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A Novel Load Flow Solution Methodology for Weakly Meshed Distribution Systems

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ABSTRACT: For calculating the state of system, which includes voltage magnitude and voltage angles at the nodes, active and reactive power flows in the distribution lines, it is necessary to develop a novel load flow solution methodology for weakly meshed distribution systems. The existing load flow increases its computational burden to solve weakly meshed distribution systems. Hence to avoid this, a novel methodology based on local and global compensating factors is presented. The comparative analysis of effectiveness of the proposed methodology, the numerical and graphical results for the radial and meshed distribution systems is presented for weakly meshed -33 node and weakly meshed -69 node distribution systems.

KEYWORDS: Distribution load flow, weakly meshed distribution system, local compensating factors, global compensating factor

I.INTRODUCTION

Owing to the ever increasing load demand, Now a days, interconnected systems are predominately used for reliable operation of the system. Therefore, load flow has become complicated in determining the operational quantities such as voltage, current through the branches, active power loss and reactive power loss [1-12]. Therefore, for analyzing the voltages at all the buses, active and reactive power losses in the existing system, an efficient and reliable proposed load flow method has been developed based on back tracking from the end nodes to the source node by calculating the local compensating factors. Finally with the help of global compensating factor, all the new bus voltages are to be updated for obtaining the new currents through the branches of the system and thereby the active and reactive power losses are to be calculated.

In the literature, so many load flow techniques have been developed so far. To analyze the non linear load flow equations traditional iterative methods are used such Newton Raphson, Gauss-Seidel and Fast Decoupled Load Flow methods have been developed for running the load flow for the transmission systems. But, the performance of those methods gives poor results for distribution systems due to high R/X ratio which deteriorates the dominance of the Jecobian matrix. For this reason, other methods have been developed such as backward/ forward sweep, Novel Based techniques and so on. The formulation of those methods is different from the Newton Raphson method.

Jen-Hao Teng [1] presented the load flow method based on two matrices, i.e bus injection to branch current matrix and branch current to bus voltage matrix and a matrix multiplication is used to obtain the load flow. Mohammad hafez Bazrafshan and Nikolaos Gatsis [2] presented the load flow technique based on a set of sufficient conditions for the load flow with wye and delta ZIP loads in unbalanced distribution networks.

Most of the literature is concentrated for solving distribution load flow for radial distribution systems only. In this paper, a novel load flow solution methodology to solve not only radial distribution systems but also weakly meshed distribution systems. This methodology works based on the compensating factors. Two different compensating factors such as local and global factors are developed to solve the load flow problem without any iterative process. Due to this, the computation burden on the system is decreased which leads to increase of accuracy of the solution.

II.ALGORITHM TO SOLVE DISTRIBUTION LOAD FLOW

A. Backtracking radial load flow methodology

The following algorithm followed to solve load flow problem for both radial and meshed distribution systems.
Step 1: Read distribution system data i.e. line resistance and reactance data, active and reactive load data.
Step 2: Give number to the nodes starts from end node.
Step 3: Identify end nodes for both the main feeder and laterals.
Step 4: Calculate node voltage using the Eqn (1)

$$\overline{V}_m = \overline{V}_n + \overline{I}_{m\text{-}n} \times \overline{Z}_{m\text{-}n} \quad (1)$$

Where, $\overline{Z}_{m\text{-}n}$ is impedance of the branch connected between nodes m and n. Here, $\overline{V}_n$ is assumed to be (1+j0) p.u. and calculate LCF using Eqn (2).

$$\text{LCF} = \frac{\overline{V}_m\,(\text{highest value})}{\overline{V}_m\,(\text{lowest value})} \quad (2)$$

Step 5: Update the line current using Eqn (3).

$$\overline{I}_{m-n}^{\,new} = \overline{I}_{m-n}^{\,old} \times \text{LCF} \quad (3)$$

Step 6: Calculate GCF and updated voltages using Eqns (4) and (5).

$$\text{GCF} = \frac{\text{Specified Voltage}(\overline{V}_{sp})}{\text{Calculated Voltage}(\overline{V}_{cal})} \quad (4)$$

$$\overline{V}_m^{\,new} = \overline{V}_m^{\,old} \times \text{GCF} \quad (5)$$

Step 7: Calculate line current and there by the losses using Eqns (6) to (8).

$$\overline{I}_{m-n} = \frac{\left(\overline{V}_m - \overline{V}_n\right)}{Z_{m-n}} \quad (6)$$

Similarly, active and reactive power losses in the branches can be calculated as

$$P_{m-n} = \overline{I}_{m-n}^{\,2} \times R_{m-n} \quad (7)$$

$$Q_{m-n} = \overline{I}_{m-n}^{\,2} \times X_{m-n} \quad (8)$$

III.WEAKLY MESHED DISTRIBUTION LOAD FLOW

The proposed back tracking distribution load flow method is extended to solve weakly meshed distribution system shown in Fig.1.

