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Understanding Load Flow Studies by using PSAT

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Abstract: Load Flow Study (LFS) is the heart of most system-planning studies and also the starting point for transient and dynamic stability studies. The load flow problem models the nonlinear relationships among bus power injections, power demands, and bus voltages and angles, with the network constants providing the circuit parameters. This article provides formulations of the load LFSs. Load Flow are necessary for planning, operation, economic scheduling and exchange of power between utilities. The principal information of LFS is to find the magnitude and phase angle of voltage at each bus and the real and reactive Load flowing in each transmission lines. LFS is a significant tool involving numerical studies applied to a power system. In this article, iterative techniques are used due to there no known analytical method to solve the problem. To finish this studies there are methods of mathematical calculations which consist plenty of step depend on the size of system. This process is difficult and takes a lot of times to perform by hand. LFS software package develops by the author use Power System Analyses Toolbox (PSAT).

Keywords: Load flow, Newton Raphson method, Fast Decoupled method.

I. INTRODUCTION

LFS [1], [2] are performed to ensure that stable, reliable and economical way of power transfer from generators to end user. Usually load flow problem are solved by iteration [3], [4], by using NR, GS or Fast Decoupled method. Day by day with the increase in number of buses in power system LFS becomes mandatory. Many research works are carrying out to make programs for LFSs. However, programs perhaps meet with convergence problem when a radial distribution system (RDS) with a large number of buses is to be solved therefore, development of a special program for RDS studies becomes mandatory [5]. In this paper GS and fast decoupled method are deeply analyzed with solution procedures and formulations can be precise and approximate, intended for either on-line or off-line application. In the parlance, with large interconnected system, it becomes necessary to reduce running cost of power transfer due to soaring price rise and improving the efficiency of whole power system [6], [7]. A small decline in percentage of operation reflect huge cost saving of power transfer from generator to load centre or in other words decrease in fuel cost for the same power transfer capacity. The general difficulty is the economic load dispatch to achieve minimum cost of operation. Now these days Environmentalist creates many environment protection norms and standards, therefore it becomes essential to minimize pollutants and conserve various forms of fuel [8]. In addition to above, it is a need to expand the limited economic optimization problem to incorporate constraints on system operation to ensure the security of the system, thereby preventing the collapse of the system due to unforeseen conditions [9]. However closely associated with this economic dispatch problem is the problem of the proper commitment of any array of units out of a total array of units to serve the expected load demands in an optimal manner [10]. For the purpose of optimum economic operation of this large scale system, modern system theory and optimization techniques are being applied with the expectation of considerable cost savings. LFS gives voltage magnitudes and angles at each bus in the steady state. One of the most important studies of load flow is that the magnitudes of the bus voltages are required to be held within a specified limit or in other words there is no violation of bus voltage. Once the bus voltage magnitudes and their angles are computed using the load flow, the real and reactive power flow through each line can be easily computed [11], [12]. We can easily find the losses by subtracting power flow at the sending and receiving ends. Also, it is very easy to determine the line loading. Generally steady state active and reactive power supplied by a buses in a network are expressed in terms of nonlinear algebraic equations, therefore it would require iterative methods for solving these equations. Some of the important advantage of LFS are given as, it is very important at planning stages of new networks or addition to existing ones like adding generator centre, meeting increase load demand and locating new transmission sites. The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting power channels. It determines the voltage of the buses. The voltage level at the certain buses must be kept within the closed tolerances. The line flows can be known. The line should not be overloaded, it means, we should not operate the close to their stability or thermal limits. To study the performance of the transmission lines, transformer and generator at steady state condition. In this article PSAT software is used for the LFSs.

II. LOAD FLOW STUDIES

The LFS is a significant method which involves numerical studies applied to a power system. Usually Load flow study usually uses simplified notation such as a per unit system and one line diagram, and focuses on various form of AC power (i.e.: reactive, real and apparent) rather than voltage and current. The advantage in studying LFS is in planning the future expansion of power systems as well as in determining the best operation of existing systems. LFS is being used for solving Load flow problem by Newton Raphson method and Fast decoupled load flow method.

