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A COMPARATIVE ANALYSIS OF DISTRIBUTION SYSTEM LOAD FLOW FOR 33-BUS SYSTEM

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ABSTRACT

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. Certain distinguishing features are present in distribution system which makes it somewhat arduous and dissimilar to examine as estimated to a transmission system. Some of these features comprises of unbalanced loads, un-transposed lines, single phase and two phase laterals. In this paper distribution system load flow has been studied and comparative analysis is made on backward-forward sweep and direct load flow solution. The purpose of study is to find the bus voltage and bus angle at each bus and also evaluate voltage regulation at particular bus so that we can apply local VAR to improve the voltage profile of the system. For unbalanced distribution system, backward sweep is used for calculation of branch current and forward sweep is used for bus voltage calculation. Simple matrix multiplication of two developed matrices – the bus injection to branch current (BIBC) matrix and the branch current to bus voltage (BCBV) matrix helps in obtaining solution for distribution system load flow. The proposed algorithm is tested with IEEE33-bus radial distribution system.

Keywords: Backward Sweep, Distribution System Load Flow, Forward Sweep, Radial Distribution System.

I INTRODUCTION

A distribution system load flow is a crucial tool in the electrical power system since it is the main point of connection between bulk power and consumers. It provides the steady state solution of various parameters like voltages, currents, and losses to be calculated. In order to investigate the issues concerned with planning, design, operation and control power flow needs to be examined for distribution system. The main goal of the load flow analysis is to find out the real and reactive powers flowing in each line along with the magnitude and phase angle of the voltage at each bus of the system for the specific loading conditions. Power flow is the most frequently carried out study by power utilities and are required to be performed for power system planning, operation, optimization and control. At the design stage, load flow analysis is used to check whether the voltage profile is expected to be within limits throughout networks. During operation stage, it is run to check out different arrangements to keep the required voltage profile and to minimize system losses.

Varieties of techniques are accessible in the literature, which utilize the topology (radial structure) of the distribution system to perform load flow analysis. Separate feeders radiate from a single sub-station and feed the distributors at only one end is called the radial distribution system. It is the type of power distribution system where power is delivered from the main branch to the sub-branches, then it splits out from the sub-branches again as seen in fig 2. [1]These load flow methods can be split into two classes. The first class comprises of dissimilar sort of Newton-Raphson method [2-6]. The other methods, for radial distribution systems, like Gauss-Siedel method comes under second class [7-11]. The use of these methods for distribution system may not be advantageous because they are mostly based on general meshed topology of typical transmission system whereas most distribution system have a radial or tree topology. Moreover, distribution system posses high R/X ratio, which cause the distribution system to be ill-natured for conventional load flow methods.

The characteristics of electric distribution systems are:

1) Radial or weakly meshed structure;

2) Unbalanced operation and distributed loads;

3) Large number of buses and branches;

4) It has wide range of resistance and reactance values;

4) Distribution system has multiphase operation.

The explicit Z-bus method [7] works on the principle of superposition. A modified Gauss-Siedel method is the mingle of the implicit Z-bus method and the Gauss Siedel method [8]. The bus injection to branch current (BIBC) matrix and the branch current to bus voltage (BCBV) matrix help in obtaining solution for distribution system load flow [9]. For unbalanced distribution system, backward sweep is used for calculation of branch current and forward sweep is used for bus voltage calculation [10]. Ladder network theory based approach trace the network to and fro from its load end to source end [11]. Load flow algorithm should be efficient since it has to be run number of times. Therefore, solution for the load flow of distribution system need to posses robust and time efficient characteristics. A method that can find the load flow solution of radial distribution system directly by making use of topological features of distribution network is used. In this method, formulation of tie consuming Jacobian matrix or admittance matrix, which is needed in conventional methods, is neglected.

II BACKWARD AND FORWARD SWEEP METHOD

Backward and forward sweep method for load flow is an iterative technique in which, at each iteration two computational stages are performed. With the aid of two sets of recursive equations, load flow of a single source network can be solved iteratively. The first set of equations for calculation of the power flow through the branches starting from the last branch and proceeding in backward direction towards the root node. The second set of equations is used for calculation of the voltage magnitude and phase angle of each node starting from the root node and proceeding in the forward direction towards the last node [12].