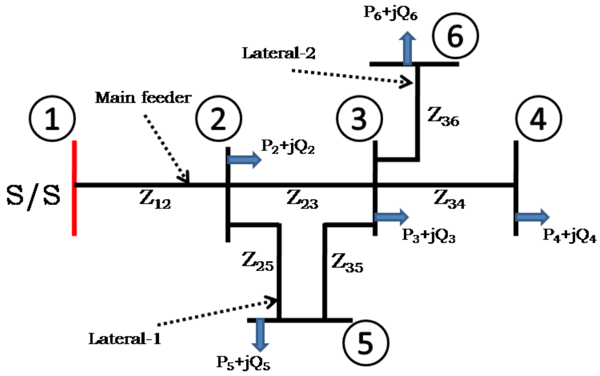

Fig.1 Sample Weakly Meshed Distribution System

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This system consist one loop formed by virtually closing the tie switch connected between nodes 3 and 5. The following methodology is used to solve the load flow problem. For this type system, the numbering of nodes and branches is followed as explained in section 2. Similarly, the end nodes are also identified using the earlier procedure. Load flow for this type system is performed by converting the weakly meshed system into radial system by opening the tie-switch temporarily. After this, the conventional radial load flow methodology is followed as explained in section 2. Through this process, voltages at all nodes are obtained. Now the tie switch is virtually closed and Kirchhoff's Voltage Law (KVL) equation is solved for this loop. In this process, the current in the tie branch is calculated. This current is assumed to be the injecting current at lowest voltage node and delivering current at highest voltage node of tie switch. For the considered system, it is assumed that, current in tie branch is I5-3 and the modified system is shown in Fig.2.

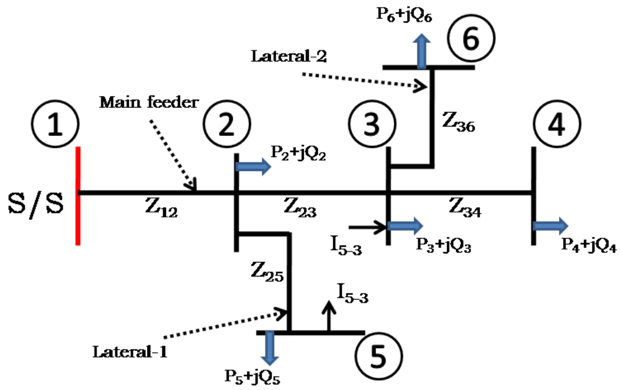

Fig.2 Modified Weakly Meshed Distribution System

Now the weakly meshed distribution system becomes radial distribution system. The procedure explained in section 2 is followed to solve the load flow problem.

IV.RESULTS AND ANALYSIS

To demonstrate the effectiveness of the proposed load flow methodology over the existing load flow methodology, two test systems namely Radial/Weakly Meshed-33 node and Radial/Weakly Meshed-69 are considered.

The entire analysis is performed for the following two cases.

Case-1: Load flow problem is solved for the weakly meshed- 33 node distribution system using the proposed methodology (explained in section 3) and is compared with the radial distribution system.

Case-2: Load flow problem is solved for the weakly meshed-69 node distribution system using the proposed methodology (explained in section 3) and is compared with the radial distribution system.

2.6.1 Case 1

In this case, Radial-33 node distribution system with 32 branches, 3715 kW active load and 2300 kVAr reactive load is considered. This radial distribution system becomes weakly meshed distribution system by closing a tie switch virtually between nodes 18 and 26 for calculating the injected currents.

In Case-1, load flow problem is solved for the weakly meshed- 33 node distribution system and the obtained results are tabulated in Table.1. From this table, it is identified that, due to formation of loop between nodes 18 and 26. By following the procedure explained in section 3, the tie line current is calculated (0.012 A) and is injected at nodes 18 and 26. This current flows from node-26 to node-18. Hence, the current injection at node-18 is positive and at node-26 is negative. Due to this, the voltage magnitude at node-18 is increased and at node-26 is decreased when compared to radial distribution system. Variation of voltage is shown in Fig.3.

