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Power Flow Analysis for Radial Distribution System Using Backward/Forward Sweep Method

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***Abstract*—**This paper proposes a backward/forward sweep method to analyze the power flow in radial distribution systems. The distribution system has radial structure and high R/X ratios. So the newton-raphson and fast decoupled methods are failed with distribution system. The proposed method presents a load flow study using backward/forward sweep method, which is one of the most effective methods for the load-flow analysis of the radial distribution system. By using this method, power losses for each bus branch and voltage magnitudes for each bus node are determined. This method has been tested on IEEE 33-bus radial distribution system and effective results are obtained using MATLAB.

***Keywords*—**Backward/Forward sweep method, Distribution system, Load flow analysis.

I. Introduction

LOAD flow studies are performed on Power Systems to understand the nature of the installed network. Load flow is used to determine the static performance of the system. A power-flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various forms of AC power (i.e.: voltages, voltage angles, real power and reactive power). It analyzes the power systems in normal steady-state operation. The distribution networks because of the some of the following special features fall in the category of ill-condition.

- Radial or weakly meshed networks
- High R/X ratios
- Multi phase, unbalanced operation
- Unbalanced distributed load
- Distributed generation

Due to the above factors the Newton Raphson and other transmission system algorithms are failed with distribution network. So the backward forward sweeping method is introduced to analyze the distribution network. This method do not need Jacobian matrix unlike NR methods. However, conventional backward forward sweep method is not useful for modern active distribution networks.

Tripathy et al. [1] presented a Newton like method for solving ill-conditioned power systems. Their method showed voltage convergence but could not be efficiently used for optimal power flow calculations.

The conventional Newton Raphson (NR) and fast decoupled load flow (FDLF) methods are inefficient in solving such systems. Even though with some advancements in the Newton-Raphson Methods the robustness of the program is obtained but still the computational time is large enough [2].

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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. [3]

A radial network leaves the station and passes through the network area with no normal connection to any other supply. The Forward-Backward Sweep Method (FBSM) in [4] is easy to program and runs quickly. The method is designed to solve the differential algebraic system generated by the Maximum Principle that characterizes the solution [5].

The Newton-Raphson method and its variants have been developed specifically for transmission systems which have a meshed structure, with parallel lines and many redundant paths from the generation points to the load points. Typically, a distribution system originates at a substation where the electric power is converted from the high voltage transmission system to a lower voltage for delivery to the customers [6].

A. Augugliaro and L. Dusonchet proposed an improved Backward /Forward sweep load flow algorithm for radial distribution systems which includes the backward sweep and the decomposed forward sweep. Backward sweep uses KVL and KCL to obtain the calculated voltage at each upstream bus [7].

The properties of the backward/forward sweep method with different line X/R ratios and the convergence conditions are explained by E. Bombard, E. Carpaneto [8]. The convergence theorem for a basic type of optimal control problem is explained in [9].

Chiang [10] had also proposed three different algorithms for solving radial distribution networks based on the method proposed by Baran and Wu .He had proposed decoupled, fast decoupled & very fast decoupled distribution load-flow algorithms. In fact decoupled and fast decoupled distribution load-flow algorithms proposed by Chiang [10] were similar to that of Baran and Wu [11].

Goswami and Basu [12] had presented a direct method for solving radial and meshed distribution networks. However, the main limitation of their method is that no node in the network is the junction of more than three branches, i.e. one incoming and two outgoing branches.

Jasmon and Lee [13] had proposed a new load-flow method for obtaining the solution of radial distribution networks. They have used the three fundamental equations representing real power, reactive power and voltage magnitude derived in [13].The majority of power flow algorithms used in industry is newton-raphson method and its variants that have been developed specifically for transmission systems which have a meshed structure, with parallel lines and many redundant paths from the generation points to the load points [14]. The Gauss-Seidel power flow technique has also shown to be extremely inefficient in solving large power system [15].