2.1 Backward Sweep Method

In backward sweep, branch current is updated in each section by taking into consideration the previous iteration voltages at each node. It starts from the branches in the last node and move towards the branches connected to the root node. The updated effective power flows in each branch is obtained in the backward propagation computation by considering the node voltages of previous iterations. It means that 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 the 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 exists three main variants of the backward-forward sweep method that differ from each other based on the type of electric quantities that at each iteration, beginning from the terminal nodes and going up to the source node (backward sweep), are evaluated.

2.2 Forward Sweep Method

The main aim of forward sweep method is to calculate voltage drop with possible current or power flow updates. During forward sweep, nodal voltages are updated starting from branches in the first node towards those in the last. The feeder substation voltage is set at its actual value. During the forward propagation, effective power in each branch is held constant to the value obtained in backward sweep method.

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 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 evaluated in the backward phase, the bus voltages are calculated starting from the source node and moving towards the last node. Voltages are then used to update, based on the reliance of loads on the voltage, the quantities used in the backward sweep in order to proceed to iteration. The process ceases when a convergence criterion is verified.

Successive iteration is obtained by comparing the calculated voltages in previous and present iterations. The convergence can be achieved if the voltage mismatch is less than the specified tolerance i.e. 0.01. Otherwise new effective power flows in each branch are evaluated through backward sweep with the present evaluated voltages and then the procedure is repeated until the solution is converged [13].

III ALGORITHM FOR BACKWARD AND FORWARD SWEEP METHOD

Major steps of the proposed solution algorithm with appropriate equations are summarized below.

Step 1: Presume rated voltage at end nodes only for first iteration and equals the value computed in the forward sweep in the consecutive iteration.

Step 2: Begin with end node and compute the node current using equation (1). Apply KCL to determine the current flowing from node i towards node i+1 using equation (2), Begin from end node.

$$I_i = \left(\frac{S_i}{V_i}\right)^* \tag{1}$$

$$I(i, i+1) = I(\text{i}+1) + \sum \text{ current in branches emanating from node (i+1)} \tag{2}$$

Step 3: Evaluate with this value of current the voltage at i^{th} node using equation (3). Proceed with this step till the junction node is reached. At junction node the computed voltage is reserved.

$$V_i = V(i+1) + I(i,i+1) * Z(i,i+1) \quad (3)$$

Step 4: Now begin with another end node of the system and evaluate voltage and current as in Step 2 and 3.

Step 5: Using equation (1) evaluate current, with the help of most recent voltage at junction node.

Step 6: Furthermore continue till reference node.

Step 7: Contrast the evaluated magnitude of the rated voltage at reference node with the specified source voltage.

Stop if the voltage difference is less than specified criteria, elsewhere forward sweep starts.

Forward Sweep

Step 1: Begin with reference node at rated voltage.

Step 2: Using equation (4), evaluate the node voltage in forward direction from reference node to end nodes.

$$V(i+1) = V_i - I(i,i+1) * Z(i,i+1) \quad (4)$$

Step 3: Now again start with backward sweep with updated bus voltage evaluated in forward sweep.

3.1 Flowchart For Backward and Forward Sweep Method

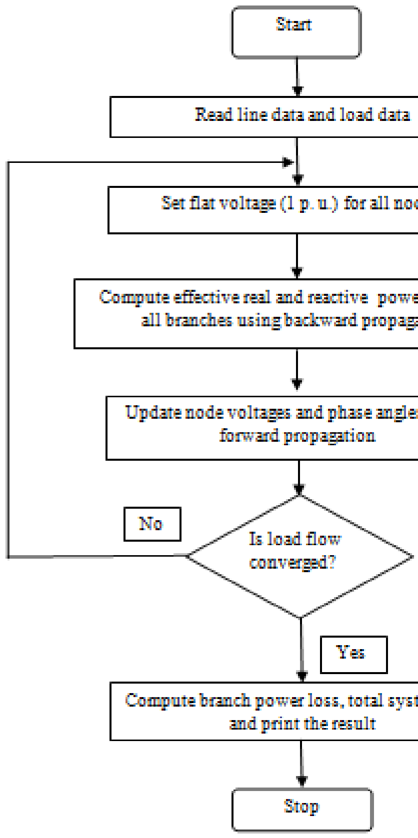

Fig. 1 Flowchart for backward and forward sweep method

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IV DIRECT LOAD FLOW APPROACH-

This method performs the load flow analysis for radial distribution system under balanced operating condition employing constant power load model. Three important steps are considered in this approach, namely

