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Forward Sweeping Method for Solving Radial Distribution Networks

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ABSTRACT: Practical rural distribution feeders have failed to converge while using NR and FDLF methods. Therefore, a new load flow technique for radial distribution networks by using node and branch numbering scheme will be developed. In the forward sweep, the voltage at each downstream bus is then updated by the real and imaginary components of the calculated bus voltages. The procedure stops after the mismatch of the calculated and specified Voltages at the substation is less than a convergence tolerance. A Forward sweeping method for solving radial distribution networks will be implemented. Thus, computationally, the proposed method will be a very efficient and requires less computer memory storage as all data is stored in vector form. The load flow will be run in MATLAB for solving the equations.

Keywords: load flow analysis, radial distribution systems, forward sweeping, buses, node voltages.

I. INTRODUCTION

. Load Flow Studies are performed on Power Systems to understand the nature of the installed network. This understanding gives the knowledge of the installed Generation Systems, Loads connected, Losses incurred, and also the flexibility of the system to allow future load connections. So, Load Flow or Power Flow analysis is becomes a vital part of any Power System, as without this information, maintaining the network and regulating it within specified limits becomes just a blind control of some wires, in which current flows [4]. Generally distribution systems are radial and the R/X ratio is very high. For this reason distribution systems are ill-condition, and conventional Newton Raphson (NR) and fast decoupled load flow (FDLF) methods [1, 2, 3, and 7] are inefficient in solving such systems.

Power flow study provides valuable information for power engineers with ability to quickly simulate the operation of the system. It is becoming apparent that presently working load flow techniques of transmission system are not suitable for distribution system [8]. The main difference is the presence of number of different types of devices, multiphase possibilities and widely varying types of loads in the distribution systems. The distribution power flow involves, first of all, finding all the node voltages. From these voltages, it is possible to compute current directly, power flows, system losses and other steady state quantities .some applications, especially in the fields of optimization of distribution system, and distribution automation (i.e., VAR planning, network optimization, state estimation, etc.), need repeated fast load flow solutions. In these applications it is important that the load flow problem is solved as efficiently as possible.

In this paper a forward sweeping method is proposed to solve the radial distribution system. The proposed method is tested by taking 12 and 28 node radial distribution systems. This method develops a new load flow technique for radial distribution systems by using node and branch numbering scheme. The forward sweeping method solves a recursive relation of voltage magnitudes. The load flow will be run in MATLAB for solving the equations. The mathematical formulation of the proposed load flow method is described in the following section.

II. PROBLEM FORMULATION

The load flow of a single source network can be solved iteratively from two sets of recursive equations in forward propagation. These recursive equations are derived as follows. Fig. 1 shows radial main feeder only. The one line diagram has n nodes and n-1 branches. Fig. 2 shows the representation of 2 nodes in a distribution line.

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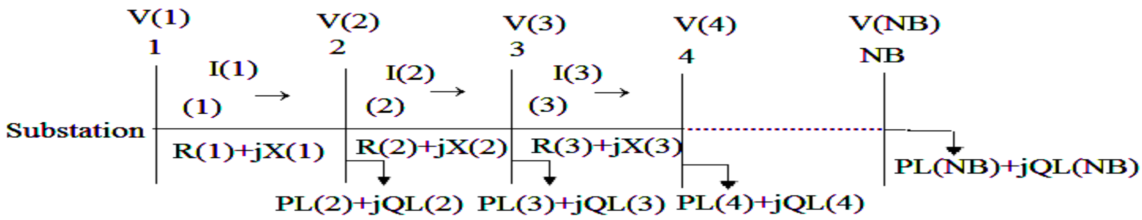

