.095743	0.075743

Fig. 1. Comparison of the Computational time obtained from the 3-Test Bus Systems

Number of Iteration
It is clear from Fig. 6 the Gauss Seidel method requires larger number of iterations to converge to given voltage mismatch tolerance, compare with other methods Approximate method is non-iterative and Fast decoupled methods takes more number of iterations to converge.



	APPROX.	GS	NR	FDLF
9 BUS	0	13	5	6
14 BUS	0	21	4	16
25 BUS	0	12	4	10

Fig. 2. Comparison of number of iterations obtained from the 3-Test Bus Systems

*Memory (in Bytes)*It is clear from Fig. 14 that Newton-Raphson requires more memory than Gauss Seidel, Approximate method, and Fast decoupled method.

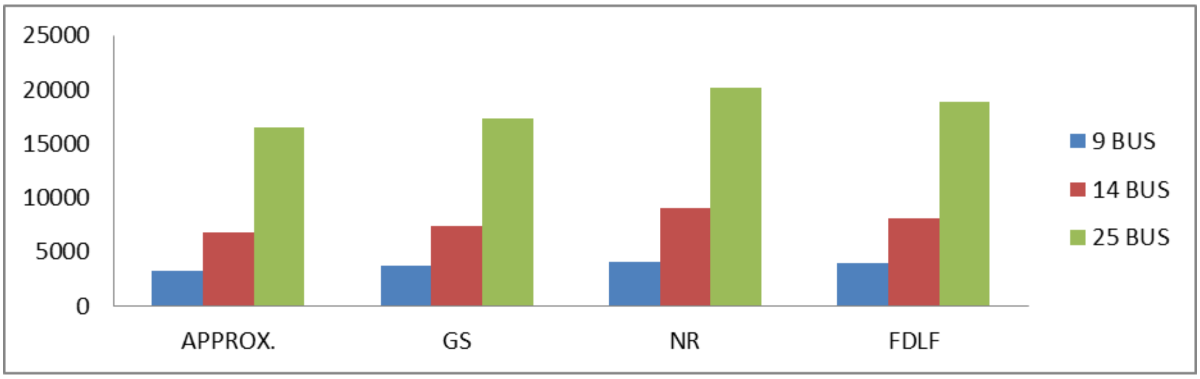
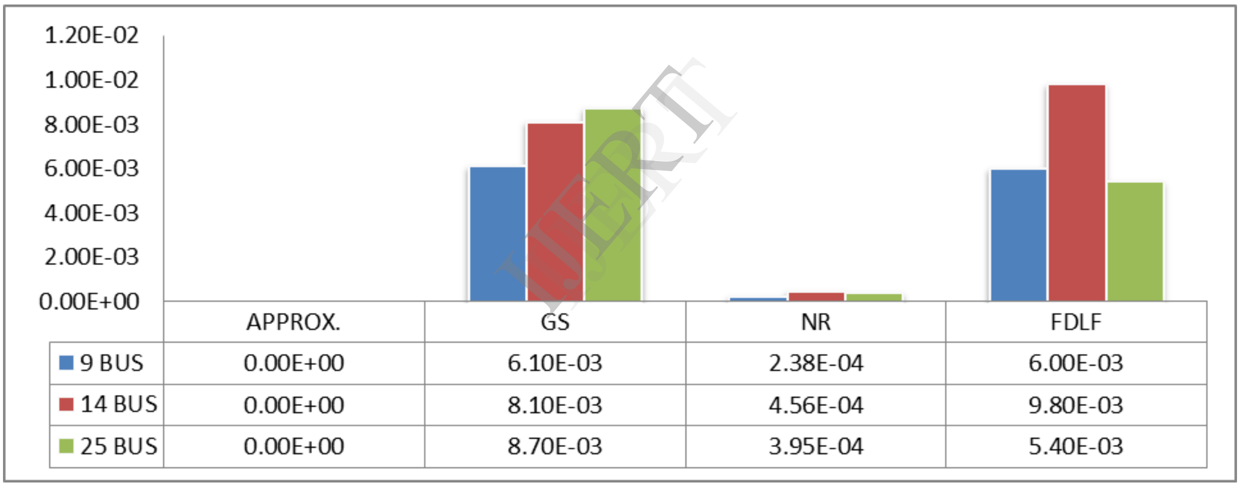


Fig. 3. Comparison of the memory requirement obtained from the 3-Test Bus Systems

Convergence Characteristics

The convergence characteristic are described by plotting the bar graphs of change in voltage magnitudes during successive iterations as a function of required tolerances as shown in Figs. 10, 11 and 12.

