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Topological Structure Analysis based Radial Distribution Network Solution with DG

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Abstract: The paper recommends a topological structure analysis for power flow in balanced radial distribution network. The topological structure analysis of a distribution network will form a matrix called load injection to branch current (LIBC) and is used to obtain a better power flow solution possible. A simple matrix multiplication is used in forward /backward propagation to attain power flow solutions. The proposed method was an effective than the conventional techniques used for power flow analysis of radial distribution networks. Proposed one has tested on IEEE test systems with Distributed generation (DG) and effective results are obtained.

Keywords: Distribution network, forward/ backward, LIBC matrices, power flow, and radial balanced network.

1. INTRODUCTION

Load flow studies are performed on power systems to obtain a steady state solution of the power system network for a given operating condition subject to operational constrains. The distribution networks fall in the category of ill conditioned networks because of the some of the following special features like

- Radial/weakly meshed networks
- R/X ratio High
- Unbalanced act
- Distributed generation

Because of above factors the usual power flow methods used in transmission systems, such as the Gauss seidel method and Newton Raphson methods, fail to meet the requirements in both performance and robustness aspects in the distribution system applications. In particular, the necessary assumptions made for the simplification of the standard fast decoupled and Newton Raphson method often were not valid in distribution systems [1],[2]. Numerous load flow algorithms specially designed for distribution systems have been proposed in the literature. In the early endeavors, a direct solution approach using an impedance matrix of a unbalanced network and Gauss approach using Zbus have suggested. Consequently, different new other techniques , such as three phase fast decoupled power flow algorithm, rectangular Newton-Raphson based method and polar based decoupled method have developed. D. Das, DP. Kotari and A. Kalam proposed an algorithm for identification of nodes and branches beyond a particular node to make the method quite fast [4]. Several authors have proposed a load flow algorithm for solution of balanced radial distribution network by forward/ backward sweep method [3],[9],[6], emerged to be the most efficient and fast for solving the power flow of radial distribution systems. A. Alsaadi and B. Gholami and M. Tarafdar Hagh, T. Ahamadzadeh, K. M. Muttaqi, D. Sutanto have proposed a solution algorithm which utilizes two matrices developed from the topological characteristics of the distribution system [8],[11], and solved the distribution network directly by using simple matrix multiplication.

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Sharing of Distributed generators (DGs) in the power system world has grown very rapidly and their contribution to the future power system is expected to be evident. Installing DGs near to the load centers benefits to the distribution network. This sort of investment can also provide reduction in power loss and improvement in voltage profile.

The novel technique proposed in this paper requires the predictable bus branch oriented data provided by most of the utilities to obtain power flow solution. The main aim of this paper is to develop a problem formulation, which takes the topological characteristics of radial distribution system, and solve the system load flow directly by using load injection to branch current matrix in forward backward sweep technique .The proposed method is convenient and reliable for power flow solution of simple radial distribution systems. The proposed algorithm is tested with 9 bus and 15 bus IEEE test systems with and without DG and the solution demonstrates the feasibility and validity of the proposed method.

2. TOPOLOGICAL STRUCTURE BASED FORWARD BACKWARD SWEEP METHOD

2.1. Forward Propagation

A forward propagation was basically a voltage drop calculation with branch currents. Bus voltages were updated in a forward propagation starting from source node to last node. The purpose of forward propagation was to calculate the voltages at each bus starting from the feeder source. The feeder source voltage is set at its rated value. During the forward propagation the power in each branch was held constant to the value obtained in backward propagation.

2.2. Backward Propagation

Backward propagation was basically a current or power flow solution with voltage updates. Propagation starts from the branches in the last layer and moving towards the branches connected to the source node. Computation of updated power flows in each branch by considering the bus voltages of previous iteration were obtained in backward propagation. That means voltage values obtained in the forward propagation were held constant during the backward propagation and updated power flows in each branch were estimated along the feeder using backward path. This indicates that the backward propagation starts at the extreme end bus and proceeds towards source bus.

2.3. Topological Structure Analysis Load Injection to Branch Current Matrix

A network topology refers to the way in which buses in a network are connected to one another. The network structure defines how they communicate. Power flow of radial distribution system will flow out of the substation, Due to the characteristics of radial balanced distribution network, the network topology based analysis have been used to solve the network .The topological structure analysis for a distribution network under balancing operation has involved steps were (1) equivalent load injections and (2) formation of LIBC matrix.

LIBC matrix which defined relationship between the load injection and branch currents, presenting the solution method aiming at the simple radial distribution networks.

Consider a simple radial distribution network shown in Figure 1 for the formation LIBC matrix.

From the Figure 1, I_{B1}, I_{B2}, I_{B3} are branch currents, Z_1, Z_2, Z_3 are branch impedances and I_{L2}, I_{L3}, I_{L4} are load currents.

