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# Power Flow Analysis of Radial Distribution System using Backward/Forward Sweep Method

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***Abstract: Power flow analysis is a basic and necessary tool for any electrical system. A standard and efficient power flow technique is required for real-time applications such as switching, optimization of network and so on. 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: Radial Distribution System, Load Flow analysis, Backward/ Forward Sweep, MATLAB.***

## I. INTRODUCTION

A standard and efficient power flow technique is required for real-time applications such as switching, optimization of network and so on. Newton Raphson and Gauss Seidel methods are not effective for power flow analysis of radial distribution system because RDS networks have some features such as high ratio of R/X, wide range of values of resistance and reactance, unbalanced distribution load and multiphase unbalanced operation. All these features make the computation of transmission system power flow different from distribution system. Hence, there is requirement of power flow method which is efficient for Radial system.

Due to above factors, the backward forward sweep method of load flow analysis is used to analyze the radial system because in this technique there is no requirement of Jacobian matrix unlike Newton Raphson method. The Backward Forward Sweep method is based on Kirchhoff's laws. This method has various advantages such as high efficiency of computation and requirement of memory is less. The convergence characteristics of this method are strong.

## II. MATHEMATICAL MODEL FOR RADIAL DISTRIBUTION NETWORK

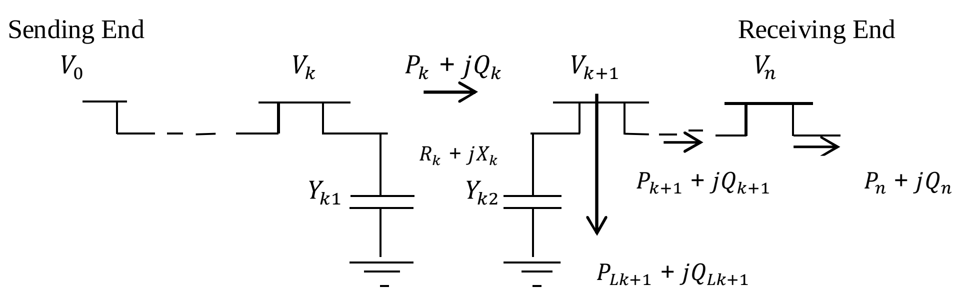

Fig.1. Single line diagram of Radial network

The simplified recursive equations are derived from single line diagram of radial distribution system as shown in Fig.1. The power losses and magnitude of voltage can be finding by using load flow analysis. The real and reactive power of this system is given as following:

$$P_{k+1} = P_k - P_{loss,k} - P_{Lk+1} \quad (1)$$
$$Q_{k+1} = Q_k - Q_{loss,k} - Q_{Lk+1} \quad (2)$$

Where,

$P_k$ is real power that is flowing out of the bus,

$Q_k$ is reactive power that is flowing out of the bus,

$P_{Lk+1}$ is load real power of bus k+1,

$Q_{Lk+1}$ is load reactive power of bus k+1.

The loss of power for line section between buses k and k+1 can be computed as follows:

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

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

Above equation give the losses of real power and reactive power in line section between buses k and k+1. Now the total real power loss and total reactive loss can be calculated by adding the losses of every section of the feeder. Hence the value of total real and reactive power loss can be expressed as;

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

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

Equations (5) and (6) are the total real power loss and total reactive power loss respectively in section of line between k and k+1.

## III. BACKWARD FORWARD SWEEP METHOD

This is an iterative method of power flow analysis of radial distribution network. The two stages of computation are performed at each iteration. There are two sets of recursive equations that are used to solve the load flow analysis through iterations. The calculations in first set of equations are done in backward direction. This set of equations calculates power flow. The path for power flow calculation is traced from the last or load node to the first or source node. The second set of equations is used to determine the value of voltage magnitude and angle. The path for calculation by this set of equations is created from the source to the load node.

### *A. Forward Sweep*

In forward sweep, voltage drop is calculated and the values of power flow and currents are updated. From first layer to last layer of the branch the nodal voltage is gradually updated. Basically, the main purpose of forward calculations is to find out the value of voltages at each node. The voltage of feeder substation is set to actual value of its voltage. The effective power during forward walk should kept constant in each branch as value obtained in backward propagation.