It is clear from below bar graphs that as accuracy increases absolute voltage mismatch of Newton Raphson method decreases i.e. this method is best to achieve the convergence.



	APPROX.	GS	NR	FDLF
9 BUS	0.00E+00	6.10E-03	2.38E-04	6.00E-03
14 BUS	0.00E+00	8.10E-03	4.56E-04	9.80E-03
25 BUS	0.00E+00	8.70E-03	3.95E-04	5.40E-03

Fig. 4. Comparison of the voltage mismatch obtained from the 3-Test Bus Systems

Real Power Losses (in MW)

As we seen from bar graphs, it is clear that real power loss obtained from Newton Raphson method are constant i.e. does not vary as accuracy increases, where as in other methods losses increases as accuracy level increase.

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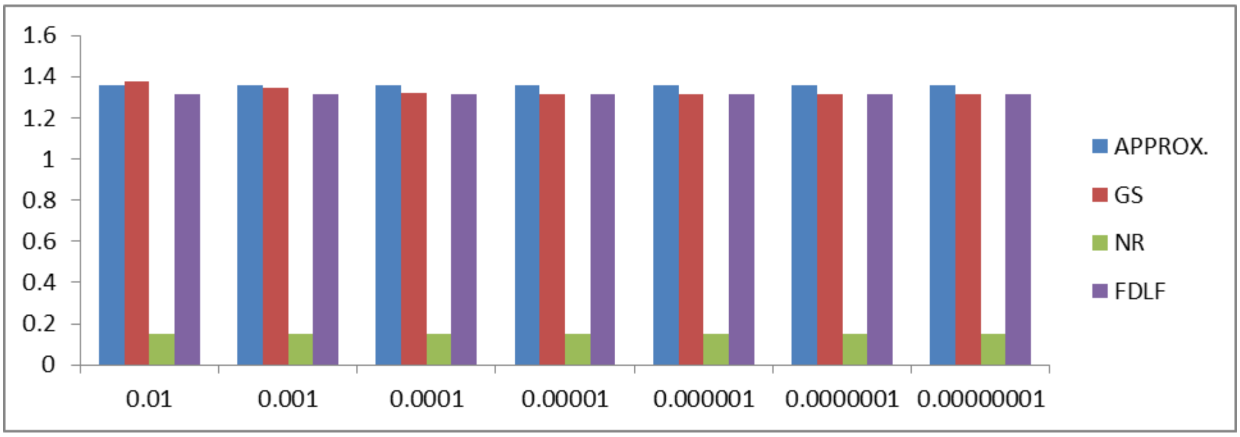

Fig. 5. Comparison of Real Power Losses as a function of accuracy obtained from 9 Bus System