By appling kirchoff's current law to the network shown in Figure 1, the relationship between branch currents and equivalent load injections can be obtained as

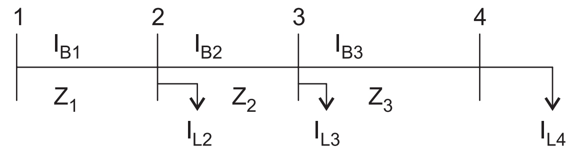

Figure 1: A simple 4 bus distribution network

$$I_{B3} = I_{L4} \quad (1)$$

$$I_{B2} = I_{L3} + I_{L4} \quad (2)$$

$$I_{B1} = I_{L2} + I_{L3} + I_{L4} \quad (3)$$

The above equations 1, 2, 3 can be written in matrix form as

$$\begin{bmatrix} I_{B1} \\ I_{B2} \\ I_{B3} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_{L2} \\ I_{L3} \\ I_{L4} \end{bmatrix} \quad (4)$$

In compact form the equation 1 can be written as

$$[I_B] = [LIBC]\,[I_L] \quad (5)$$

Where

I_L = Load injection current vector of order (3 × 1)

I_B = Branch current vector of order (3 × 1)

LIBC = Load injection to branch current matrix of order (3 × 3)

From the equation 1 it is observed that Load injection to branch current matrix (LIBC) is an upper triangular matrix. It contains only 0 and 1 elements. 0 indicates open line and 1 indicates connected line. With this concept of taking 1 as connected line and taking 0 as open line to form LIBC matrix, an algorithm has developed and is discussed in section 2.4.

2.4. Algorithm for LIBC Matrix Formation

1. Read the system data-line data, number of buses (*n*), number of branches (*b*) and source node.
2. Line data arranged in matrix form as LD Matrix.
3. Initialize matrix LIBC to Null Matrix.
4. Set *b* = size (LD, 1).
5. For *i* = 1 to *b*.
6. If LD(*i*, 2) = 1, go to next step otherwise go to step 9.
7. Find LIBC(LD(*i*, 3) – 1, LD(*i*, 3) – 1) = 1
8. Go to step 11.
9. Find LIBC(:,LD(*i*, 3) – 1) = LIBC(:,LD(*i*, 2) – 1).
10. Find LIBC (LD(*i*, 3) – 1, LD(*i*, 3) – 1) = 1.
11. Increment *i* by one.
12. Is *i* <= *b*, *b* is the number of branches then go to step 6 otherwise go to next step.
13. Print LIBC Matrix.

3. PROBLEM FORMULATION

Power flow solution includes the calculation of bus voltages and line flows of a network. Associated with each bus, there are four quantities which are magnitude of voltage, voltage phase angle, real power and reactive power can be calculated. In backward propagation, initially calculated injected load currents with knowing data of the system using the equation (6) then by applying kirchoff's current law to the system formed LIBC matrix as followed process explained in section 2.3.

$$I_L = \text{conj}\,((P - jQ)/V) \tag{6}$$

Where

I_L = load injection current vector

P = real power injection vector

Q = reactive power injection vector

V = bus voltage vector

Branch currents, I_B for the base case of the network can be calculated using equation (5)

From the branch impedances of the system an impedance matrix $[Z_B]$ can be formed and diagonalised it. Hence the diagonalized matrix will be

$$\Lambda = \begin{bmatrix} z_1 & 0 & 0 \\ 0 & z_2 & 0 \\ 0 & 0 & z_3 \end{bmatrix} \tag{7}$$

In forward propagation bus voltages can be calculated as:

The voltage drop at each bus corresponding to the reference bus is

$$[\Delta V] = [LIBC^T] \times \Lambda \times [I_B] \tag{8}$$

By substituting equation (5) in euation(8) then voltage drop at each bus will be

$$[\Delta V] = [LIBC^T] \times \Lambda \times [LIBC]\,[I_L] \tag{9}$$

The bus voltages can be calculated as

$$[V_B] = [V_1] - [\Delta V] \tag{10}$$

Where

$[V_B]$: bus voltage vector

$[V_1]$: substation voltage vector

The voltage mismatch can be calculated as:

$$[dV_B] = |V^{k+1}| - |V^k| \tag{11}$$

Where k is number of iteration. If the voltage mismatch is less than or equal to specified tolerance then load flow solution is obtained and calculate real and reactive power loss using the equations (12) and (13).

$$LP_{ij} = I_B^2 \times R_{ij} \tag{12}$$

$$LQ_{ij} = I_B^2 \times X_{ij} \tag{13}$$

Where R_{ij} : resistance of the branches

X_{ij} : reactance of the branches

4. POWER FLOW ALGORITHM

The flow chart of the proposed algorithm is given below.

