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A Fast Power Flow Solution of Radial Distribution Networks

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1.Introduction

In order to evaluate the performance of a power distribution system and to examine the effectiveness of proposed alterations to a system in the planning stage, it is essential that a load flow analysis of the system is to be carried out. One of the most fundamental and widely used analysis tools to study radial distribution system is load flow analysis.

As the distribution network is known to be an ill-conditioned power system due to their radial structure and wide ranging resistance and reactance values, popularly used Newton – Raphson and Fast Decoupled load flow algorithms cannot be used to analyze the distribution system [1]. Many researchers [2,4] have suggested modified versions of the conventional load flow methods for solving ill-conditioned power networks. Recently some researchers [11,13] have paid much attention to obtaining solutions for distribution networks. Kersting [3] have presented a load flow technique based on ladder network theory. Shirmohammadi et al. [5] have presented a compensation based power flow method for weakly meshed distribution and transmission systems. Baran and Wu [6] and Chiang [9] have obtained the load flow solution in a distribution system by the iterative solution of the three fundamental equations representing real power, reactive power and voltage magnitude. They have computed system Jacobian matrix using chain rule in their method. In fact decoupled and fast-decoupled distribution load flow algorithms proposed by Chiang [9] are similar to that of Baran and Wu [6]. Renato [8] has proposed a method for obtaining the load flow solution of radial distribution networks.

In this paper, a simple method of load flow technique for distribution systems is proposed. The proposed method involves only the evaluation of a simple algebraic expression of receiving end voltages. The mathematical formulation of the proposed load flow method is explained in the following section.

2.Mathematical Formulation

In any radial distribution system, the electrical equivalent of a branch 1, which is connected between nodes 1 and 2 having impedance Z_1 is shown in Fig. 1.

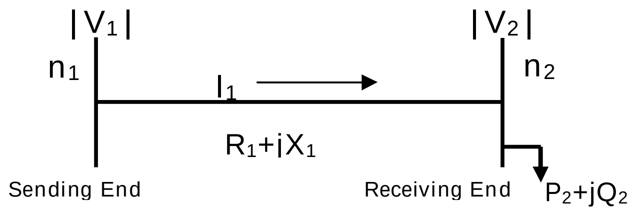

Fig. 1 Electrical equivalent of a typical branch '1'

The voltage at source node is taken as 1.0 p.u. The voltage at node 2 is given by

$$V_2 = V_1 - I_1 Z_1$$

In general $$V_{n2} = V_{n1} - I_j Z_j \qquad (1)$$

where 'n1' and 'n2' are sending and receiving ends of branch 'j' respectively. By using Eqn. (1), the voltage at any node (except node 1) can be calculated.

In most of the test systems, the loads are taken as constant power loads, and at each bus, the real and reactive power loads are specified. The load current at node 'i' is calculated by

$$IL_i = \left(\frac{PL_i + jQL_i}{V_i}\right)^*, \text{ for } i = 2,3, \text{----}, nn \qquad (2)$$

Where,

PL_i = Real power load at node i

QL_i = Reactive power load at node i

nn= Number of nodes

The real and reactive power losses of branch 'j' can be calculated as

$$LP_j = I_j^2 r_j \qquad (3)$$

$$LQ_j = I_j^2 x_j \quad \text{for } j=1, 2, \text{----}, nb. \qquad (4)$$

where nb= Number of branches

The current in each branch is calculated by applying KCL at node '2' shown in figure 2 the branch current equation obtained is as follows

$$I_1 = I_2 + I_5 + I_7 + IL_2 \qquad (5)$$

From the above, the current can be calculated in any branch. By following the above procedure i.e., branch current calculations in backward walk and the voltage at each node are calculated in the forward walk.

Initially, a flat voltage profile is assumed at all nodes i.e., 1.0 p.u. Load currents are computed iteratively with the updated voltages at each node. In the proposed load flow method, current summation is done in the backward walk and voltages are calculated in the forward walk. The maximum difference of voltage magnitudes in successive iterations is taken as convergence criteria, and 0.0001 is taken as tolerance value.