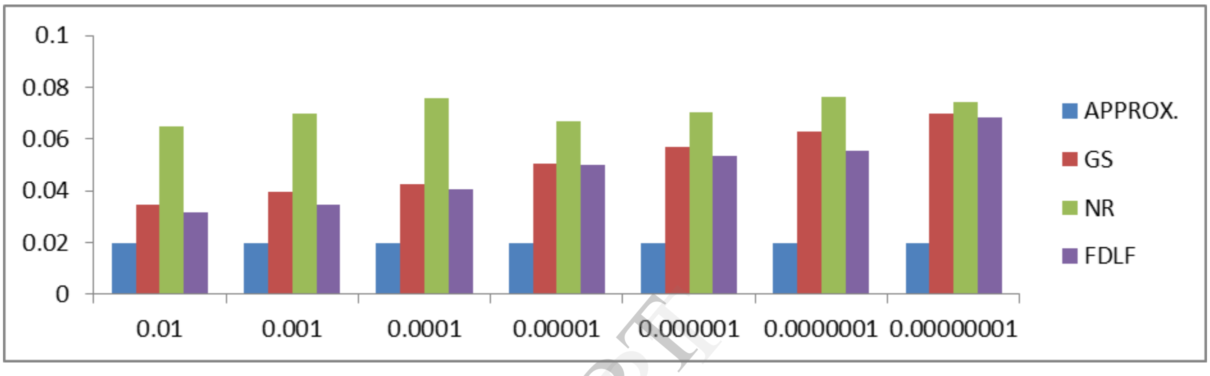

Fig. 6. Comparison of Real Power Losses as a function of accuracy obtained from 14 Bus System

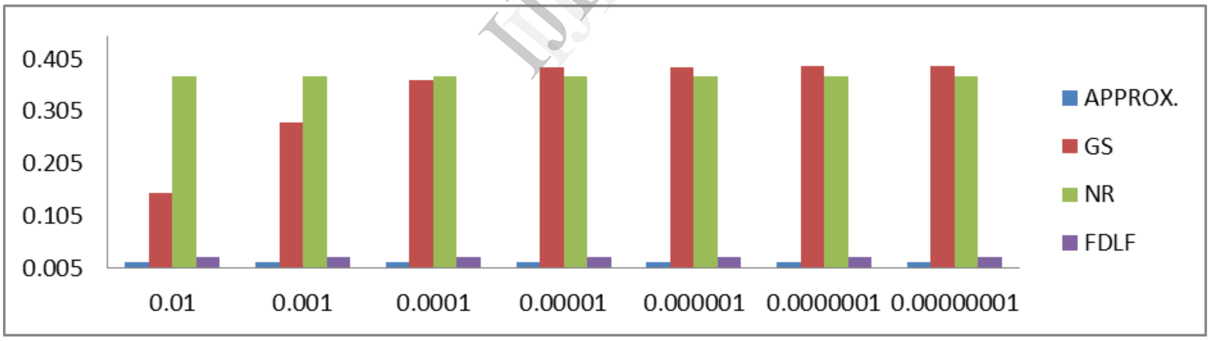

Fig. 7. Comparison of Real Power Losses as a function of accuracy obtained from 25 Bus System

Reactive Power Losses (MVAR)

As we seen from bar graphs, it is clear that reactive power loss obtained from Newton Raphson method are constant, where as in other methods losses increases as accuracy level increase.

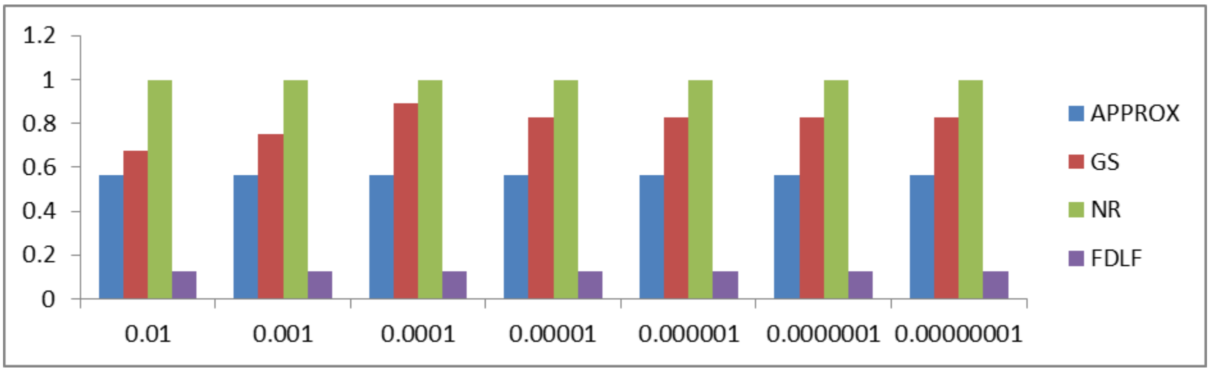

Fig. 8. Comparison of Reactive Power Losses as a function of accuracy obtained from 9 Bus System

