

Topology based approach for Efficient Load flow Solution of Radial Distribution Networks

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Abstract: In this paper, load flow solution is obtained for radial distribution system using a new algorithm. Network topology is exploited to build two matrices for obtaining load flow solution of radial distribution system. Effective load at each node consists of two parts. Part one is the sum of all active and reactive powers connected to nodes beyond a particular node. And part two is the power loss in all the lines connected beyond the node under consideration. Two new network matrices are proposed to obtain the two parts of the effective load. 'bus injection to Node power matrix' is used to identify first part of the effective load at each node and 'Line loss to node power matrix' is used to calculate the second part of the effective load at each node. In this method, simple algebraic expression of voltage magnitude is used. This method is very efficient and requires very less computer memory. The proposed algorithm is applied to 15bus and 85 bus systems used in the literature and the results are compared. Results are accurate up to the fourth decimal.

I. INTRODUCTION

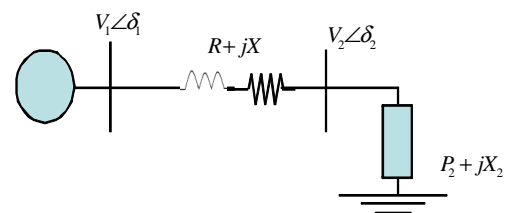
Distribution load flow is important for distribution automation systems, and distribution management systems. Network optimization, VAR planning, switching, state estimation etc. need the support of robust and efficient load flow solution. Traditional transmission system load flow methods Gauss-Siedel and Newton Raphson techniques, cannot be used for distribution systems as R/X ratio is high. Kresting and Mendive [1] have presented a load flow technique based on the ladder network theory. Teng and Lin(1994) proposed solution for meshed topology

In India, all the 11KV rural distribution feeders are radial and too long. The voltages at the far end of many such feeders are very low with very high voltage regulation. D. Das and D. P. Kothari have proposed a load flow solution method by writing a algebraic equation for bus voltages [2]. Network

topology based technique for three phase un-balanced systems is developed by J.H. Teng [3]. Equivalent current injection at each node is considered for the analysis in their work. Shirmohamadi *et al* [3] have presented a compensation based power flow for weakly meshed transmission and distribution systems. Baran and Wu [5] and Chiang [6] have obtained the load flow solution in a distribution system by iterative solution of three fundamental equations representing real power, reactive power and voltage magnitude. In many developing countries, the 11KV rural distribution feeders are radial and too long. The voltages at the far end are very low with very high regulation.

In this paper, the proposed method involves only evaluation of a simple algebraic expression of voltage magnitude [2] and no trigonometric terms. Topology based approach is used for evaluating equivalent load at every node. This eliminates the complex process of identifying nodes connected beyond a particular node as described in [2]. The two developed matrices, 'bus injection to node power matrix' and 'line loss to node power matrix' are very easy to form. The features of this method are robustness and computer economy. Convergence is always guaranteed. The assumption is that shunt capacitance is negligible at the distribution voltage level.

II. FORMULATION FOR THE MODEL



P_2 and Q_2 are effective active and reactive powers supplied beyond node 2. Formulae have been derived in ref[2]. This model of calculating voltages is termed in [2] as simple and efficient method of load flow by Das and Kothari. The same equations are used along with the matrices developed from network topology. This model also requires less memory and rapid. The load flow equations used are,

$$A(j) = P_2 R(j) + Q_2 X(j) - \frac{V_2^2}{2} \quad (1)$$

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$$B[j] = \sqrt{[A[j]^2 - (R_2^2 + Q_2^2)(R[j]^2 + X[j]^2)]} \quad (2)$$

$$V_2 = \sqrt{[B[j] - A[j]]} \quad (3)$$

$$P_{loss}[j] = R[j] * \left[\frac{R_2^2 + Q_2^2}{V_2^2} \right] \quad (4)$$

$$Q_{loss}[j] = X[j] * \left[\frac{R_2^2 + Q_2^2}{V_2^2} \right] \quad (5)$$

A. Bus-Injection to Node Power matrix: (BINP)

For distribution systems, the models which are based on the effective load at every node is very convenient. At each bus 'i' the complex power S is specified by,

$$S_i = P_i + j Q_i \quad \text{--- (6)}$$

P_i and Q_i are the real power and imaginary powers at ith node. The set of equations can be written by applying Kirchhoff's current law (KCL) to the distribution network. The KCL equations will equally hold good for powers also. For example, consider a simple 6 bus system. N₂, N₃, N₄, N₅ and N₆ are the equivalent powers at each Node

$$\begin{aligned} N_2 &= S_3 + S_4 + S_5 + S_6 \\ N_3 &= S_3 + S_5 \\ N_4 &= S_4 + S_6 \end{aligned} \quad \text{---- (7)}$$