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Table.1 Load flow results for case-1

Node No	Radial load flow method		Meshed load flow method	
	Voltage Magnitude (p.u.)	Voltage Angle (deg)	Voltage Magnitude (p.u.)	Voltage Angle (deg)
1	1.0000	0	1.0000	0.0000
2	0.9974	0.0148	0.9974	0.0119
3	0.9851	0.0985	0.9851	0.0817
4	0.9787	0.1658	0.9787	0.1377
5	0.9724	0.2341	0.9724	0.1944
6	0.9568	0.1446	0.9568	0.1155
7	0.9538	-0.0872	0.9537	-0.0556
8	0.9497	-0.0539	0.9499	-0.0026
9	0.9444	-0.1312	0.9448	-0.0180
10	0.9395	-0.198	0.9402	-0.0236
11	0.9387	-0.1914	0.9395	-0.0110
12	0.9375	-0.1812	0.9384	0.0110
13	0.9323	-0.2778	0.9336	0.0055
14	0.9304	-0.3585	0.9317	-0.0245
15	0.9292	-0.3976	0.9306	-0.0250
16	0.9280	-0.4223	0.9296	-0.0090
17	0.9263	-0.5017	0.9280	0.0136
18	0.9258	-0.512	0.9276	0.0418
19	0.9969	0.0039	0.9969	0.0013
20	0.9933	-0.0636	0.9933	-0.0644
21	0.9927	-0.0831	0.9927	-0.0835
22	0.9920	-0.1036	0.9920	-0.1035
23	0.9817	0.0673	0.9817	0.0527
24	0.9754	-0.022	0.9754	-0.0305
25	0.9723	-0.0662	0.9723	-0.0715
26	0.9551	0.1858	0.9551	0.1415
27	0.9530	0.2443	0.9528	0.1787
28	0.9432	0.3386	0.9429	0.1979
29	0.9362	0.4249	0.9357	0.2244
30	0.9332	0.5338	0.9325	0.2935
31	0.9297	0.4534	0.9288	0.1683
32	0.9289	0.4312	0.9280	0.1297
33	0.9286	0.4237	0.9278	0.0976

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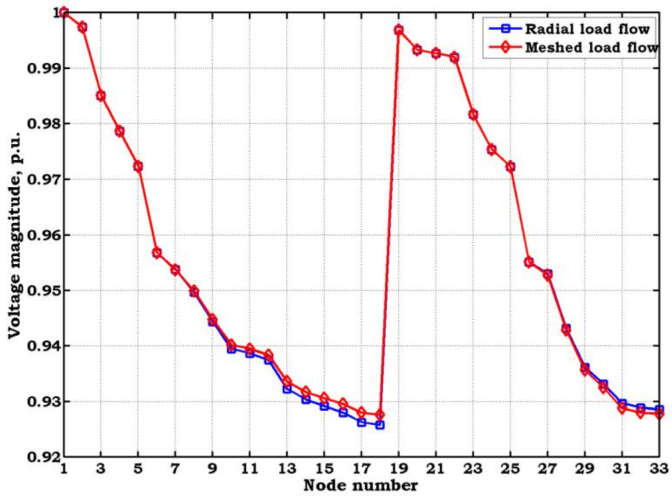

Fig.3 Variation of voltage magnitude for case-1

Similarly, the active and reactive power losses in each of the distribution lines for the radial and meshed distribution systems variation is shown in Fig.4.

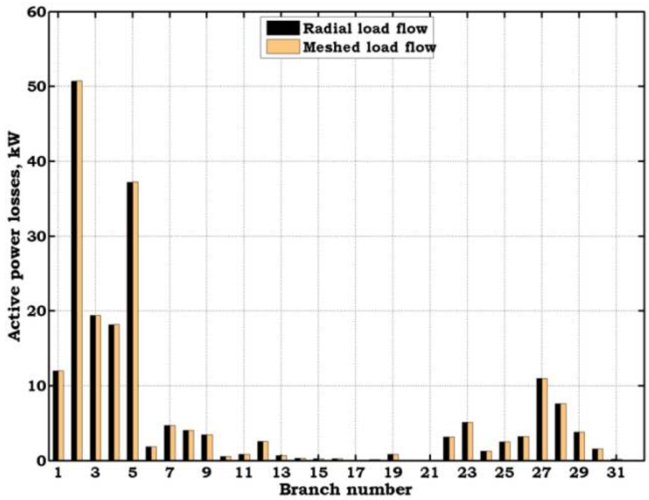

Fig.4 Variation of active power losses for Meshed-33 node system

Similarly, the consolidated results for this case are tabulated in Table.2. From this table, it is identified that, due to interconnection of nodes in weakly meshed distribution system, the total active power losses are decreased when compared to radial distribution system. Similarly, in weakly meshed distribution system, the low voltage node is identified to be 18, which is farer from the source node and this voltage value is enhanced when compared to radial distribution system. It is also observed that, in meshed system, due to calculation of loop current and node current injections, the computational time taken is increased when compared to radial distribution system.