1) Equivalent current injection
2) Formulation of BIBC matrix
3) Formulation of BCBV matrix

(i) Equivalent current injection

This method is based on current injection. At bus i, the complex S_i is specified and the corresponding equivalent current injection at the k^{th} iteration of the solution is computed as

$$S_i = (P_i + jQ_i) \qquad i=1,2,...........,N \tag{5}$$

$$I_i^k = I_i^r\left(V_i^k\right) + j\left(I_i^i\right)\left(V_i^k\right) = \left(\frac{P_i + jQ_i}{V_i^k}\right)^* \tag{6}$$

Where,

S_i is the complex power at i^{th} bus
P_i is the real power at i^{th} bus
Q_i is the reactive power at i^{th} bus
V_i^k is the bus voltage at the k^{th} iteration for i^{th} bus
I_i^k is equivalent current injection at the k^{th} iteration for i^{th} bus
I_i^r and I_i^i are the real and imaginary parts of the equivalent current injection at the k^{th} iteration for i^{th} bus.

(ii) Formulation of BIBC matrix

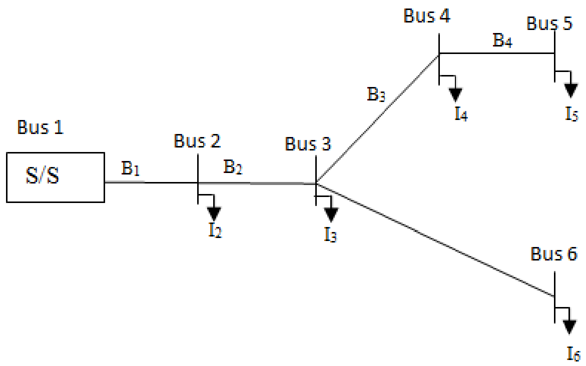

Fig.2 A simple radial distribution system.

Above fig. 2 is used as an example to understand the formulation of BIBC matrix. Using equation (6) power injections can be converted i to equivalent current injections and a set of equations can be written by applying Kirchhoff's Current Law (KCL) to the distribution network. Formulation of branch currents can be done as a function of the equivalent current injections. For example the branch currents $B_{5,}$ $B_{3,}$ and B_1can be expressed as

$$\begin{aligned} B_5 &= I_6 \\ B_3 &= I_4 + I_5 \\ B_1 &= I_2 + I_3 + I_4 + I_5 + I_6 \end{aligned} \qquad (7)$$

Moreover, the Bus-Injection to Branch-Current (BIBC) can be obtained as,

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \qquad (8)$$

[B] = [BIBC] [I]

(iii) Algorithm for formulation of BIBC matrix-

The power injections can be converted to the equivalent current injection and the relationship between the bus-current injection and branch current injections are obtained by Kirchhoff' s Current Law (KCL) to the distribution network. The branch currents are formulated as equivalent of current injection.

Step 1: Create a null matrix of dimension $m*(n-1)$.

Where,
m = number of branches.
n = number of buses.

Step 2: If a line section (B_k) is located between bus-i and bus-j, copy the column of the i^{th} bus of the BIBC matrix to the column of the j^{th} bus and fill +1 in the position of the k^{th} row and the j^{th} bus column.

Step 3: Repeat procedure (2) until all the line sections are included in the BIBC matrix.

(iv) Formulation of BCBV matrix

The BCBV matrix is accountable for the relationship between the branch currents and the bus voltages. By use of BCBV matrix, the respective variation of the bus voltages which is generated by the variation of the branch currents can be established directly.

$$\begin{aligned} V_2 &= V_1 - B_1 Z_{12} \\ V_3 &= V_2 - B_2 Z_{23} \\ V_4 &= V_3 - B_3 Z_{34} \end{aligned}$$

By using above equations, the voltage of bus 4 can be rewritten as,

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \tag{9}$$

From equation (7) it can be observed that the bus voltage can be expressed as a function of the branch currents, line parameters and substation voltage. By utilizing same procedure for rest of the buses, BCBV matrix can be derived as,

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix}$$

[ΔV] = [BCBV] [B]

(v) Algorithm for the formulation of BCBV matrix

Following steps can be opted to formulate BCBV matrix.

Step 1: Create a null matrix of dimension $(n-1)*m$.

Where,

m = number of branches.

n = number of buses.