In this paper a forward backward sweeping method is proposed to solve the radial distribution system. The proposed method is tested by taking 33bus radial distribution systems. The backward 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. Distribution System

An electric power distribution system is the final stage in the delivery of electric power; it carries electricity from the transmission system to individual consumers. Primary distribution lines carry the medium voltage power to distribution transformers which is located near the customer's premises. Distribution transformers again lower the voltage to the utilization voltage of household appliances and typically feed several customers through secondary distribution lines at this voltage.

A. Types of Distribution System

Distribution networks are divided into two types,

a) Radial Distribution System
b) Ring Main Distribution System

Generally the ring main system is more expensive than the radial system because more switches and conductors are required to construct the ring main system. It is not preferred when the generation is at low voltage and its construction cost also high. Due to the above factors the radial system is used in distribution system.

B. Radial Distribution System

Separate feeders are radiate from a single substation and feed the distributors at only one end is called radial system. Radial distribution is the type of power distribution where the power is delivered from the main branch to the sub branches then it split out from the sub-branches again as seen in Fig. 1, where the power is transferred from root node and then it is split at L1. The radial structure implies that there are no loops in the network and each bus is connected to the source via exactly one path. It is the cheapest but the least reliable network configuration. The Radial distribution system is widely used in sparsely populated areas.

A radial network leaves the station and passes through the network area with no normal connection to any other supply. This is typical in long rural lines with isolated load areas**.** In this type of Radial Delivery Network (RDN) each node is connected to the substation via at least one path.

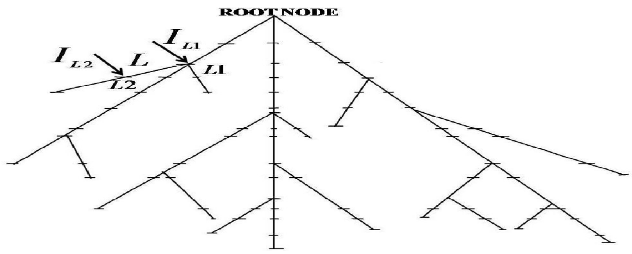

Fig. 1 Radial distribution network

The following criterion is assumed for node and line numbering:

1. The nodes are numbered sequentially in ascending order proceeding from layer to layer, in such a way that any path from the root node to a terminal node encounters nodes numbered in the ascending order.
2. Each branch starts from the sending bus (at the root side) and is identified by the number of its (unique) ending bus. [8]

The main advantage of radial network is its simple construction, low initial cost, useful when generation is at low voltage. Radial network is preferred when the station is located at the centre of the load.

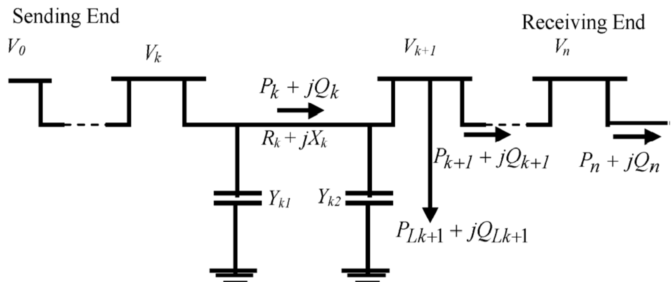

Fig. 2 Single line diagram

III. Formulation of the Problem

The Power flows in a distribution system are computed by the following set of simplified recursive equations derived from the single-line diagram shown in Fig. 2. The power flow analysis can be used to obtain the voltage magnitude, power losses of the 33 bus system. The objective function is to find the power flow.

$$P_{k+1} = P_k - P_{Loss,k} - P_{Lk+1} \tag{1}$$
$$Q_{k+1} = Q_k - Q_{Loss,k} - Q_{Lk+1} \tag{2}$$

where P_k –Real power flowing out of bus; Q_k –Reactive power flowing out of bus; P_{Lk+1} –Real load power at bus k+1; Q_{Lk+1} –Reactive load power at bus k+1

The power loss in the line section connecting buses k and k+1 may be computed as

$$P_{loss}(k, k+1) = R_k \frac{P_k^2 + Q_k^2}{V_k^2} \tag{3}$$
$$Q_{loss}(k, k+1) = X_k \frac{P_k^2 + Q_k^2}{V_k^2} \tag{4}$$

Where $P_{loss}(k,k+1)$ –Real power Loss in the line section connecting buses k and k+1; $Q_{loss}(k,k+1)$-Reactive power Loss in the line section connecting buses k and k+1.