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Table.2 Consolidated Load Flow Results for case 3

Parameter	Radial load flow method	Meshed load flow method
Total active power losses (kW)	194.486	191.7368
Minimum voltage node	18	18
Minimum voltage value (p.u)	0.9258	0.9276
Computational time (sec)	0.06	0.104

Case-2:

In Case-2, load flow problem is solved for the weakly meshed- 69 node distribution system and the obtained results are tabulated in Table.3. From this table, it is identified that, due to formation of loop between nodes 27 and 65. By following the procedure explained in section 3, the tie line current is calculated and is injected at nodes 27 and 65. This current flows from node-27 to node-65. Hence, the current injection at node-27 is negative and at node-65 is positive. Due to this, the voltage magnitude at node-27 is decreased and at node-65 is increased when compared to radial distribution system. Variation of voltage profiles is shown in Fig.5.

Table.3 Load flow results for Weakly Meshed-69 node system

Node	Radial load flow method		Meshed load flow method	
No	Voltage magnitude (p.u.)	Voltage angle (deg)	Voltage magnitude (p.u.)	Voltage angle (deg)
1	1	0	1	0
2	1	-0.0011	1	-0.0011
3	0.9999	-0.0022	0.9999	-0.0022
4	0.9999	-0.0053	0.9999	-0.0053
5	0.9991	-0.0163	0.9991	-0.0164
6	0.9914	0.0417	0.9914	0.0413
7	0.9834	0.1028	0.9833	0.1021
8	0.9815	0.1175	0.9814	0.1167
9	0.9805	0.1251	0.9804	0.1242
10	0.9759	0.2022	0.9719	0.258
11	0.9748	0.2193	0.97	0.2883
12	0.9336	0.7822	0.9637	0.3894
13	0.931	0.8247	0.956	0.5124
14	0.9285	0.8675	0.9483	0.64
15	0.9259	0.9094	0.9405	0.7685
16	0.9255	0.9173	0.939	0.7926
17	0.9247	0.9302	0.9364	0.8368
18	0.9247	0.9303	0.9364	0.8373
19	0.9243	0.9381	0.9343	0.8729
20	0.924	0.9432	0.933	0.8961
21	0.9236	0.9513	0.9309	0.9335
22	0.9236	0.9514	0.9308	0.9348
23	0.9235	0.9526	0.93	0.9498
24	0.9234	0.9553	0.9281	0.9826
25	0.9232	0.9581	0.9242	1.051
26	0.9232	0.9593	0.9226	1.0794
27	0.9232	0.9597	0.9218	1.095
28	0.9999	-0.0025	0.9999	-0.0025
29	0.9999	-0.0051	0.9999	-0.0051
30	0.9997	-0.0029	0.9997	-0.0029
31	0.9997	-0.0026	0.9997	-0.0026
32	0.9996	-0.0007	0.9996	-0.0007
33	0.9994	0.0037	0.9994	0.0037

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34	0.999	0.0096	0.999	0.0096
35	0.999	0.0106	0.999	0.0106
36	0.9999	-0.0027	0.9999	-0.0027
37	0.9998	-0.0091	0.9998	-0.0091
38	0.9996	-0.0115	0.9996	-0.0115
39	0.9996	-0.0122	0.9996	-0.0122
40	0.9995	-0.0122	0.9995	-0.0123
41	0.9989	-0.0232	0.9989	-0.0232
42	0.9986	-0.0278	0.9986	-0.0278
43	0.9985	-0.0284	0.9985	-0.0285
44	0.9985	-0.0286	0.9985	-0.0286
45	0.9984	-0.0304	0.9984	-0.0304
46	0.9984	-0.0304	0.9984	-0.0304
47	0.9998	-0.0071	0.9998	-0.0071
48	0.9986	-0.0513	0.9986	-0.0513
49	0.9948	-0.1887	0.9948	-0.1888
50	0.9942	-0.2083	0.9942	-0.2083
51	0.9814	0.1178	0.9813	0.117
52	0.9814	0.118	0.9813	0.1172
53	0.9781	0.1435	0.9789	0.1378
54	0.9754	0.1651	0.9772	0.1536
55	0.9717	0.1951	0.9749	0.1754
56	0.968	0.2247	0.9727	0.1966
57	0.9491	0.5562	0.9612	0.4136
58	0.9398	0.7246	0.9556	0.5224
59	0.9362	0.7917	0.9534	0.5656
60	0.932	0.8782	0.9509	0.6184
61	0.9258	0.9352	0.9473	0.6557
62	0.9256	0.9374	0.9476	0.6538
63	0.9252	0.9405	0.9481	0.6505
64	0.9236	0.9552	0.9505	0.6344
65	0.9232	0.9597	0.9559	0.5936
66	0.9364	0.7351	0.97	0.2894
67	0.9364	0.7351	0.97	0.2894
68	0.9333	0.7879	0.9634	0.3951
69	0.9333	0.7879	0.9634	0.3951