A. 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 phage angle of voltage, magnitude of voltage, active 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. For LFS it is assumed that the loads are constant and they are defined by their real and reactive power consumption. The main objective of the load flow is to find the voltage magnitude of each bus and its angle when the powers generated and loads are pre-specified. To facilitate this we classify the different buses of the power system shown in the chart below.

Classification of buses

- **Load Buses:** In these buses no generators are connected and hence the generated real power P_{Gi} and reactive power Q_{Gi} are taken as zero. The load drawn by these buses are defined by real power $-P_{Li}$ and reactive power $-Q_{Li}$ in which the negative sign accommodates for the power flowing out of the bus. This is why these buses are sometimes referred to as PQ bus. The objective of the load flow is to find the bus voltage magnitude $|V_i|$ and its angle δ_i.

- **Voltage Controlled Buses:** These are the buses where generators are connected. Therefore the power generation in such buses is controlled through a prime mover while the terminal voltage is controlled through the generator excitation. Keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator, we can specify constant P_{Gi} and $| Vi |$ for these buses.

- **Slack or Swing Bus:** Usually this bus is numbered 1 for the LFS s. This bus sets the angular reference for all the other buses. Since it is the angle difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However it sets the reference against which angles of all the other bus voltages are measured. For this reason the angle of this bus is usually chosen as 0°. Furthermore it is assumed that the magnitude of the voltage of this bus is known.

B. Bus Admittance Matrix

1. The first step is to number all the nodes of the system from 0 to *n*. Node 0 is the reference node (or ground node).
2. Replace all generators by equivalent current sources in parallel with an admittance.
3. Replace all lines, transformers, loads to equivalent admittances whenever possible.
4. The bus admittance matrix *Y* is then formed by inspection as follows (this is similar to what we learned in circuit theory): sum of admittances connected to node $i_{iy} = i$ and $y_{ij} = y_{ji}$ = -sum of admittances connected from node *i* to node *j*
5. The current vector is next found from the sources connected to nodes 0 to *n*. If no source is connected, the injected current would be 0.
6. The equations which result are called the node-voltage equations and are given the "bus" subscript in power studies thus bus I = Y V.

III. UNDERSTANDING LOAD FLOW SOLUTION

In Power System Engineering, the load flow study is an important tool involving numerical studies applied to a power system. Unlike traditional circuit studies , a power flow study uses simplified notation such as a one line diagram and per unit system , and focuses on various forms of AC power (i.e. reactive ,real and apparent) rather than voltage and current. It analyses the power systems in normal steady state operation. There exist a number of software implementations of LFSs.

A. Newton-Raphson Method

The Newton-Raphson method is widely used for solving non-linear equations. It transforms the original non-linear problem into a sequence of linear problems whose solutions approach the solutions of the original problem. Let G = F(x, y) be an equation where the variables x and y are the function of arguments of F. G is a specified quantity. If F is non-linear in nature there may not be a direct solution to get the values of x and y for a particular value of G. In such cases, we take an initial estimate of x and y and iteratively solve for the real values of x and y until the difference is the specified value of G and the calculated value of F(using the estimates of x and y) i.e. ΔF is less than a tolerance value. The procedure is as follows Let the initial estimate of x and y be x0 and y0 respectively**.** Using Taylor series, we have

$$G = F(x^0, y^0) + \left|\frac{\partial F}{\partial x}\right|_{x0,y0} \Delta X + \left|\frac{\partial F}{\partial y}\right|_{x0,y0} \Delta y \quad \ldots..(1)$$

Where *the terms* $\frac{\partial F}{\partial x}$ and $\frac{\partial F}{\partial y}$ are calculated at x0 and y0

$$G - F(x0, y0) = \Delta F = \frac{\partial F}{\partial x}\Delta X + \frac{\partial F}{\partial y}\Delta y \quad \ldots\ldots\ldots\ldots..(2)$$

In the matrix form it may be written as

$$\Delta F = \begin{bmatrix} \frac{\partial F}{\partial x} & \frac{\partial F}{\partial y} \end{bmatrix} \begin{bmatrix} \Delta X \\ \Delta y \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots(3)$$