Step 2: If a line section (B_k) is located between bus-i and bus-j, copy the row of the i^{th} bus of the BCBV matrix to the row of the j^{th} bus and fill the line impedance (Z_{ij}) in the position of the j^{th} bus row and the k^{th} column.

Step 3: Repeat procedure (2) until all the line sections are included in the BCBV matrix shown in fig.2.

Rewriting equation (9) in general form, we have

$$[\Delta V] = [BCBV][B] \tag{10}$$

(vi) Algorithm for Direct Load Flow Approach

A concise idea of how bus voltages can be obtained for a radial distribution system is summarised below:

Step 1: Input data.

Step 2: Form the BIBC matrix.

Step 3: Form the BCBV matrix.

Step 5: Set iteration count k=0.

Step 6: Set iteration count k=k+1.

Step 7: Solve the equations iteratively and update voltages $I_i^k = \left(\frac{P_i + Q_i}{V_i}\right)^*$

$$[\Delta V^{k+1}] = [DLF][I^k]$$

If $I_i^{k+1} - I_i^k >$ tolerance, go to Step-6 else print result.

Fig. 3 depicts detailed direct load flow approach for radial distribution system. It is clear from the figure that for every iteration the bus voltages have been updated. The iteration has been continued until the tolerance value has been reached.

(vii) Flowchart for Direct Load Flow Approach

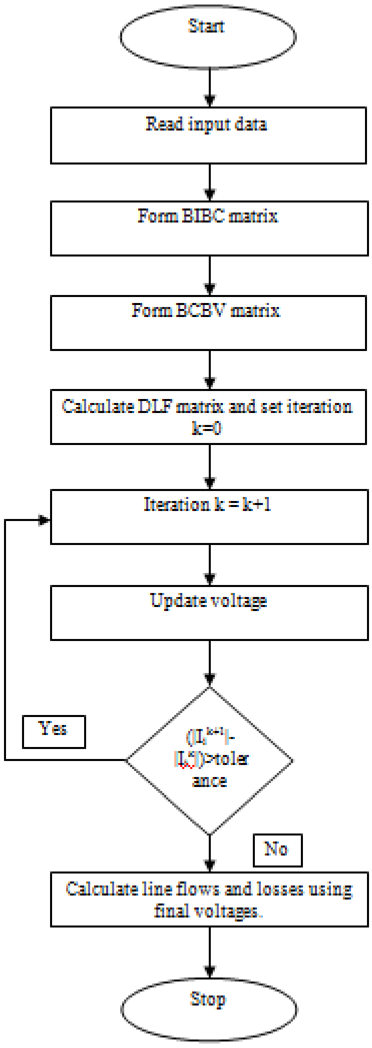

Fig.3 Flowchart of direct load flow approach for radial distribution system

V TEST RESULT

1. **Backward and Forward sweep method**

Bus Number	Voltage Magnitude(kV)	Phase Angle(degrees)
4	11.9897	-2.51017
8	10.7551	-9.65493

12	9.48369	-17.6946
16	8.54813	-32.4042
20	8.42893	-50.029
24	8.62177	-59.6625
28	8.59818	-65.0349
32	8.64143	-68.0823

Table 1: Voltage Magnitude and Phase Angle for selected buses for 33-Bus System using backward and forward sweep method

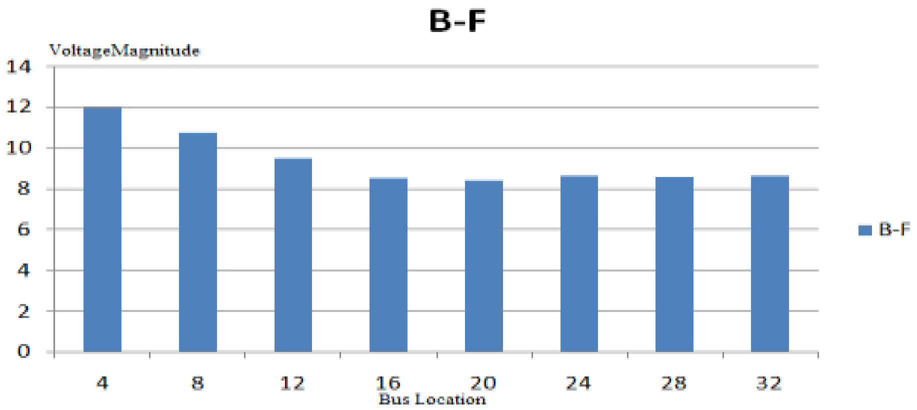

Fig. 4 A graph between voltage magnitude and bus location for backward and forward sweep method

It can be observed from table 1 and fig.4 that the voltage drop is very high and hence voltage regulation is very poor. So in order to improve the voltage regulation, local FACTS devices are employed in the distribution power system.