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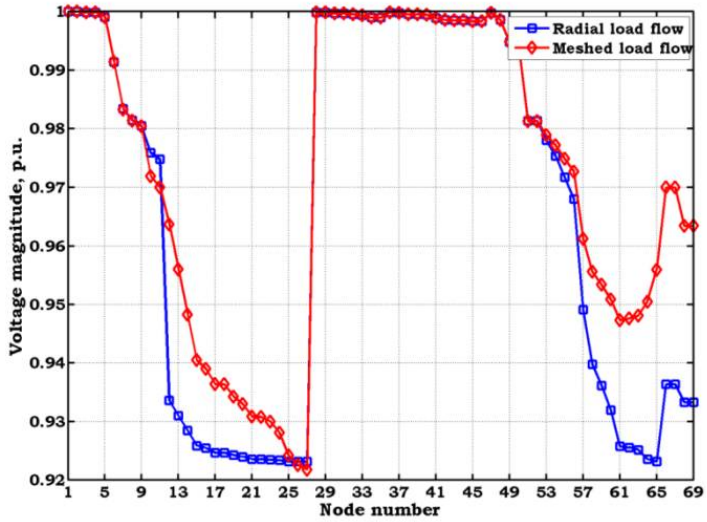

Fig.5 Variation of voltage magnitude for case-2

Similarly, the active and reactive power losses in each of the distribution lines for the radial and meshed distribution systems variation is shown in Fig.6.

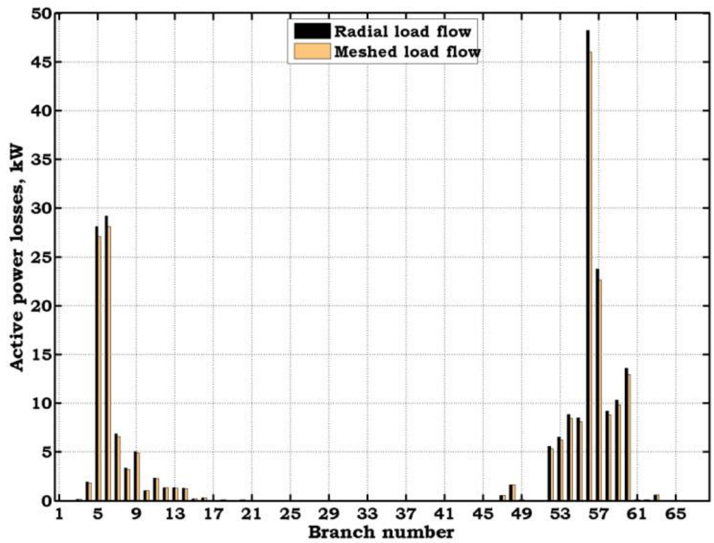

Fig.6 Variation of active power losses for Case-2

Similarly, the consolidated results for this case are tabulated in Table.4. From this table, it is identified that, due to virtual closing of tie switch between nodes 27 and 65 nodes in weakly meshed distribution system, the total active power losses are decreased when compared to radial distribution system. Similarly, in weakly meshed distribution system, the low voltage node is identified to be 27, which is farer from the source node and this voltage value is enhanced when compared to radial distribution system. It is also observed that, in meshed system, due to calculation of loop current and node current injections, the computational time taken is increased when compared to radial distribution system.

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Table.4 Consolidated Load Flow Results for case 4

Parameter	Radial load flow method	Meshed load flow method
Total active power losses (kW)	221.526	212.254
Minimum voltage node	27	27
Minimum voltage value (p.u)	0.9232	0.9218
Computational time (sec)	0.12	0.14

VI.CONCLUSION

In this paper a novel load flow solution methodology has been presented. This method works based on compensating factors, such as, local and global factors. Due to this, the voltage magnitudes have been obtained without any iterative process. Due to this, the computational time has been decreased. It has been also identified that, the total power losses are decreased in meshed distribution system when compared to radial distribution system. This is due to the presence of loop in meshed distribution system. The effectiveness of proposed methodology has been tested on Radial/Weakly meshed-33 node and Radial/Weakly meshed-69 node test systems with supporting numerical and graphical results.

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