### *B. Backward Sweep*

In backward sweep, the calculation is starts from last node and moving toward the first node. Basically, backward propagation is solution of power flow or current with possible voltage updates. In each branch the node voltages of previous iteration is consider in backward walk to obtained the updated effective power flows. During the backward walk the voltages values that are obtained in forward walk are kept constant. Then by using backward path, the power flows updated values are transmitted along the feeder. Backward forward sweep method has three variants. These variants are different from each other and it is based on electric quantities in backward propagation. These three variants can be calculated as follows:

*1)* The branch currents are evaluated by current summation method.
*2)* In each branch the power flows are evaluated by power summation method.
*3)* The driving point admittances, node by node are evaluated by method of admittance summation.

On the other hand, by the variants of this method within each iteration, the loads are simulates. This is done with a constant power, a constant current and a constant admittance model. These three variants are identical in forward propagation and bus voltages are calculated from source node towards the last node based on calculation of backward sweep. To precede the iteration, voltages are updated based on the quantities used in backward sweep. When the convergence criterion is verified the process will stop. The calculated values of voltages are compared with previous iterations. If the difference between the new and old values is less than 0.0001 that is specified tolerance, then the convergence criterion will verify. If convergence is not achieved, the process will continue and new values of power flow will calculate by backward propagation until the solution will not satisfied the convergence criterion.

Now, the reformulation of backward forward method is done for convergence analysis of iterative process. Consider branch in between node 'k' and 'k+1' and by backward propagation effective power flows is calculated. The effective real and reactive powers is given as,

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

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

Where,

$$P'_{k+1} = P_{k+1} + P_{Lk+1} \quad (9)$$

$$Q'_{k+1} = Q_{k+1} + Q_{Lk+1} \quad (10)$$

Where, $P_{k+1}$ is effective real power from 'k+1' node
$Q_{k+1}$ is effective reactive power from 'k+1' node

The value of voltages and angle at each node are evaluated in forward propagation. Let the voltage at node 'k' k' is $V_k < \delta_k$ and voltage at node 'k+1' is $V_{k+1} < \delta_{k+1}$. The impedance connected between 'k' and 'k+1' is $z_k = r_k + jx_k$ and the current in this section is given as;

$$I_k = \frac{V_k < \delta_k - V_{k+1} < \delta_{k+1}}{r_k + jx_k} \quad (11)$$

To find the values of voltage and angle at all nodes the recursive equations are used. Initially assume 1.0 p. u. voltage at all node. The backward forward algorithm gives the detailed power flow calculation operation.

### *C. Backward/Forward Sweep Algorithm*

Step 1: Read bus data and line data of the distribution system and also base MVA and base KV.
Step 2:.Evaluate the injected active and reactive power at each node, i.e.

$$P_{inj} = P_{gen} - P_{load} \quad (12)$$

$$Q_{inj} = Q_{gen} - Q_{load} \quad (13)$$

Step 3: Set k=1, the iteration count.
Step 4: For convergence criterion set ε=0.001,$\Delta P_{max}$= 0.0 and $\Delta Q_{\max}$ = 0.0.
Step 5: Evaluate the value of nodal current injection at node 'i' as

$$I_i^{(k)} = (S_i / V_i^{(k-1)})^* - Y_i V_i^{(k-1)} \qquad i=1, 2……n \quad (14)$$

Step 6: Apply backward sweep and calculate the branch current using KCL.
Step 7: Forward sweep is apply to calculate the voltage at each node using KVL.
Step 8: Now calculate the power injection at node 'i' as

$$S_i^k = V_i^k (I_i^k)^* - Y_i |V_i^k|^2 \quad (15)$$

Step 9: Check convergence, if $\Delta P_{max} <= \varepsilon$ and $\Delta Q_{max} <= \varepsilon$, then go to step 11, else step 10.
Step 10: Then set k=k+1 and go to step 4.
Step 11: In 'k' iteration print that problem is converged.
Step 12: Stop.