2. Direct Load Flow Approach

Bus Number	Voltage Magnitude(kV)	Phase Angle(degrees)
4	12.6552	-0.0111165
8	12.6514	-0.0242695
12	12.6494	-0.0303347
16	12.6480	-0.0359606
20	12.6589	-0.00359804
24	12.6552	-0.0127223
28	12.6500	-0.0272495
32	12.6464	-0.040034

Table 2: Voltage Magnitude and Phase Angle for selected buses for 33-Bus System using direct load flow approach.

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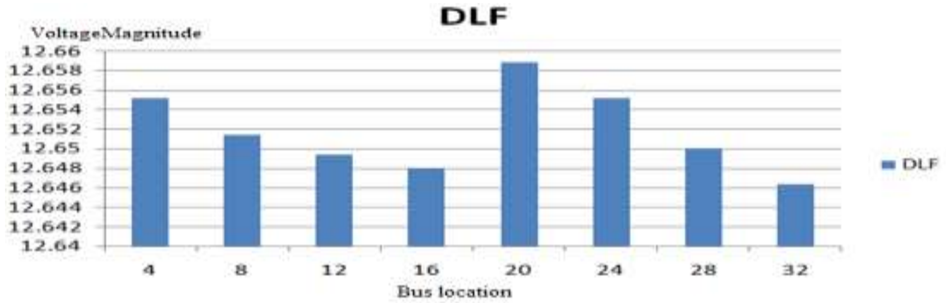

Fig. 5 A graph between voltage magnitude and bus location for direct load flow approach.

With the help of table 2 and fig.5, it is seen that the voltage profile is flat and hence losses are minimised using direct load flow approach.

3. Comparison of Backward-Forward Method and Direct Load Flow Approach-

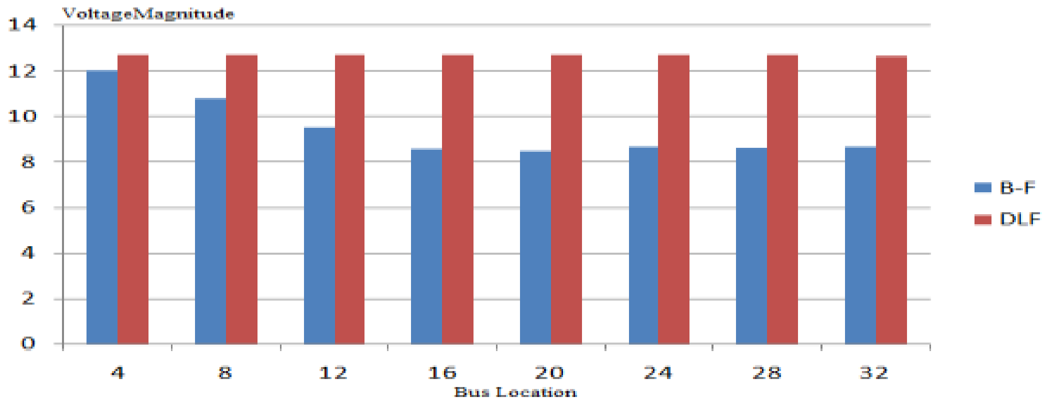

Fig. 6 A graph is plotted for Backward - Forward Sweep Method and Direct Load Flow Approach.

It can be observed from fig. 6 that direct load flow approach is much more significant than backward - forward sweep method, since voltage regulation is improved with this approach and losses are also curtailed.

VI CONCLUSION

The load flow methods which are widely used for distribution systems load flow solution is analyzed on 33-bus radial distribution systems using backward - forward sweep method and direct load flow approach. Flat voltage profile is achieved by direct load flow approach and hence losses are reduced; therefore this method is highly significant. This makes it robust, efficient, good and fast convergence characteristics. In future, the system can be extended for more number of buses and also this analysis can be done for more than one generator or DG sources can also be added. This can be enhanced for weakly meshed analysis too.

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