Or

$$\begin{bmatrix} \Delta X \\ \Delta y \end{bmatrix} = inv \begin{bmatrix} \frac{\partial F}{\partial x} & \frac{\partial F}{\partial y} \end{bmatrix} \Delta F \quad \ldots\ldots\ldots\ldots(4)$$

After the first iteration x is updated to x^1 = x0 + Δx and y to y^1 = y0 + Δy. The procedure is continued till after some iteration both ΔF is less than some tolerance value ε. The values of x and y after the final update at the last iteration is considered as the solution of the function F. For the load flow solution , the non-linear equations are given by equation (3).
Using (3) we get the equation of real power and reactive power in matrix form as

$$\begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial V} \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad \ldots\ldots\ldots(5)$$

Size of the matrix = NB + (NB - (NV+1)) – 1 = 2(NB – 1) – NV
where,
(NB - (NV+1)) is the number of PQ buses.
NV the number of PV buses.
NB is the total number of buses.

The matrix of equation (5) consisting of the partial differentials, is known as the Jacobian matrix and is very often denoted as [J]. ΔP is the difference between the specifies value of P, i.e. (P^{sp}) and the calculated value of P using the estimates of δ and |V| in a previous iteration. We calculate ΔQ similarly. The Newton Load flow is the most robust power flow algorithm used in practice. However, one drawback to its use is the fact that the terms in the Jacobian matrix must be recalculated each iteration, and then the entire set of linear equations in equation (5) must also be resolved each iteration. Since thousands of complete Load flow are often run for planning or operations study, ways to speed up this process were devised.

B. XB and BX fast decoupled load flow method

The Fast Decoupled load Flow (FDLF) was originally proposed in [Stott and Alsac] and has been further developed and generalized in several variations. In PSAT we uses the XB and BX versions of FDLF method. The Load flow Jacobian matrix [J] can be decomposed in four sub-matrices, these matrices can also be written as

$$\begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \frac{\Delta V}{V} \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots(6)$$

Where, $H_{ik} = \frac{\partial Pi}{\partial \delta k}$, $N_{ik} = V_k \frac{\partial Pi}{\partial Vk}$, $J_{ik} = \frac{\partial Qi}{\partial \delta k}$, $L_{ik} = V_k \frac{\partial Qi}{\partial Vk}$

The assumptions which are valid in normal power system, are made as follows:
(i) Under normal loading condition angle differences, $(\delta_i - \delta_k)$, across transmission lines are small, i.e. $\cos(\delta_i - \delta_k) \cong 1$, $\sin(\delta_i - \delta_k) \cong 0$
(ii) for a transmission line its reactance is more than its resistance. In other words, X/R>>1. So, G_{ik} can be ignored because $G_{ik} << B_{ik}$.

In view of the above, $G_{ik}\sin(\delta_i - \delta_k) << B_{ik}$ and $Q_i << B_{ii} v_i^2$.
With these assumptions, the simplified jacobian matrix is given below

$$\begin{bmatrix} H & 0 \\ 0 & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \frac{\Delta V}{V} \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \qquad \ldots\ldots\ldots\ldots(7)$$

$$\sum_{k=2}^{NB} \text{Hik}\ \Delta\delta\text{k} = \Delta P\text{i} \qquad (\text{i}= 1,2,3,\ldots\text{NB}) \qquad \ldots\ldots\ldots..(8)$$

$$\sum_{k=NV+1}^{NB} [\text{Lik}] \frac{\Delta Vk}{Vk} = \Delta Qi \qquad \text{i=NV+1,NV+2,....NB)} \ .\ (9)$$

The element of H and L submatrices become considerably specified as

$$\text{Hii} = \frac{\partial Pi}{\partial \delta i} = -B_{ii} V_i^2 \qquad (\text{i} = \text{k}) \qquad \ldots\ldots. (10)$$

$$\text{Hik} = \frac{\partial Pi}{\partial \delta k} = -V_i V_k B_{ik} \qquad (\text{i} \neq \text{k}) \qquad \ldots\ldots\ldots\ldots (11)$$

$$\text{Lii} = Vi \frac{\partial Qi}{\partial \delta i} = -B_{ii} V_i^2 \qquad (\text{i} = \text{k}) \qquad \ldots\ldots\ldots\ldots (12)$$

$$\text{Lik} = V_k \frac{\partial Qi}{\partial \text{Vk}} = -V_i V_k B_{ik} \qquad (\text{i} \neq \text{k}) \qquad \ldots\ldots\ldots\ldots (13)$$