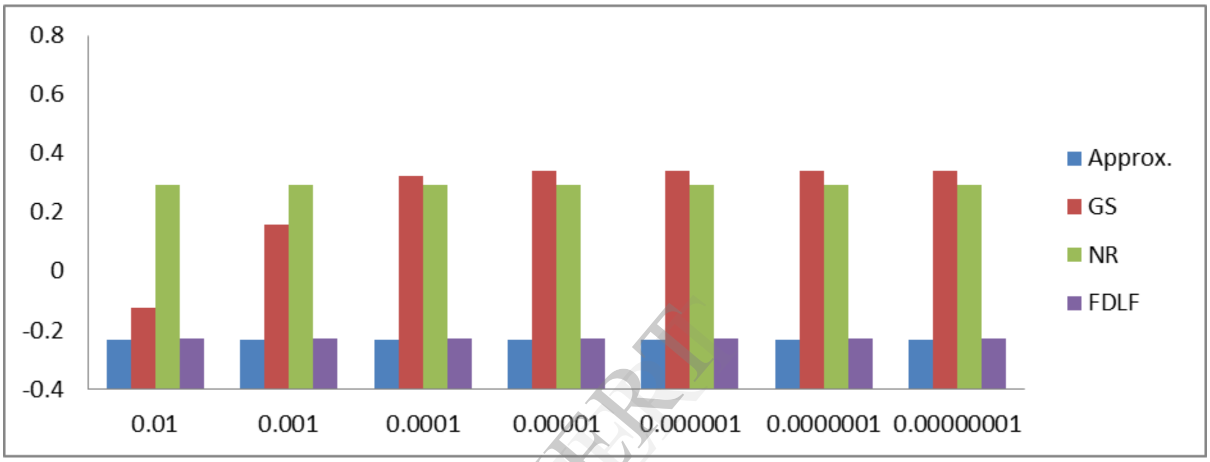

Fig. 9. Comparison of Reactive Power Losses as a function of accuracy obtained from 14 Bus System

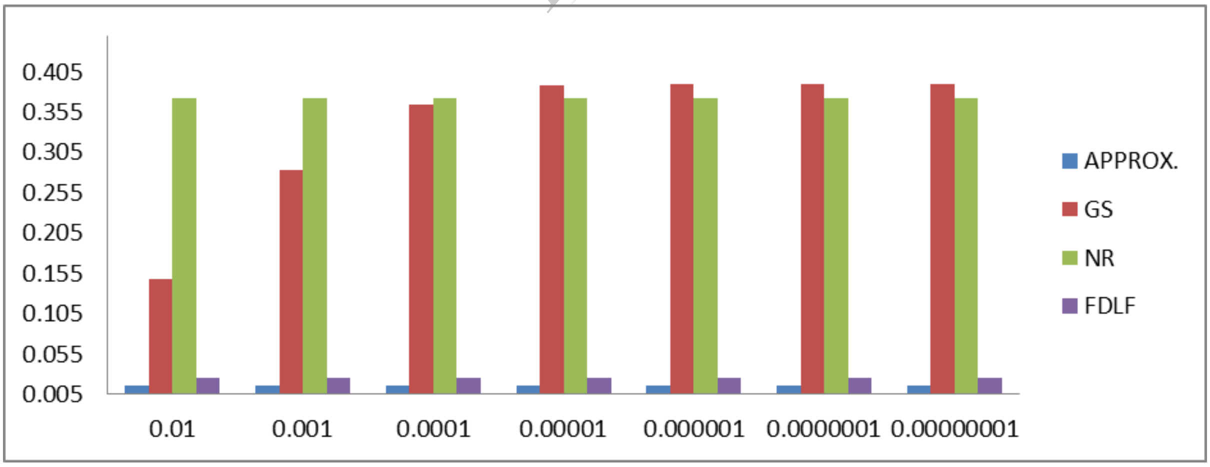

Fig. 10. Comparison of Reactive Power Losses as a function of accuracy obtained from 25 Bus System