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Fig.1 Radial main feeder

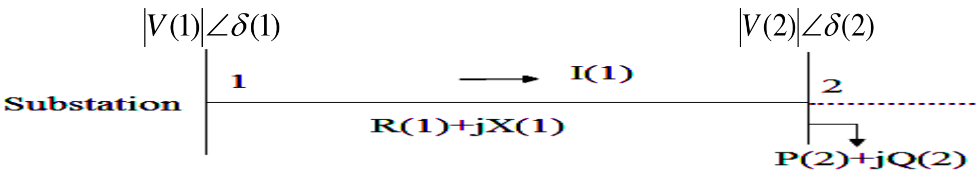

Fig.2 Representation of two nodes in a distribution line

The voltage magnitude and angle at each node are calculated in forward direction. Consider a voltage $|V_1|\angle\delta_1$ at node '1' and $|V_2|\angle\delta_2$ at node '2', then the current flowing through the branch '1' having an impedance, $Z_1 = R_1 + jX_1$ connected between '1' and '2' is given as,

$$I_1 = \frac{|V_1|\angle\delta_1 - |V_2|\angle\delta_2}{R_1 + jX_1} \qquad (1)$$

The Complex power injected by the source into the 2nd bus of a power system is,

$$P_2 - jQ_2 = V_2 * I_1$$

$$I_1 = \frac{P_2 - jQ_2}{V_2^*} \qquad (2)$$

Equating both the Eqns. (1) & (2) and cross multiplying, we have

$$|V_1||V_2|\angle\delta_1 - \angle\delta_2 - |V_2|^2 = (P_2 - jQ_2)^*(R_1 + jX_1) \qquad (3)$$

Equating the real and imaginary parts on both sides of Eqn. (3)

$$|V_1||V_2|COS(\delta_1 - \delta_2) = |V_2|^2 + P_2^* R_1 + Q_2^* X_1 \qquad \text{..... (A)}$$

$$|V_1||V_2|SIN(\delta_1 - \delta_2) = P_2^* X_1 + Q_2^* R_1 \qquad \text{..... } (B)$$

Squaring and adding equation A&B:-

$$|V_2|^4 + 2[P_2 * R_1 + Q_2 * X_1 - (|V_1|^2)/2]$$

$$+ (P_2^2 + Q_2^2)(R_1^2 + X_1^2) = 0$$

Solving the quadratic equation gives the roots as:-

$$A = [P_2 * R_1 + Q_2 * X_1 - (|V_1|^2)/2]$$

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$$B = (P_2^{\,2} + Q_2^{\,2})(R_1^{\,2} + X_1^{\,2})$$

$$|V_2| = ((A^2 - B)^{0.5} - A)^{0.5}$$

Voltage magnitude at node 2

$$|V_2| = [\{(P_2 R_1 + Q_2 X_1 - 0.5|V_1|^2)^2 + Q_{i+1}^{\,2})\}^{1/2} - (P_{i+1} R_i - (P_2 R_1 + Q_2 X_1 - 0.5|V_1|^2)]^{1/2}$$

Generalized form of voltage magnitude

$$|V_{i+1}| = [\{(P_{i+1} R_i + Q_{i+1} X_i - 0.5|V_i|^2)^2 - (R_i^{\,2} + X_i^{\,2})(P_{i+1}^{\,2} - (R_1^{\,2} + X_1^{\,2})(P_2^{\,2} + Q_2^{\,2})\}^{1/2} + Q_{i+1} X_i - 0.5|V_i|^2)]^{1/2} \quad (4)$$

Eqn. 4 is a recursive relation of voltage magnitude. It is possible to find out voltage magnitudes of all other nodes. The total active & reactive powers are written in generalised form

$$P_{i+1} = \sum_{j=i+1}^{NB} PL_j + \sum_{j=i+1}^{NB-1} LP_j \qquad \text{For i=1, 2,…NB-2}$$

$$Q_{i+1} = \sum_{j=i+1}^{NB} QL_j + \sum_{j=i+1}^{NB-1} LQ_j \qquad \text{For i=1, 2 ...NB-2} \quad (5)$$

The total real and reactive power load fed through node 2 are given by

$$P_2 = \sum_{i=2}^{NB} PL_i + \sum_{i=2}^{NB-1} LP_i$$

$$Q_2 = \sum_{i=2}^{NB} QL_i + \sum_{i=2}^{NB-1} LQ_i \quad \text{...... (5.1)}$$

From Eqn. 5.1, it is clear that total load fed through node 2 is the load of node 2 itself plus the load of all other nodes plus the losses of all branches except branch 1.

