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Reactive Power Loss & Efficiency Calculation Using Load Flow Technique In Distribution System For Pune City

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Abstract - Reactive power compensation is an important issue in electric power systems, involving operational, economical and quality of service aspects. Consumer loads (residential, industrial, service sector, etc.) impose active and reactive power demand, depending on their characteristics. This paper presents an efficient method for solving the load flow problem in distribution systems and which is implemented for Pune city (India) to check the validity of proposed method. A simple algebraic matrix equation to solve the load flow problem is derived by using the complex power balance equations. By adopting the rectangular coordinate, which requires the neglect of only second order terms in the linearization procedure, the proposed method gives better convergence characteristics. Newton-Raphsonmethod is the famous load flow calculation technique, and normally used dueto its rapidness of numerical convergence. The proposed method estimates the incremental changesof active power on each generation bus with respect to the total system power loss, efficiency and the estimated value are used to update the slack bus power.

Keywords - *Reactive power,load flow, Distribution feeders, Y_{BUS} formulation.*

I. INTRODUCTION

Reactive power compensation is an important issue in electric power systems, involving operational, economical and quality of service aspects. Consumer loads (residential, industrial, service sector, etc.) impose active and reactive power demand, depending on their characteristics. Active power is converted into “useful” energy, such as light or heat. Reactive power must be compensated to guarantee an efficient delivery of active power to loads, thus releasing system capacity, reducing system losses, and improving system power factor and bus voltage profile.

Load flow analysis has a great importance in future expansion planning, in stability studies and in determining the best economical operation for existing systems. Also load flow results are very valuable for setting the proper protection devices to insure the security of the system. In order to perform a load flow study, full data must be provided about the studied system, such as connection diagram, parameters of transformers and lines, rated values of each equipment, and the assumed values of real and reactive power for each load. [3]

The power flow calculations are the most important and powerful tools in power systems engineering. Newton-Raphson *(NR)* method, among the various power flow calculation techniques, is normally used due to its rapidness of numerical convergency. In the conventional Newton-Raphson method, however, there is a somewhat unrealistic assumption under which all the system power losses are considered to be supplied by the slack bus generator. The unrealistic feature of the assumption may make little difficulty in general cases of power systems engineering, but in certain cases, especially such as voltage stability studies, it can make the results of load flow solution distorted from those of the real system. In the situations close to voltage collapse, power system has relatively large transmission loss which makes load flow solution often diverges. In those situations, even in convergence case, the results of load flow solution would be more distorted than in the normal, and these distorted solutions can make the results of voltage stability analysis inaccurate [2].

II. MATHEMATICAL FORMULATION

There are several different methods of solving the resulting nonlinear system of equations. The most popular is known as the Newton-Raphson Method. This method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses)

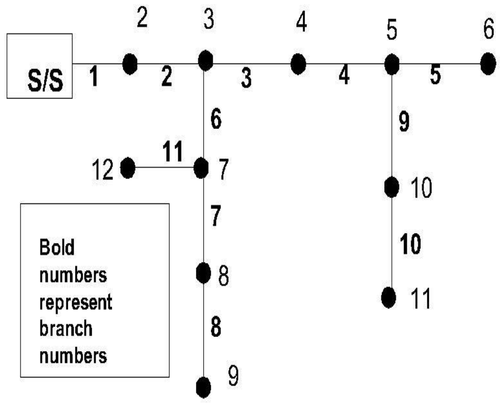

Fig. 1: Single Line Diagram of Radial Distribution Network

Let bus indices 1 to m denote pure load buses, (m+l) to (n-1) denote pure generation buses, and n denote slack bus, then LF problem is to find, m+n-1 unknown variables, bus voltage magnitudes (V) and n-1 bus voltage angles (δ), from the following nonlinear simultaneous equations.

$Pi = \sum_{j=1}^{n}$ Vi Vj (Gij cos δij + Bij sin δij,
I Є (L+G) (1a)

$Qi = \sum_{j=1}^{n}$ Vi Vj (Gij sin δij - Bij cos δij,
j Є L (1b)

Where,

Pi, Qi = Active, Reactive pure injection power at bus i.

Gij, Bij = conductance. susceptance between bus i and j

δij = δi - δj

L = {l. ... m}: index set of load bus

G = {m+l,..,n-l} : index set of generation bus (slack bus excluded).