VIII. CONCLUSION

From above results it indicates that Newton Raphson method is more reliable because it converges faster and it takes least number of iterations when compared with the other methods, In general the Newton Raphson algorithm takes the least number of iteration to converge despite its longer computing time but as accuracy increases computing time of Newton Raphson is quite less than other methods. The number of iteration for the Gauss-Seidel increases directly as the number of the buses of the network, whereas the number of iterations for the Newton Raphson method remains practically constant, independent of the system size and approximate method is a non-iterative method. It is based on approximations However, since the convergence characteristics of the Fast decouple method is geometric compare to the quadratic convergence of the Newton Raphson, thus it has more number of iteration. Therefore because of high accuracies obtained in only a few iterations, the Newton Raphson method is important for use and more reliable than any of the methods.

IX. REFERENCES

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APPENDIX

IEEE 9-BUS SYSTEM INPUT DATA

Line number	From bus	To bus	Line impedance (p.u.)		Half line charging susceptance (p.u)
			Resistance	Reactance	
1	1	4	0	0.0576	0
2	4	5	0	0.0920	0.158
3	5	6	0.0390	0.1700	0.358
4	3	6	0	0.0586	0
5	6	7	0.0119	0.1008	0.209
6	7	8	0.0085	0.0720	0.149
7	8	2	0	0.0625	0
8	8	9	0.0320	0.1610	0.306
9	9	4	0.0100	0.0850	0.176

Bus number	Bus voltage		Generation		Load		Reactive Power limits	
	Magnitude (p.u.)	Phase angle (degree)	Real Power (MW)	Reactive Power (MVAR	Real Power (MW)	Reactive Power (MVAR	Q_{min} (MVAR)	Q_{max} (MVAR)
1	1.04	0	1.1417	-0.169	0	0	0	0
2	1.02533	0	0.40	0	21.7	12.7	-50	50
3	1.02536	0	0	0	94.2	19.1	-40	40
4	1	0	0	0	47.8	-3.9	--	--
5	1	0	0	0	7.6	1.6	--	--
6	1	0	0	0	11.2	7.5	--	--
7	1	0	0	0	0	0	--	--
8	1	0	0	0	0	0	--	--
9	1	0	0	0	29.5	16.6	--	--

IEEE 14-BUS SYSTEM INPUT DATA

Line number	From bus	To bus	Line impedance (p.u.)		Half line charging susceptance (p.u)	MVA rating
			Resistance	Reactance		
1	1	2	0.01938	0.05917	0.02640	120
2	1	5	0.05403	0.22304	0.02190	65
3	2	3	0.04699	0.19797	0.01870	36
4	2	4	0.05811	0.17632	0.02460	65
5	2	5	0.05695	0.17388	0.01700	50
6	3	4	0.06701	0.17103	0.01730	65
7	4	5	0.01335	0.04211	0.00640	45
8	4	7	0	0.20912	0	55
9	4	9	0	0.55618	0	32
10	5	6	0	0.25202	0	45
11	6	11	0.09498	0.1989	0	18
12	6	12	0.12291	0.25581	0	32
13	6	13	0.06615	0.13027	0	32
14	7	8	0	0.17615	0	32
15	7	9	0	0.11001	0	32
16	9	10	0.03181	0.0845	0	32
17	9	14	0.12711	0.27038	0	32
18	10	11	0.08205	0.19207	0	12
19	12	13	0.22092	0.19988	0	12
20	13	14	0.17093	0.34802	0	12

Bus number	Bus voltage		Generation		Load		Reactive Power limits	
	Magnitude (p.u.)	Phase angle (degree)	Real Power (MW)	Reactive Power (MVAR	Real Power (MW)	Reactive Power (MVAR	Q_{min} (MVAR)	Q_{max} (MVAR)
1	1.060	0	114.17	-16.9	0	0	0	10
2	1.045	0	40	0	21.7	12.7	-42.0	50.0
3	1.010	0	0	0	94.2	19.1	23.4	40.0
4	1	0	0	0	47.8	-3.9	--	--
5	1	0	0	0	7.6	1.6	--	--
6	1	0	0	0	11.2	7.5	--	--
7	1	0	0	0	0	0	--	--
8	1	0	0	0	0	0	--	--
9	1	0	0	0	29.5	16.6	--	--
10	1	0	0	0	9.0	5.8	--	--
11	1	0	0	0	3.5	1.8	--	--
12	1	0	0	0	6.1	1.6	--	--
13	1	0	0	0	13.8	5.8	--	--
14	1	0	0	0	14.9	5.0	--	--