Where S₃, S₄, S₅ and S₆ are complex load powers respectively at buses 3,4,5 and 6. Effective load at Node [N] can be obtained by,

$$[N] = [BINP] [S] \quad \text{---- (8)}$$

The constant BINP matrix has entries of 1 and 0 only. For a distribution system with m-branch sections and n-load buses, the dimension of the BIBC is m X n. The bus where there is no load need not enter into matrix [S]

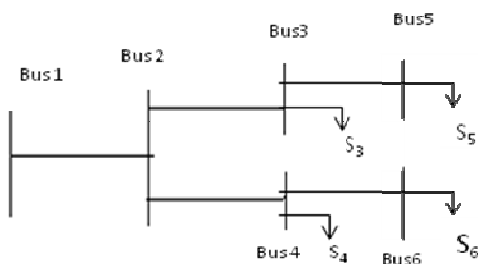


Fig. 1 Sample distribution system.

$$\begin{bmatrix} N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} S_3 \\ S_4 \\ S_5 \\ S_6 \end{bmatrix} \quad \text{--- (9)}$$

B. Line Loss to Node Power matrix: (LLNP)

The relation between the line losses and node power can be obtained by following equations.

$$\begin{aligned} N_2' &= S_{11} + S_{12} + S_{13} + S_{14} + S_{15} \quad \text{similarly,} \\ N_3' &= S_{14} \\ N_4' &= S_{15} \end{aligned} \quad \text{---- (10)}$$

Complex power losses associated with lines 1,2,3,4,5 are given by S₁₁, S₁₂, S₁₃, S₁₄ and S₁₅ respectively. Sum of the line losses appearing at Node 2, 3, 4, 5 and 6 are given by N₂, N₃, N₄, N₅, N₆. Total Line loss supplied by node2, N₂

End nodes will not have to supply and line loss component. So, they will have all zeros in their corresponding rows. Node 2 will have to supply all the line losses except branch -1 loss. S_L is the column matrix containing all line losses.

$$[N'] = [LLNP] [S_L]$$

$$\begin{bmatrix} N_2' \\ N_3' \\ N_4' \\ N_5' \\ N_6' \end{bmatrix} = \begin{bmatrix} 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} S_{11} \\ S_{12} \\ S_{13} \\ S_{14} \\ S_{15} \end{bmatrix} \quad \text{--- (11)}$$

$$\text{Effective load at each node} = N + N' \quad \text{--- (12)}$$

After calculating the effective load at each node, recalculate the receiving end voltages using the above equations(1) – (3). And calculate power losses using equations (4) and (5). The voltage values at all nodes change after adding losses.

Algorithm for the proposed Method :

1. Read the system data, V₁= 1.0 pu. Line losses are assumed to be zero in the first iteration.
2. Build BINP matrix and LLNP matrix.
3. Obtain P_{effective} + j*Q_{effective}, at each node using equation(8). N represents the part of load powers in the effective load at various nodes.

$$[N] = [BINP] [S]$$

where, S is the column matrix of all loads.

4. Initialize iteration count =1.
5. Obtain receiving end voltages using simple formulae mentioned above.

$$V_2 = \sqrt{[B[J] - A[J]1}$$

6. Calculate power loss on all lines using the formulae,

$$P_{loss}[J] = R[J] * \left[\frac{P_2^2 + Q_2^2}{V_2^2} \right]$$

$$Q_{loss}[J] = X[J] * \left[\frac{P_2^2 + Q_2^2}{V_2^2} \right]$$

$$S_{loss} = P_{loss} + jQ_{loss}$$

7. Multiply the power loss column matrix, S_L with LLNP matrix to get N' matrix. N' represents the part of line losses in the effective load at various nodes.
 $[N'] = [LLNP] [S_L]$
8. Calculate the total effective load at various nodes by adding the N and N' matrix.
 Effective load at each node = $N + N'$
9. Increment the iteration count Repeat the steps from step (5) using new effective loads at every node.
10. If the difference in the voltages between present iteration and previous iteration is greater than 0.001 pu, then increment the iteration count and repeat from step(5), otherwise, print the result.

III. RESULTS

For fifteen bus system, number of iterations taken is 3. The algorithm is efficient, robust and rapid. It requires less memory and convergence is faster. For the first time, topology is fully exploited with the modeling equations suggested in [2]. Voltages obtained in different iterations are presented in Table II. The results are promising and compared with [2] results. Data for the 15, 85 bus system is given in [2]. 85 bus system result is compared with the result of [6] in Table III.