The total power loss of the feeder, $P_{T,loss}$ may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_{T,loss}(k,k+1) = \sum_{k=1}^{n} P_{loss}(k,k+1) \quad (5)$$

$$Q_{T,loss}(k,k+1) = \sum_{k=1}^{n} Q_{loss}(k,k+1) \quad (6)$$

where $P_{T,loss}(k,k+1)$ –Total Real Power Loss in the line section; $Q_{T,loss}(k,k+1)$ - Total Reactive Power Loss in the line section [16].

IV. Backward/ Forward Sweep Method

Let us consider a radial network, the backward/forward sweep method for the load-flow computation is an iterative method in which, at each iteration two computational stages are performed: The load flow of a single source network can be solved iteratively from two sets of recursive equations. The first set of equations for calculation of the power flow through the branches starting from the last branch and proceeding in the backward direction towards the root node. The other set of equations are for calculating the voltage magnitude and angle of each node starting from the root node and proceeding in the forward direction towards the last node.

A. Forward Sweep

The forward sweep is basically a voltage drop calculation with possible cur-rent or power flow updates. Nodal voltages are updated in a forward sweep starting from branches in the first layer toward those in the last. The purpose of the forward propagation is to calculate the voltages at each node starting from the feeder source node. The feeder substation voltage is set at its actual value. During the forward propagation the effective power in each branch is held constant to the value obtained in backward walk.

B. Backward Sweep

The backward sweep is basically a current or power flow solution with possible voltage updates. It starting from the branches in the last layer and moving towards the branches connected to the root node .The updated effective power flows in each branch are obtained in the backward propagation computation by considering the node voltages of previous iteration. It means the voltage values obtained in the forward path are held constant during the backward propagation and updated power flows in each branch are transmitted backward along the feeder using backward path. This indicates that the backward propagation starts at the extreme end node and proceeds towards source node.

It is well known that there exist three main variants of the forward/backward sweep method that differ from each other based on the type of electric quantities that at each iteration, starting from the terminal nodes and going up to the source node (backward sweep), are calculated.

1. The current summation method, in which the branch currents are evaluated;
2. The power summation method, in which the power flows in the branches are evaluated;
3. The admittance summation method, in which, node by node, the driving point admittances are evaluated. In other terms, the three variants of the B/F method simulate the loads within each iteration, with a constant current, a constant power and a constant admittance model. In the forward phase, the three variants are identical since, based on quantities calculated in the backward phase, the bus voltages are calculated starting from the source node and going towards the ending nodes. Voltages are then used to update, based on the dependency of loads on the voltage, the quantities used in the backward sweep in order to proceed to iteration. The process stops when a convergence criterion is verified.

By comparing the calculated voltages in previous and present iterations, the successive iteration is obtained. The convergence can be achieved if the voltage mismatch is less than the specified tolerance i.e., 0.0001. Otherwise new effective power flows in each branch are calculated through backward walk with the present computed voltages and then the procedure is repeated until the solution is converged.

The backward/forward sweep method is now reformulated in a way suitable for the analysis of the convergence of the iterative process. Consider Fig. 2, a branch is connected between the nodes ‘k’ and ‘k+1’.The effective active (P_k) and reactive (Q_k) powers that of flowing through branch from node ‘k' to node ‘k+1’ can be calculated backwards from the last node and is given as,

$$P_k = P'_{k+1} + r_k \frac{(P'^2_{k+1} + Q'^2_{k+1})}{V^2_{k+1}} \quad (7)$$

$$Q_k = Q'_{k+1} + X_k \frac{(P'^2_{k+1} + Q'^2_{k+1})}{V^2_{k+1}} \quad (8)$$

where

$$P'_{k+1} = P_{k+1} + P_{Lk+1}$$
$$Q'_{k+1} = Q_{k+1} + Q_{Lk+1}$$

P_{Lk+1} and Q_{Lk+1} are loads that are connected at node ‘k+1’, P_{k+1} and $Q_{k+1}$are the effective real and reactive power flows from node ‘k+1’.