By substituting eqs. (10) and (11) in eqs. (8) we get,

$$\sum_{k=2}^{NB} [-\text{Vi Vk Bik}]\partial\delta k = \Delta P\text{i} \quad (\text{i}= 2,3,4,\ldots,\text{NB}) \ldots (14)$$

setting ^{V}k = 1 p.u. on right hand sideof equation(5)

$$\sum_{k=2}^{NB} -[B_{ik}]\Delta\delta k = \frac{\partial Pi}{Vi} \qquad \ldots\ldots\ldots(15)$$

By substituting eqs. (12) and (13) in(9) we get,

$$\sum_{k=NV+1}^{NB} -[V_i V_k B_{ik}] \frac{\Delta Vk}{Vk} = \Delta Qi \qquad \ldots\ldots\ldots(16)$$

setting ^{V}k = 1 p.u. on right hand sideof equation (6)

$$\sum_{k=NV+1}^{NB} [-\text{Bik}]\ \Delta\,\text{Vk} = \frac{\Delta Qi}{Vi} \qquad \ldots\ldots\ldots(17)$$

Above eq. Can be written in matrix form,

$$[\mathbf{B'}][\Delta\delta] = \left[\frac{\Delta P}{V}\right] \qquad \ldots\ldots.(18)$$

$$[\mathbf{B''}][\Delta V] = \left[\frac{\Delta Q}{V}\right] \qquad \ldots\ldots.(19)$$

Where B' is the matrix having elements $-\text{Bik}$ (i= 2,3, …,NB and k =2,3, …,NB)
B'' is the matrix having elements $-\text{Bik}$ (i=NV+1,NV+2,….NB and k=NV+1,NV+2,…NB)
Where B' and B'' can be thought as admittance matrices with the following simplifications:
1. Line charging, shunts and transformer tap ratios are neglected when computing B'.
2. Phase shifters are neglected and line charging and shunts are doubled when computing B''.

The XB and BX variations differ only in further simplifications of the B' and B'' matrices respectively, as follows:

In XB version: line resistances are neglected when computing **B'.**
In BX version: line resistances are neglected when computing **B''**
PSAT allows using XB and BX version of FDLF methods for system which contain only PV generators, PQ loads and one slack bus.