IEEE 25-BUS SYSTEM INPUT DATA

Line number	From bus	To bus	Line impedance (p.u.)		Half line charging susceptance (p.u)
			Resistance	Reactance	
1	1	3	0.0720	0.2876	0.0179
2	1	16	0.0290	0.1379	0.0337
3	1	17	0.1020	0.2794	0.0148
4	1	19	0.1487	0.3897	0.0224
5	1	23	0.1085	0.2245	0.0573
6	1	25	0.0753	0.3593	0.0873
7	2	6	0.0617	0.2935	0.0186
8	2	7	0.0511	0.2442	0.0155
9	2	8	0.0579	0.2763	0.0175
10	3	13	0.0564	0.1487	0.0085
11	3	14	0.1183	0.3573	0.0185
12	4	19	0.0196	0.0514	0.0113
13	4	20	0.0382	0.1007	0.0220
14	4	21	0.0970	0.2547	0.0558
15	5	10	0.0497	0.2372	0.0557
16	5	17	0.0144	0.1269	0.1335
17	5	19	0.0929	0.2442	0.0140
18	6	13	0.0263	0.0691	0.0040
19	7	8	0.0529	0.1465	0.0078
20	7	12	0.0364	0.1736	0.0110
21	8	9	0.0387	0.1847	0.0118
22	8	17	0.0497	0.2372	0.0572
23	9	10	0.0973	0.2691	0.0085
24	10	11	0.0898	0.2359	0.0135
25	11	17	0.1068	0.2807	0.0161
26	12	17	0.0460	0.2196	0.0135
27	14	15	0.0281	0.0764	0.0044
28	15	16	0.0256	0.0673	0.0148
29	17	18	0.0806	0.2119	0.0122
30	18	19	0.0872	0.2294	0.0132
31	20	21	0.0615	0.1613	0.0354
32	21	22	0.0414	0.1087	0.0238
33	22	23	0.2250	0.3559	0.0169
34	22	24	0.0970	0.2595	0.0567
35	24	25	0.0472	0.1458	0.0317

Bus number	Bus voltage		Generation		Load		Reactive Power limits	
	Magnitude (p.u.)	Phase angle (degree)	Real Power (MW)	Reactive Power (MVAR	Real Power (MW)	Reactive Power (MVAR	Q_{min} (MVAR)	Q_{max} (MVAR)
1	1.030	0	Inf	Inf	0	0	-20	1.0
2	1.002	0	93.6	0	10	3	-20	1.5
3	1.050	0	151.3	0	50	17	-50	1.5
4	1.015	0	48.0	0	30	10	-50	0.5
5	1.007	0	178.4	0.5	25	8	-50	0.5
6	1.040	0	163.4	0	15	5	0	0
7	1	0	0	0	15	5	0	0
8	1	0	0	0	25	0	0	0
9	1	0	0	0	15	5	0	0
10	1	0	0	0	15	5	0	0
11	1	0	0	0	5	0	0	0
12	1	0	0	0	10	0	0	0
13	1	0	0	0	25	8	0	0
14	1	0	0	0	20	7	0	0
15	1	0	0	0	30	10	0	0
16	1	0	0	0	30	10	0	0
17	1	0	0	0	60	20	0	0
18	1	0	0	0	15	5	0	0
19	1	0	0	0	15	5	0	0
20	1	0	0	0	25	8	0	0
21	1	0	0	0	20	7	0	0
22	1	0	0	0	20	7	0	0
23	1	0	0	0	15	5	0	0
24	1	0	0	0	15	5	0	0
25	1	0	0	0	25	8	0	0