The voltage magnitude and angle at each node are calculated in forward direction. Consider a voltage$V_k < \delta_k$at node ‘k’ and $V_{k+1} < \delta_{k+1}$ at node ‘k+1’, then the current flowing through the branch having an impedance, $z_k = r_k + x_k$connected between ‘k’ and ‘k+1’is given as,

$$I_k = \frac{V_k < \delta_k - V_{k+1} < \delta_{k+1}}{r_k + jx_k} \quad (9)$$

The magnitude and the phase angle equations can be used recursively in a forward direction to find the voltage and angle respectively of all nodes of radial distribution system.

Initially, a flat voltage profile is assumed at all nodes i.e., 1.0 pu. The branch powers are computed iteratively with the updated voltages at each node. In the proposed load flow method, power summation is done in the backward walk and voltages are calculated in the forward walk.

Fig. 3 gives the detailed operation of the power flow calculation using backward forward sweeping algorithm.

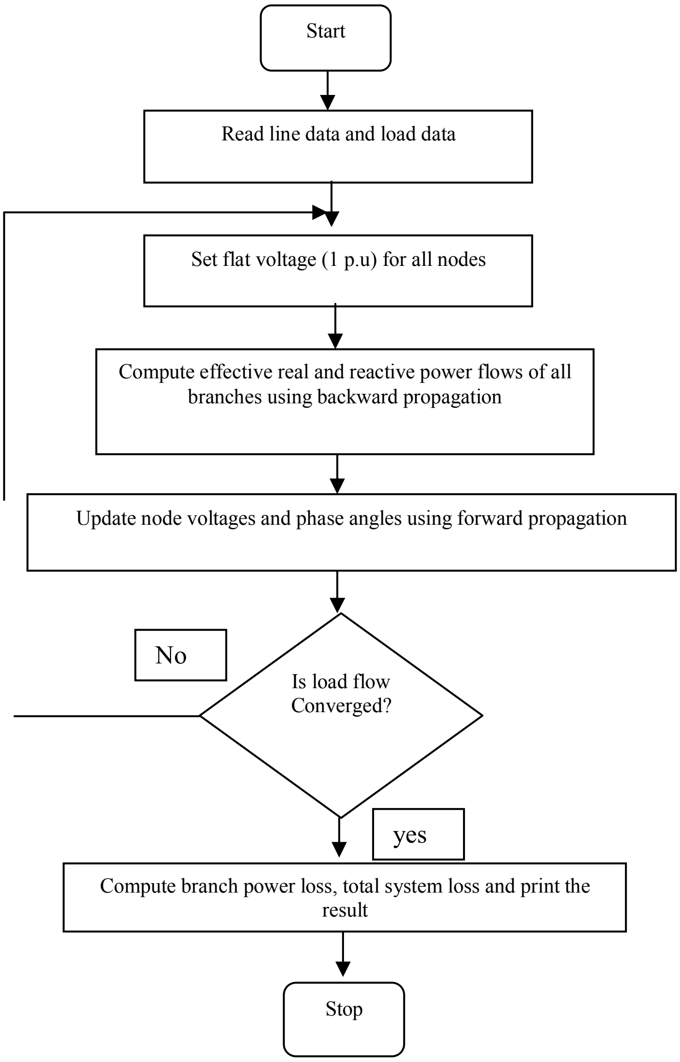

Fig. 3 Flow chart for backward forward sweep method

V. Test System

The proposed backward Forward sweep algorithm is applied to IEEE 33–bus network. The test system contains five tie switches and 32 sectionalizing switches. Fig. 4 shows the 33 bus test system [17]. In the network sectionalize switches (normally closed) are numbered from 1 to 32 and tie-switches (normally open) are numbered from 33 to 37. The proposed method is also used to find power flow.