The total real and reactive power losses of radial distribution system can be calculated as,

$$LP_i = \frac{R_i * (P_{i+1}^{\,2} + Q_{i+1}^{\,2})}{|V_{i+1}|^2}$$

$$LQ_i = \frac{X_i * (P_{i+1}^{\,2} + Q_{i+1}^{\,2})}{|V_{i+1}|^2} \quad (6)$$

III. POWER FLOW CALCULATION

Initially assuming a flat voltage profile i.e., setting the voltage equal to 1.0 Pu at every node, the flow chart for load flow is shown in Fig. 3. The updated effective power flows in each branch are obtained using Eqns. (5) by considering the node voltages of previous iteration. The purpose of the forward sweeping is to calculate the voltages at each node and their angles using Eqns. (4) starting from the feeder source node.

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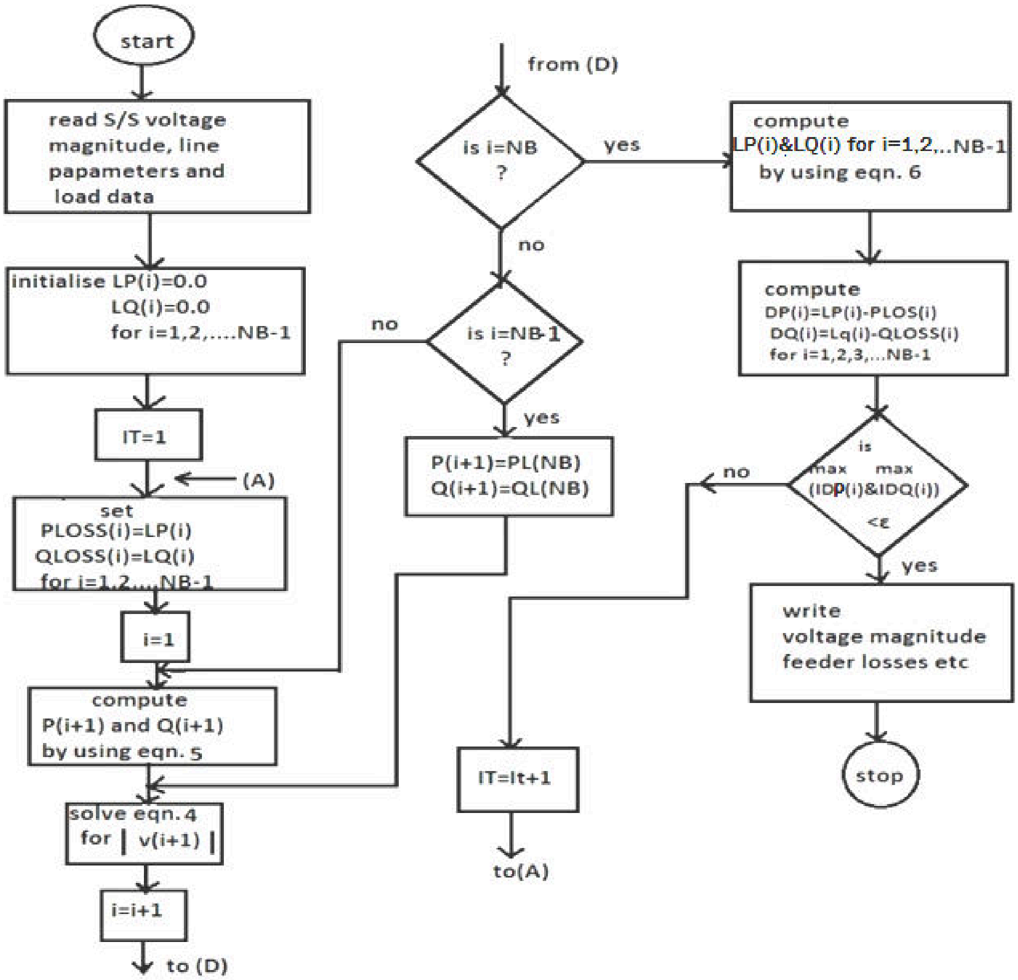

Fig.3 flow chart for the algorithm of radial distribution network

The load flow algorithm is as follows:

Step1: Read the number of buses and nodes in the given system. Read the line resistance and reactance for all the branches. Read real and reactive power at all the nodes.

Step2: Initialize the variables.