IV. CASE STUDY

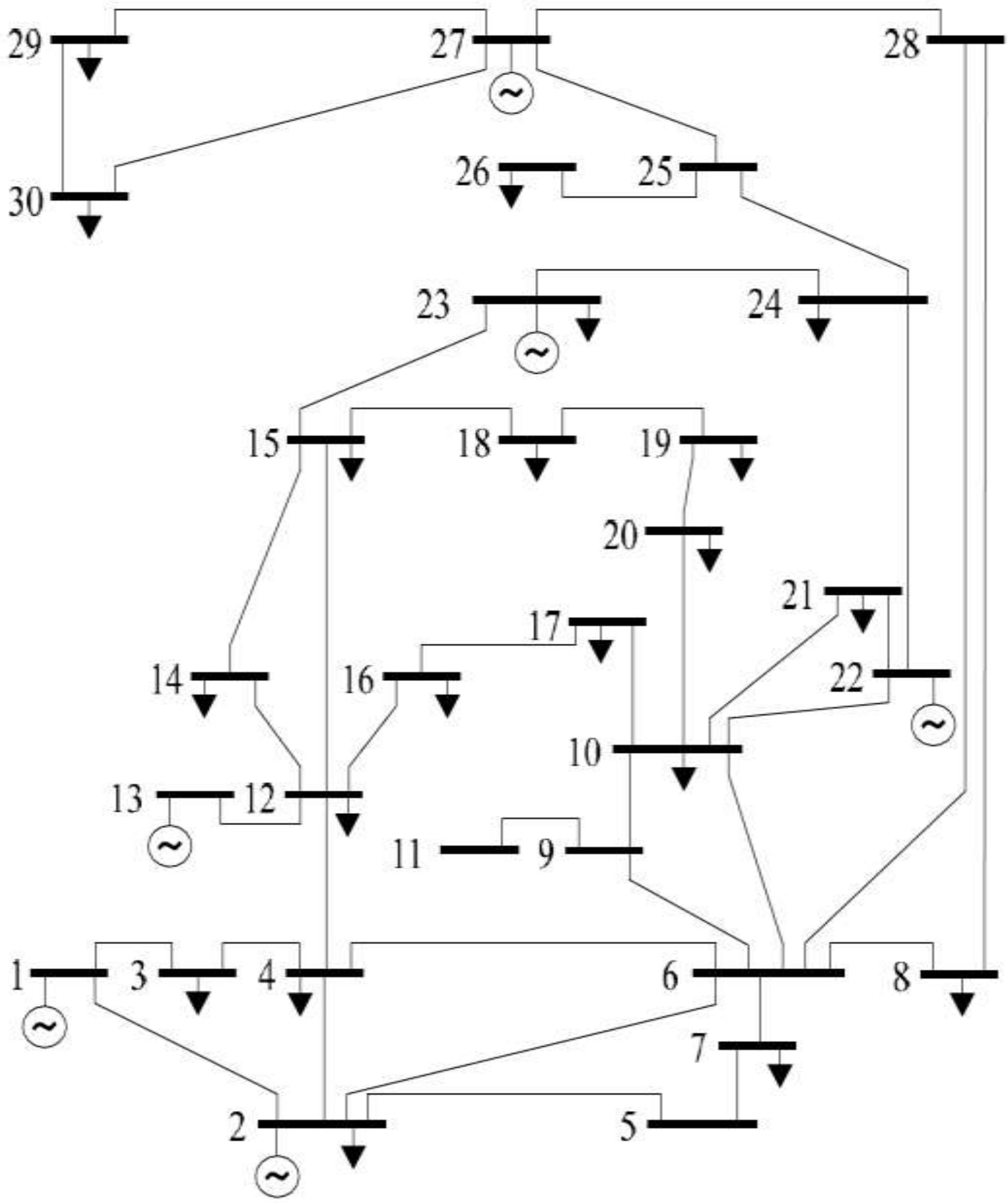

Fig. 1: 30 bus system

Fig. 1 shows the IEEE 30 bus system, now application of PSAT software to this system gives the following result. Fig. 2 shows voltage phase profile comparison between NR method & XB Fast decoupled method. Graph plotted shows that voltage phase profile has slight variation in phase at all the buses. Fig. 3 shows that Reactive Power profile at different buses. There is variation of reactive power requirement at bus 1, 2. Fig. 4 shows the real power profile at different buses. Fig. 5 shows the voltage magnitude profile. Table 1 shows the comparison between NR method & XB Fast Decoupled Method.

Table 1: The comparison between Load flow methods

S.No.	N-R method	XB Fast Decoupled
1.	Number of iterations is less.	Number of iterations is more.
2.	Computation time per iteration is more.	Computation time per iteration is less.
3.	It has quadratic convergence characteristic	It has linear convergence characteristic
4.	The number of iterations is independent of the size of the system.	The number of iterations depends of the size of the system.
5.	The choice of slack bus is arbitrary.	The choice of slack bus is not arbitrary due to PSAT inbuilt function files.