In general, Pi, Vi (i Є G), Vn, δn (n : slack bus), Pj, Qj (j Є L) are considered as preliminarily specified in the conventional LF formulations. In some literature, Pi, Vi (i Є G), Vn, δn are called controlled variables.*NR* Method then finds the unknown variabes Vi, i Є L and δi, i Є L+G (these are called state variables basically with iterative updating scheme from a given initial point (V^0, δ^0), based on the 1st order Tayler approximation of eq. (1)[4]

Unknown variable updating scheme

The iterative *scheme* commonly used can be explained in brief with the following equations;

$$\begin{bmatrix} \Delta\delta \\ \hline \Delta V/V \end{bmatrix} = \begin{bmatrix} H & M \\ N & L \end{bmatrix}^{-1} \begin{bmatrix} \Delta P \\ \hline \Delta Q \end{bmatrix} \quad (2)$$

Where, ΔP = Active power mismatch ,

ΔQ = Reactive power mismatch

Δδ = Voltage angle difference.

ΔV = Voltage magnitude difference,

H=(∂P/∂δ), M=(∂P/∂V)V, N=(∂Q/∂δ), L=(∂Q/∂V)V, Jacobian sub matrix[4]

Then, newly updated magnitude and angle of bus voltage are obtained:

$V_{new} = V^o + (\Delta V/V)\, V^o$ (3a)

$\delta\ new = \delta^o + \Delta\delta$ (3b)

If V, δ are converged after a few iterations. then the final values are accepted as the solution of the LF calculation.[5]

Calculation of line power flows and slack bus power

Given the solution the power flow of each transmission line and slack bus power are obtained with following expressions:[7]

$Pij = ViVj(Gij \cos \delta iJ + Bij \sin \delta ij) - Vi^2 Gij$ (4a)

$Qij = Vi\ Vj\ (Gij \sin \delta ij - Bij \cos \delta ij\ i\ j\ ) + Vi^2\ (Bij - bij/2)$ (4b)

Where,

bij = shunt susceptance of the line between bus i and j

Pij, Qij = Active, reactive power flow from bus i to j

And

$Pn= \sum_{j=1}^{n} VnVj(Gnj\ cos\delta nj + Bnj\ sin\delta nj)$ *(5a)*

$Qn= \sum_{j=1}^{n} VnVj(Gnj\ sin\delta nj - Bnj cos\delta nj)$ *(6)*

$V_i^{*}\sum_{i=1}^{N} Yij\ Vj = P_i^{sp} - j\ Q_i^{sp}$, i=1, …,N, $i \neq s$ (7)

Where s denotes the slack bus

With an appropriate solution guess $V_0 = [V_{10}, V_{20},\ldots, V_{N0}]$, the above equation can be rewritten as

$(V^{*}_{i0} + \Delta V_i^{*}\sum_{j=1}^{N} Y_{ij}\,(V_{j0} + \Delta V_j) = P_i^{sp} - j\ Q_i^{sp}$, (8) By neglecting the second order terms, we can obtain the following linearized equation

$$V^*_{i0}\sum_{(j=1,j\neq s)}^{N} Y_{ij}\,\Delta V_j + \left(\sum_{j=1}^{N} Y_{ij}\, V_{j0}\right)\Delta V_i^* \approx (P_i^{sp} - j\,Q_i^{sp}) - V^*_{i0}\sum_{j=1}^{N} Y_{j}\,\Delta V_{j0} \qquad (9)$$

From Eq.(1), we can obtain the following approximated relation.

$$\sum_{(j=1)}^{N} Y_{ij}V_{j0} = (P_i^{sp} - jQ_i^{sp})/ V^*_{i0} \qquad (10)$$

Substituting (10)into (9) and dividing both sides by V^*_{i0}, yield

$$\sum_{(j=1,j\neq s)}^{N} Y_{ij}\Delta V_j + \{(P_i^{sp} - jQ_i^{sp})/(V^*_{i0})^2\}\Delta V_i^* \approx \Delta I_i \quad , \quad i= 1, 2,\ldots,N \;\&\; I \neq s \qquad (11)$$