Step3: Set the convergence criteria i.e. tolerance, tol=0.1.

Step4: Initialize the real and reactive power for all the nodes to zero. Lossap (i) =0; Lossap (i) =0

Step5: Set the bus count k=1.

Step6: Set initially Paloss (i) =Lossap (i); Qaloss (i) =Lossap (i);

Step7: Set the bus count i=1.

Step8: Calculate the total real and reactive power at the node (i+1), using equations.

Step9: Compute the voltage at all nodes at (i+1) node, i.e. |va (i+1)| using equation

Step10: Advance the bus count, i=i+1.

Step11: Whether bus count i=NB? , if yes go to step3 otherwise go to next step.

Step12: Whether bus count i= (NB-1)? , if yes set Pa (i+1) = Paload (NB). Qa (i+1) =Qaload (NB). Then go to step3 otherwise go to step8.

Step13: Calculate the real and reactive power at the ith node Lossap (i), lossaq (i).

Step14: Calculate the difference of real and reactive power losses at all the nodes. Dap(i)=|Lossap(i)-Paloss(i)| Daq(i)=|lossaq(i)-Qaloss(i)| For i=1,2……..(NB-1).

Step15: Whether |Dap (i) |max and |Daq (i) |max is less than the convergence criteria. If yes go to next step, otherwise go to step6.
Step16: Print the voltage magnitude at all the nodes and also print the real and reactive power losses at all the nodes. Print the number of iterations taken.
Step17: Stop.

IV.RESULTS

A. *Example 1*

The line and load data of 12-node, 12.66 KV radial distribution system shown in fig. 4 is taken from [4],
Substation

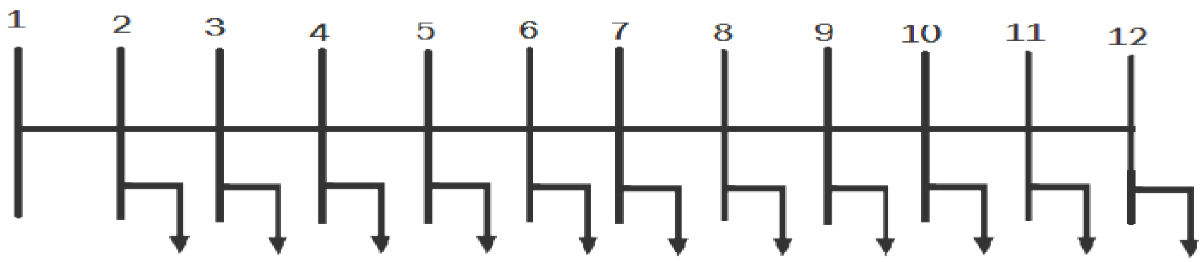

Fig .4 12-node radial distribution system

TABLE I
Voltage magnitudes of 12-node system

Node No.	Voltage magnitude(pu)	
	Proposed method	Existing method
1	1.000000	1.00000
2	0.995764	0.99433
3	0.991805	0.98903
4	0.985500	0.98057
5	0.977484	0.96982
6	0.975036	0.96653
7	0.972960	0.96374
8	0.966682	0.95530
9	0.960708	0.94727
10	0.958615	0.94446
11	0.957947	0.94356
12	0.957792	0.94335

The total real and reactive power losses of the system are 15.28 KW and 5.93 KVAR respectively. These are 26.21% and 26.24% of their total loads. The minimum voltage of the system is 0.957792 p.u.at node 12. Comparison of load flow results of the proposed method and the existing method [2] is given in table II.

TABLE II
Comparison of load flow results 12-node system

DESCRIPTION	TOTAL LOSS		Minimum voltage and its node number
	REAL POWER(KW)	REACTIVE POWER(KVAR)	
EXISTING METHOD(FDLF METHOD)	20.71	8.04	0.94335 at Node 12
PROPOSED METHOD(FORWARD SWEEPING METHOD)	15.28	5.93	0.957792 at Node 12

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B. *Example 2*

The line and load data of 28-node, 12.66KV radial distribution system shown in fig.5 is taken from [4],