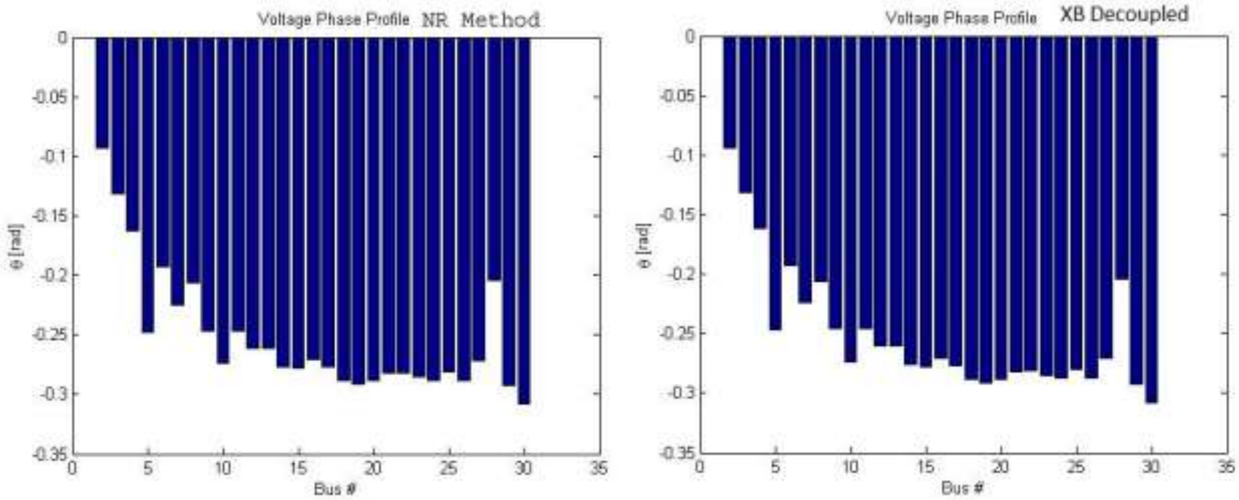

Fig. 2: Comparison of voltage profile

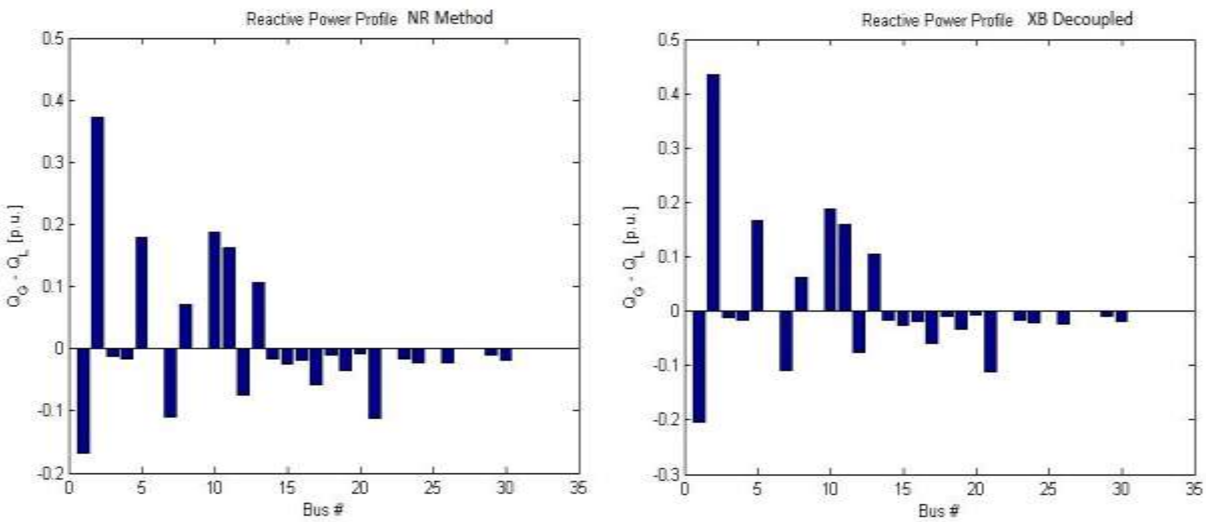

Fig. 3 Comparison of Reactive Power Profile

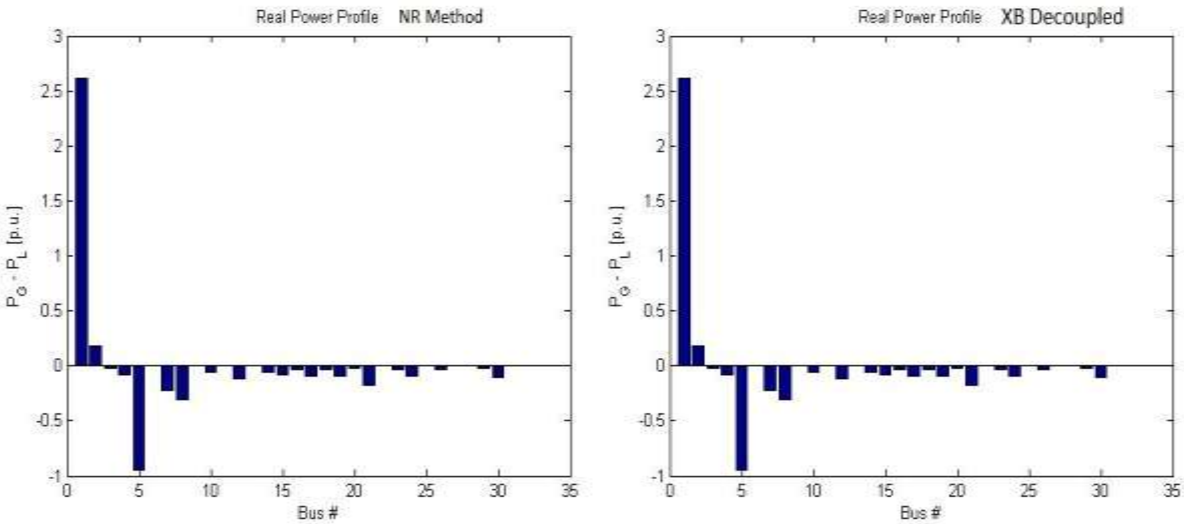

Fig. 4 Comparison of Real Power Profile

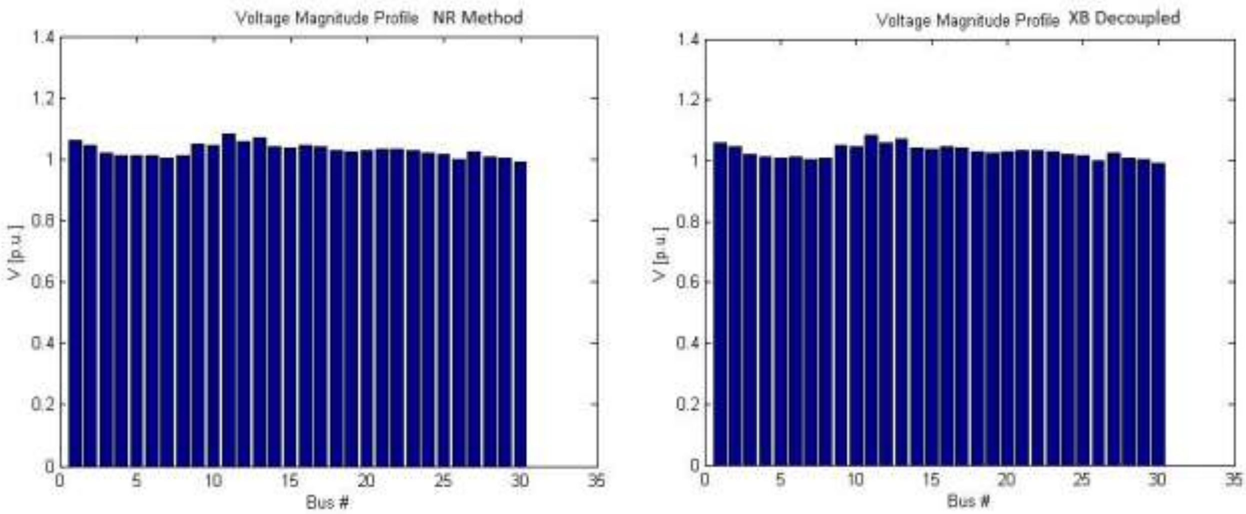

Fig. 5 Comparison of Voltage Magnitude Profile

V. CONCLUSION

This article shows the NR Method and XB fast decoupled method involved in solving the nonlinear load flow problems by using PSAT software. Further research work can be done for finding more powerful methods to solve the Load flow equations with more efficiency in terms of time, computer memory storage as well as robustness. The principal information obtained from the Load flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line. We have formulated IEEE 30 bus for analyzing load flow by using PSAT. Voltage magnitude and angles of a 30 bus system were observed for different values of Reactance loading and the findings have been presented. From the findings, it is concluded that increasing the reactance loading resulted in an increased voltage regulation. In Newton-Rahpson method, calculations are complex, but the number of iterations is low even when the number of buses is high, while in XB fast decoupled method number of iteration are more but it takes small time for convergence.

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