3.Identification of Nodes Beyond All the Branches

The following algorithm explains the methodology to identify nodes beyond all the branches. This will help in finding the branch currents of the system.

3.1 Algorithm for Node Identification

Step 1 : Read the system data.
Step 2 : Initialize 'memory location from' vector(MF) and index to zero.
Step 3 : Initialize the node count and branch count to 1.
Step 4 : If node count is equal to sending end of branch (SE) go to Step 7 otherwise go to Step 6.
Step 5 : If node count is equal to receiving end of branch (RE) go to Step 8 otherwise go to Step 9.
Step 6: Increment index by 1 and store the branch number and RE in Adb and Adn vectors respectively.
Step 7: Increment index by 1 and store the branch number and SE in Adb and Adn vectors respectively.
Step 8: If branch count is less than or equal to number of branches increment branch number then go to Step 5 otherwise go to step10.
Step 9: Store index value in 'memory location to' vector (MT) and then increment the value of MT and store in MF.
Step10: If node count is less than or equal to number of nodes increment the node number then go to Step 4 otherwise go to Step11.
Step11: Stop.

3.2 Illustration

Consider the single line diagram of 15-node radial distribution system which is shown in Fig. 2. Table 1 and Table 2 can be formulated by using above algorithm. Table 1 gives the information regarding adjacent branches and adjacent nodes of each node. Table 2 gives the information regarding the memory locations for each node.

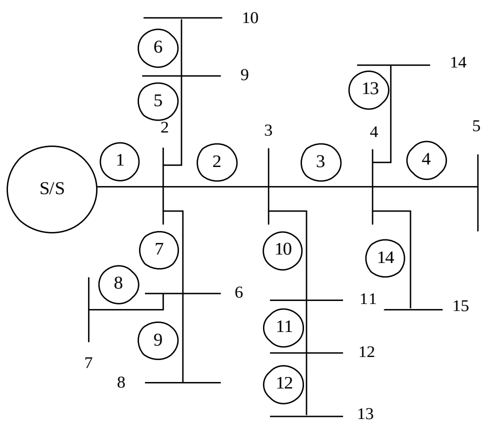

Fig. 2. 15-node Radial Distribution Systems

Consider node ‘4’ from Fig. 2, starting from branch 1 to nb, check either sending or receiving end of considered branch is same as ‘4’, if condition is satisfied store that branch number as adjacent branch, receiving and sending ends as adjacent nodes. For node ‘4’ adjacent nodes are 3, 5, 14, 15 and adjacent branches are 3, 4, 13, 14. This information can be obtained from the memory tags for node ‘4’. The node tags are 9 and 12, referring to 9-12 rows of Table 1 gives the required information.

Table 1 Adjacent nodes and branches of each node shown in Fig. 2

S. No	Adjacent Nodes (Adn)	Adjacent Branches (Adb)	Node No
1	2	1	1
2	1	1	2
3	3	2	
4	6	7	
5	9	5	
6	2	2	3
7	4	3	
8	11	10	
9	3	3	4
10	5	4	
11	14	13	
12	15	14	
13	4	4	5
14	2	7	6
15	7	8	
16	8	9	
17	6	8	7
18	6	9	8
19	2	5	9
20	10	6	
21	9	6	10
22	3	10	11
23	12	11	
24	11	11	12
25	13	12	
26	12	12	13
27	4	13	14
28	4	14	15

Table 2. Memory tags for the system shown in Fig. 2

Node no	Memory tag from (MF)	Memory tag to (MT)
1	1	1
2	2	5
3	6	8
4	9	12
5	13	13
6	14	16
7	17	17
8	18	18
9	19	20
10	21	21
11	22	23
12	24	25
13	26	26
14	27	27
15	28	28

Where Adn[2 * nb] is used to store the adjacent nodes.
Adb[2 * nb] is used to store the connected branches.
MF[i]=Memory location from
MT[i]= Memory location to for a particular node i (i=1 to nb)