## IV. RESULT AND DISCUSSION

Backward/Forward Sweep method is tested on IEEE 33-bus radial distribution system using MATLAB 2015b. IEEE 33 bus radial Distribution system has 33 nodes and 32 branches. The base voltage of the system is 12.66KV and the base MVA is 10.
Table 1 shows the values of voltages at each node of 33-bus radial distribution system and table 2 illustrate the values of real power loss (kW) and reactive power loss (kVAr) at each branch of the system
The total real power loss in 33 bus radial distribution system is 208.28kW and total reactive power loss is 139.3kVAr.

Table 1 Voltages at each node of 33 bus system

| Node number | Voltage magnitude (p. u.) |
|---|---|
| 1 | 1 |
| 2 | 0.99719 |
| 3 | 0.98392 |
| 4 | 0.97697 |
| 6 | 0.97011 |
| 7 | 0.95308 |
| 8 | 0.94985 |
| 9 | 0.94537 |
| 10 | 0.93960 |
| 11 | 0.93426 |
| 12 | 0.93347 |
| 13 | 0.93209 |
| 14 | 0.9265 |
| 15 | 0.92443 |
| 16 | 0.92314 |
| 17 | 0.92189 |
| 18 | 0.92005 |
| 19 | 0.9195 |
| 20 | 0.91897 |
| 21 | 0.91544 |
| 22 | 0.91474 |
| 23 | 0.91411 |
| 24 | 0.91063 |
| 25 | 0.90418 |
| 26 | 0.90096 |
| 27 | 0.89918 |
| 28 | 0.89681 |
| 29 | 0.88626 |
| 30 | 0.87869 |
| 31 | 0.87541 |
| 32 | 0.87161 |
| 33 | 0.87051 |

Table 2 Real and Reactive power losses of 33 bus system

| Sending Node | Receiving node | $P_{loss}$ (kW) | $Q_{loss}$ (kVAr) |
|---|---|---|---|
| 1 | 2 | 12.311 | 6.2755 |
| 2 | 3 | 52.0044 | 26.508 |
| 3 | 4 | 20.048 | 10.21 |
| 4 | 5 | 18.816 | 9.5832 |
| 5 | 6 | 38.1 | 32.89 |
| 6 | 7 | 1.915 | 6.3302 |
| 7 | 8 | 4.8165 | 1.5917 |
| 8 | 9 | 4.1456 | 2.9784 |
| 9 | 10 | 3.5283 | 2.5009 |
| 10 | 11 | 0.54848 | 0.18134 |
| 11 | 12 | 0.87322 | 0.28874 |
| 12 | 13 | 2.6404 | 2.0774 |
| 13 | 14 | 0.72459 | 0.95376 |
| 14 | 15 | 0.35377 | 0.31486 |
| 15 | 16 | 0.27926 | 0.20393 |
| 16 | 17 | 0.25011 | 0.33393 |
| 17 | 18 | 0.053451 | 0.041914 |
| 2 | 19 | 0.19021 | 0.18151 |
| 19 | 20 | 0.98556 | 0.88807 |
| 20 | 21 | 0.119974 | 0.13988 |
| 21 | 22 | 0.052376 | 0.069251 |
| 3 | 23 | 3.6881 | 2.52 |
| 23 | 24 | 6.0125 | 4.7477 |
| 24 | 25 | 1.5203 | 1.1896 |
| 6 | 26 | 2.8921 | 1.4731 |
| 26 | 27 | 3.7014 | 1.8845 |
| 27 | 28 | 12.555 | 11.07 |
| 28 | 29 | 8.7102 | 7.5881 |
| 29 | 30 | 4.3716 | 2.2267 |
| 30 | 31 | 1.7795 | 1.7586 |
| 31 | 32 | 0.24 | 0.27972 |
| 32 | 33 | 0.014893 | 0.023156 |
| Total P and Q losses | | 208.28 kW | 139.3kVAr |

## V. CONCLUSIONS

In this paper, the performance of the backward/forward sweep method of radial distribution network is discussed. The backward and forward propagation iterative equation carries the distribution power flow. The power of each branch has been calculated by using backward propagation and by using forward propagation the voltage magnitudes at each node are calculated. In addition, the operation of this technique in distribution management system remains very straightforward. This technique takes full benefit of the radial structure of distribution systems, to attain high speed, robust convergence and low memory requirements. The algorithm is tested on IEEE 33 bus radial distribution system and results have been tabulated.

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