To demonstrate the efficiency of the backward Forward sweep algorithm, the proposed method is tested on the 33–bus system. The details of the 33–bus system are given below:

Number of buses – 33
Number of branches – 37
Number of tie lines – 5
Tie lines – S33, S34, S35, S36, S37
Total real power – 3715 KW
Total reactive power – 2300 KVAR

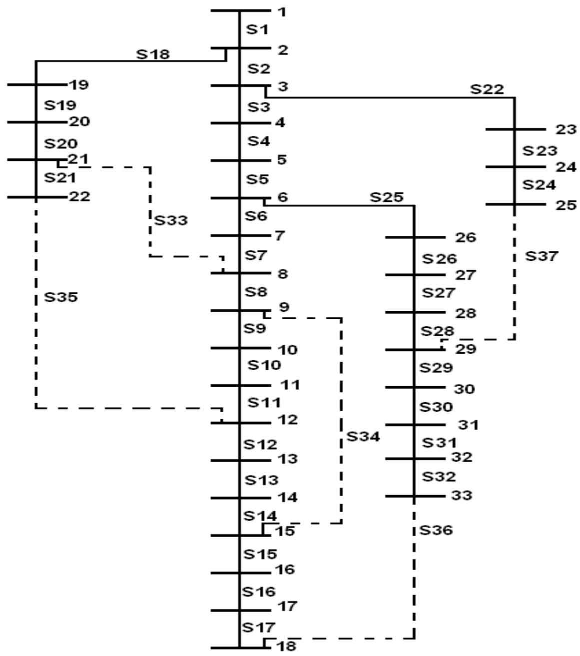

Fig. 4 33- bus system

TABLE I
Branch Losses of 33–Bus System

Bus Connection	Real power loss(KW)	Reactive power loss(KVAR)
1-2	9.17	4.67
2-3	37.3	19.0
3-4	15.5	7.92
4-5	14.4	7.34
5-6	29.3	25.3
6-7	1.26	4.15
7-8	3.75	1.24
8-9	4.14	2.97
9-10	3.53	2.50
10-11	0.54	0.18
11-12	0.87	0.28
12-13	2.65	2.08
13-14	0.72	0.95
14-15	0.35	0.31
15-16	0.28	0.20
16-17	0.25	0.33
17-18	0.05	0.04
2-19	0.00	0.00
19-20	0.83	0.75
20-21	0.10	0.11
21-22	0.04	0.05
3-23	0.00	0.00
23-24	2.81	2.22
24-25	1.10	0.86
6-26	0.00	0.00
26-27	2.93	1.49
27-28	9.90	8.73
28-29	6.85	5.97
29-30	3.38	1.72
30-31	1.05	1.04
31-32	0.10	0.12
32-33	0.01	0.02

The voltage, real and reactive power losses of 33 bus system is obtained by using the backward forward sweep method. The power loss for each branch is shown in Table I. The voltage magnitude at different nodes of this system is given by Table II. The minimum voltage of proposed system is 0.9136 p.u at node 18.

TABLE II
NODE VOLTAGE OF 33–BUS SYSTEM

BusNo:	Bus Voltage(p.u)
1	1
2	0.9974
3	0.9851
4	0.9782
5	0.9714
6	0.9548
7	0.9517
8	0.9469
9	0.9397
10	0.9334
11	0.9325
12	0.9308
13	0.9239
14	0.9213
15	0.9191
16	0.9174
17	0.9146
18	0.9136
19	0.9965
20	0.9917
21	0.9907
22	0.9894
23	0.9816
24	0.9762
25	0.9715
26	0.9529
27	0.9504
28	0.9392
29	0.9312
30	0.9275
31	0.9189
32	0.9177
33	0.9168

The performance of the proposed methodology is shown in Table III.

TABLE III
PERFORMANCE OF THE PROPOSED METHODOLOGY

Total real power losses(KW)	Total reactive power losses(KVAR)	Minimum Voltage(P.U)
203.65	102.60	0.9136

V. CONCLUSION

The performance of the backward/forward sweep method of radial networks has been presented. The backward and forward propagation iterative equation carries the distribution power flow. By using backward propagation the power of each branch has been calculated. The voltage magnitudes at each node are calculated in forward propagation. The iterations have fast convergence ability. The results for IEEE 33 bus test system have been tabulated. It was found that the proposed load flow method is suitable for fast convergence characteristics and radial structure.

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