4 Load Flow Solution

4.1 Algorithm for load flow solution of radial distribution system

Step 1: Read line and load data of radial distribution system. Assume initial node voltages 1 p.u, set $\varepsilon = 0.0001$.
Step 2: Start iteration count, c =1.
Step 3: Calculate load currents at each node by using Eqn. (2)
Step 4: Initialize real power loss and reactive power loss vectors to zero.
Step 5: Using the node currents calculated in Step 3, calculate branch currents.
Step 6: Calculate node voltages, real and reactive power loss of each branch using Eqns. (1), (3) and (4) respectively.
Step 7: Check for convergence i.e., $|\Delta V_{max}| \leq \varepsilon$ in successive iterations. If it is converged go to next step otherwise increment iteration number and go to Step 3.
Step 8: Calculate total real power and reactive power losses for all branches.
Step 9: Print voltages at each node, real and reactive power losses and number of iterations.
Step 10: Stop.

The method is illustrated with example in the following section.

4.2 Example

The 33-node, 12.66 kV radial distribution system [7] is shown in Fig. 3. The load flow results of a 33-node radial distribution system are given in Table 3. The total real and reactive power losses of this system are 202.66 kW and 135.13 kVAR respectively. These are 5.45% and 5.87% of their total loads. The minimum voltage of the system is 0.9131 p.u. at node18. The maximum voltage regulation of system is 8.69%. The number of iterations taken to compute this system is 3. The method given in [10] takes 4 iterations to converge but this method took 3 iterations to converge. The CPU time also considerably reduced from 0.16sec to 0.09sec (core 2 Duo). The voltages of the proposed method are compared with existing method [14] and results are found to be in good agreement.

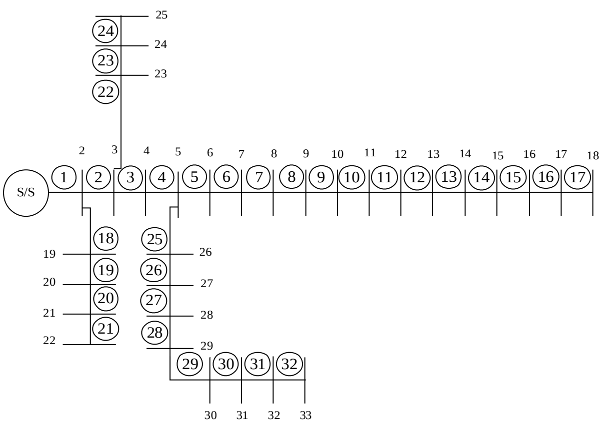

Fig 3. 33-node Radial Distribution Systems

Table 3. Load flow results of 33-node radial distribution system

Node No.	Voltage (p.u) Existing method [14]	Voltage (p.u) Proposed Method	Node No.	Voltage (p.u) Existing method [14]	Voltage (p.u) Proposed Method
1	1.0000	1.0000	**18**	**0.9130**	**0.9131**
2	0.9970	0.9970	19	0.9965	0.9965
3	0.9829	0.9830	20	0.9929	0.9929
4	0.9754	0.9755	21	0.9922	0.9922
5	0.9680	0.9681	22	0.9915	0.9916
6	0.9596	0.9597	23	0.9793	0.9794
7	0.9461	0.9462	24	0.9726	0.9727
8	0.9413	0.9414	25	0.9693	0.9694
9	0.9350	0.9351	26	0.9477	0.9478
10	0.9292	0.9293	27	0.9452	0.9452
11	0.9182	0.9182	28	0.9337	0.9337
12	0.9268	0.9269	29	0.9254	0.9254
13	0.9208	0.9208	30	0.9219	0.9220
14	0.9185	0.9185	31	0.9178	0.9178
15	0.9171	0.9171	32	0.9169	0.9169
16	0.9157	0.9157	33	0.9166	0.9166
17	0.9137	0.9137			

Conclusions

A simple load flow technique has been proposed for solving radial distribution systems. It completely exploits the radial feature of the distribution system. The proposed method always guarantees convergence for any type of radial distribution system. The effectiveness of the proposed method has been tested on 33 node radial distribution system.It has been found from the case with which the method was tested that the method has good and fast convergence characteristics compared with existing method. However, the proposed method can easily include composite load modeling, if the compositions of the loads are known.

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