In the above equation, the current mismatch ΔI_i^{sp} is determined by

$$\Delta I_i^{sp} = (P_i^{sp} - jQ_i^{sp})/V^*_{i0} - \sum_{(i=1)}^{N} Y_{ij}V_{j0}$$

$$= \{(P_i^{sp} - jQ_i^{sp}) - (P_i - jQ_i)\}/ V^*_{i0} \qquad (12)$$

$$= (\Delta P_i - j\Delta Q_i)/ V^*_{i0}$$

Where, $\Delta P_i = P_i^{sp} - P_i$

$\Delta Q_i = Q_i^{sp} - Q_i$

The above equation can be rewritten in a matrix form as follows:

$$Y_{BUS}\,\Delta V + D\Delta V^* = \Delta I \qquad (13)$$

Where, $\Delta V = [\Delta V_1,\Delta V_2, ..., \Delta V_N)^T$

$\Delta I = [\Delta I_1,\Delta i_2, ..., \Delta I_N)^T$

$D = \mathrm{diag}\{(P_i^{sp} - jQ_i^{sp})/(V^*_i)^2\}$

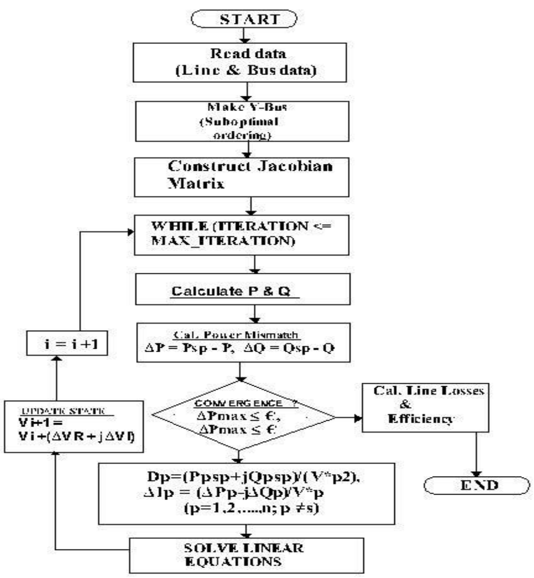

Fig. 2 : Flow Chart for the proposed method

III. RESULT AND RESULT ANALYSIS

12 node Line data

Branch	Sending-end	Receiving -end	r(pu)	x(pu)
1	1	2	0.0192	0.0575
2	2	3	0.0452	0.1652
3	3	4	0.0570	0.1737
4	4	5	0.0132	0.0379
5	5	6	0.0472	0.1983
6	3	7	0.0581	0.1763
7	7	8	0.0119	0.0414
8	8	9	0.0460	0.1160
9	5	10	0.0267	0.0820
10	10	11	0.0120	0.0420
11	7	12	0.0	0.2080

12 node Load data

Nodes	P_{Li} at RE (kW)	Q_{Li} at RE (KVARr
1	0	0
2	21.7	12.7
3	2.4	1.2
4	7.6	1.6
5	94.2	19.0
6	0.0	0.0
7	22.8	10.9
8	30.0	30.0
9	0.0	0.0
10	5.8	2.0
11	0.0	0.0
12	6.1	1.6

Result Table

Bus	Type	PLi	QLi	Efficiency
1	1	0	0	0
2	3	21.7	12.7	63
3	3	2.4	1.2	66.67
4	3	7.6	1.6	82.6
5	3	94.2	19.0	83.2
6	3	0.0	0.0	0
7	3	22.8	10.9	67.6
8	3	30.0	30.0	50

Bus	Type	PLi	QLi	Efficiency
9	3	0.0	0.0	0
10	3	5.8	2.0	74.3
11	3	0.0	0.0	0
12	3	6.1	1.6	79.2

IV. CONCLUSIONS

In this study, a simple and efficient load flow solution has been proposed for determining system power loss & efficiency for distribution system in Pune city(INDIA).

A simple algebraic matrix equation has been derived from conventional complex power balance equation. Since only second order terms are required to be neglected in the linearization procedure, the proposed method gives better convergence characteristics. Only diagonal elements of matrix and current mismatch vector are updated each iteration in the proposed algorithm, which remarkably improves the computation speed with use of the sparsity technique and near-optimal ordering.

The proposed method can be applied to any city with fast calculation speed& it can be well applied to the distribution system with a wide range of R/X ratios.

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