TABLE I
COMPARISON OF BUS VOLTAGES OF 15 BUS SYSTEM

Bus No	Bus voltages in p.u.	
	By proposed method	Given by Reference[2]
1	1	1.0000
2	0.971284	0.97128
3	0.956671	0.95667
4	0.950907	0.95090
5	0.94992	0.94992
6	0.958232	0.95823
7	0.956009	0.95601
8	0.956955	0.95695
9	0.967971	0.96797
10	0.966898	0.96690
11	0.949954	0.94995
12	0.94583	0.94583
13	0.944519	0.94452
14	0.94861	0.94861
15	0.948441	0.94844

TABLE II
BUS VOLTAGES IN PU OBTAINED IN DIFFERENT ITERATIONS..

Bus No.	Bus voltages in pu. in different iterations			
	Iteration1	Iteration2	Iteration3	Iteration4
2	0.971806	0.971289	0.971284	0.971284
3	0.957311	0.956676	0.956671	0.956671
4	0.951559	0.950912	0.950907	0.950907
5	0.950573	0.949926	0.94992	0.94992
6	0.958778	0.958238	0.958232	0.958232
7	0.956556	0.956014	0.956009	0.956009
8	0.957502	0.95696	0.956955	0.956955
9	0.968497	0.967976	0.967971	0.967971
10	0.967424	0.966903	0.966898	0.966898
11	0.950614	0.94996	0.949954	0.949954
12	0.946496	0.945836	0.945831	0.94583
13	0.945185	0.944525	0.944519	0.944519
14	0.949264	0.948616	0.94861	0.94861
15	0.949096	0.948447	0.948441	0.948441

TABLE III
COMPARISON OF VOLTAGES OF 85 BUS SYSTEM

Bu sno	Voltages obtained by proposed method	Voltages given in ref[6]	Bu sno	Voltages obtained by proposed method	Voltages given in ref[6]
1	1	1			
2	0.995676	0.995678	44	0.878084	0.87814
3	0.989259	0.989264	45	0.87705	0.877107
4	0.981067	0.981075	46	0.876448	0.876504
5	0.97708	0.97709	47	0.876345	0.876402
6	0.962749	0.962766	48	0.875038	0.875111
7	0.953938	0.953959	49	0.874778	0.874854
8	0.915787	0.915825	50	0.874326	0.874407
9	0.913975	0.914013	51	0.873983	0.874064
10	0.910456	0.910494	52	0.872321	0.872395
11	0.907725	0.907763	53	0.87176	0.871834
12	0.905465	0.905503	54	0.871348	0.871422
13	0.904482	0.90452	55	0.871909	0.871983
14	0.904184	0.904222	56	0.874675	0.874751
15	0.904006	0.904044	57	0.911481	0.91152
16	0.995372	0.995374	58	0.904591	0.904631
17	0.988653	0.988657	59	0.904459	0.904499
18	0.974363	0.974374	60	0.900404	0.900444
19	0.972684	0.972695	61	0.899337	0.899378
20	0.972101	0.972112	62	0.898603	0.898643
21	0.971401	0.971412	63	0.899415	0.899451
22	0.970739	0.97075	64	0.895566	0.895602
23	0.972561	0.972572	65	0.895399	0.895435
24	0.953542	0.953562	66	0.895265	0.895301
25	0.910232	0.910275	67	0.893579	0.893616
26	0.905959	0.906007	68	0.890702	0.890738
27	0.900353	0.900408	69	0.888571	0.888607
28	0.897752	0.89781	70	0.88802	0.888057
29	0.89299	0.893019	71	0.887765	0.887801
30	0.888598	0.888635	72	0.893446	0.893482
31	0.886531	0.886571	73	0.889334	0.889309
32	0.885241	0.885283	74	0.889132	0.889106

33	0.884206	0.884251	75	0.888866	0.888841
34	0.879696	0.879752	76	0.887615	0.887652
35	0.877215	0.87728	77	0.895233	0.895418
36	0.877129	0.877194	78	0.909995	0.910033
37	0.905694	0.905742	79	0.893326	0.893362
38	0.899619	0.899674	80	0.903936	0.903974
39	0.892587	0.892617	81	0.903436	0.903974
40	0.884599	0.884642	82	0.902776	0.903408
41	0.883658	0.8837	83	0.902735	0.902773
42	0.88353	0.883572	84	0.902552	0.90259
43	0.883444	0.883486	85	0.904106	0.904144

IV. CONCLUSIONS

In this paper, load flow solution is obtained for radial distribution system using a new method. Network topology is used to build two matrices for obtaining load flow solution of radial distribution system. Two new network matrices are developed to obtain the two parts of the effective load. 'bus injection to Node power matrix' is used to identify major part of the effective load at each node and 'Line loss to node power matrix' is used to calculate the other part of the effective load at each node. This method is very efficient and requires very less computer memory. The proposed algorithm is applied to 15bus, and 85 bus systems used in the literature and the results are compared with those given in the research papers. Results are accurate up to the fourth decimal.

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