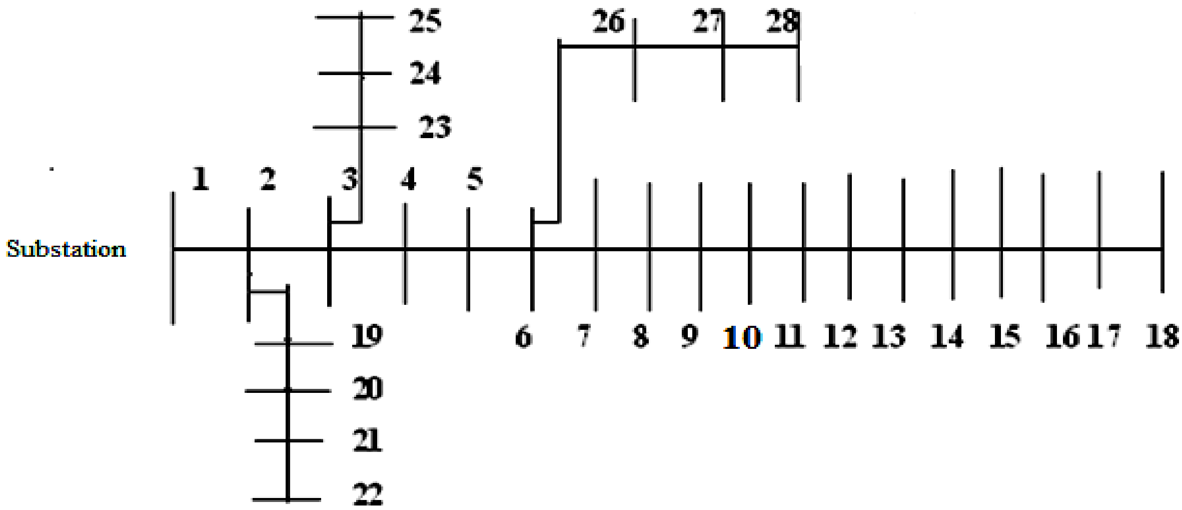

Fig. 5 28-node radial distribution system

TABLE III
Voltage magnitudes of 28-node system

Node No.	Voltage magnitude (pu)		Node No.	Voltage magnitude (pu)	
	Proposed method	Existing method		Proposed method	Existing method
1	1.0000	1.0000	15	0.9158	0.9427
2	0.9900	0.9862	16	0.9509	0.9370
3	0.9756	0.9664	17	0.9399	0.9258
4	0.9655	0.9523	18	0.9392	0.9248
5	0.9518	0.9381	19	0.9380	0.9232
6	0.9413	0.9276	20	0.9373	0.9223
7	0.9313	0.9184	21	0.9369	0.9217
8	0.9271	0.9160	22	0.9296	0.9155
9	0.9256	0.9157	23	0.9291	0.9140
10	0.9232	0.9154	24	0.9285	0.9128
11	0.9184	0.9461	25	0.9284	0.9126
12	0.9170	0.9443	26	0.9283	0.9122
13	0.9162	0.9433	27	0.9268	0.9155
14	0.9160	0.9430	28	0.9267	0.9153

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The total real and reactive power losses of the system are 62.22 KW and 41.87 KVAR respectively. These are 9.62% and 9.10% of their total loads. The minimum voltage of the system is 0.9158 p.u.at node 15. Comparison of load flow results of the proposed method and the existing method [2] is given in table IV.

TABLE IV
Comparison of load flow results 28-node system

DESCRIPTION	TOTAL LOSS		Minimum voltage and its node number
	REAL POWER(KW)	REACTIVE POWER(KVAR)	
EXISTING METHOD(FDLF METHOD)	68.84	46.06	0.9122 at Node 26
PROPOSED METHOD(FORWARD SWEEPING METHOD)	62.22	41.87	0.9158 at Node 15

V.CONCLUSION

The forward sweeping method guarantees the convergence of any practical radial distribution networks with realistic R/X ratio. The forward sweeping method is practically more efficient with respect to the voltage magnitudes and real and reactive power losses. From the results 12-node system can be observed that without any change in the voltage profile the real power losses are reduced by 26.21% and reactive power losses are reduced by 26.24% and 28-node system can be observed that without any change in the voltage profile the real power losses are reduced by 9.62% and reactive power losses are reduced by 9.10%.

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