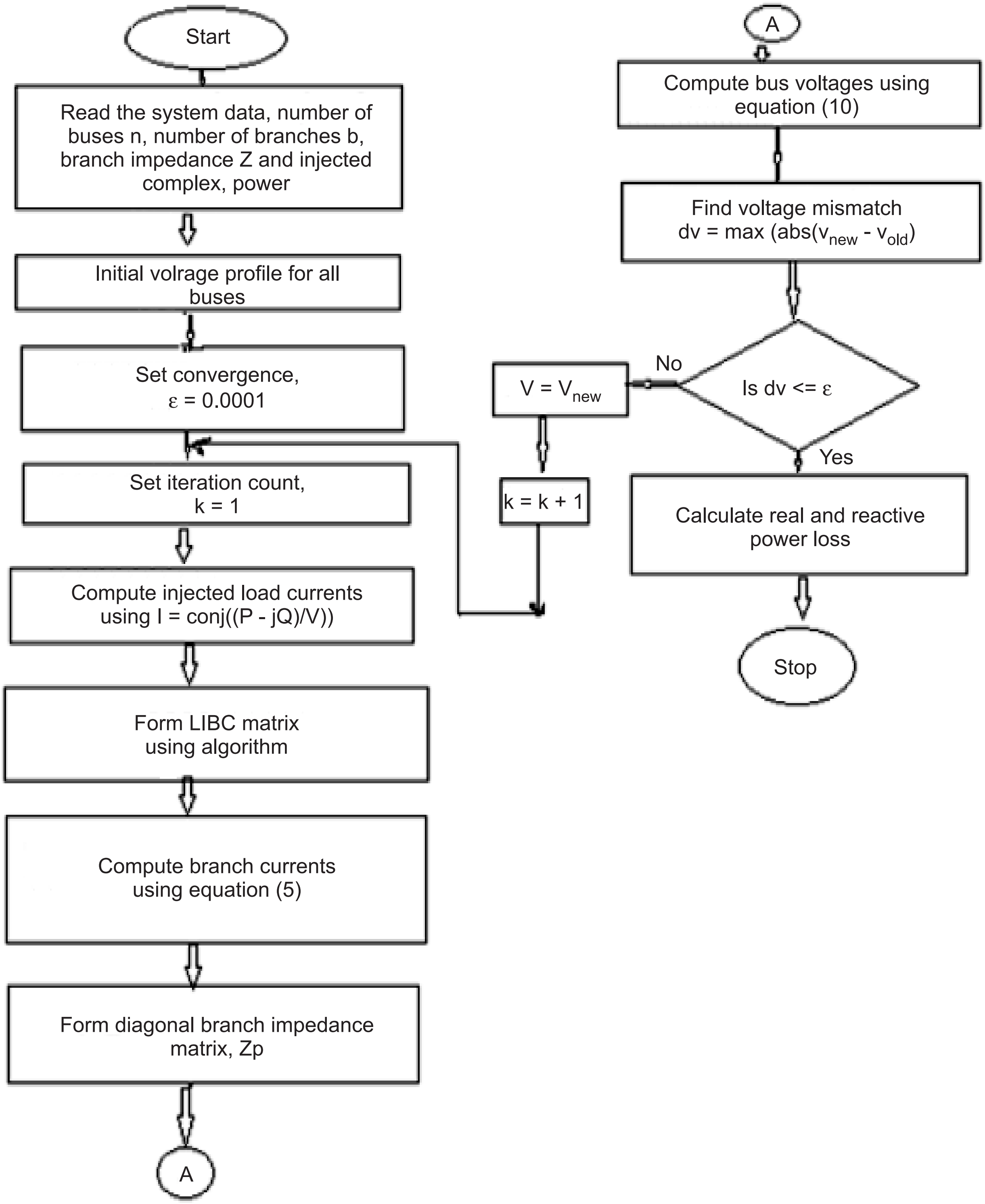

Figure 2: Flow Chart of power flow algorithm

5. RESULTS

The proposed method is tested on IEEE 9 bus and 15 bus radial distribution networks [9], [10]. The solution of test systems are tabulated below

Example 1: IEEE 9 bus test system shown in Figure 3 and results are tabulated in Table 1.

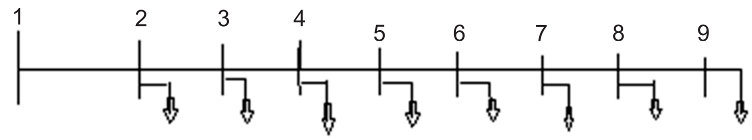

Figure 3: 9 bus test system

Table 1
Load flow results of 9 bus radial system

Br. No.	*From*	*To*	*Voltage magnitude without DG(pu)*	*Voltage magnitude with DG(pu)*	*Real power loss without DG(pu)*	*Real power loss with DG(pu)*	*Reactive power loss with out DG(pu)*	*Reactive power loss with DG(pu)*
1	1	2	0.9928	0.9932	0.0383	0.0343	0.0269	0.0241
2	2	3	0.9868	0.9878	0.0303	0.0263	0.0114	0.0099
3	3	4	0.9815	0.9831	0.0213	0.0179	0.0087	0.0073
4	4	5	0.975	0.9772	0.0179	0.0156	0.0081	0.007
5	5	6	0.9683	0.9713	0.0133	0.0109	0.0065	0.0053
6	6	7	0.9619	0.9661	0.0103	0.0078	0.0028	0.0021
7	7	8	0.9597	0.9647	0.0018	0.001	0.0005	0.0003
8	8	9	0.9594	0.9645	0.0001	0	0	0

The results are shown in Figure 4

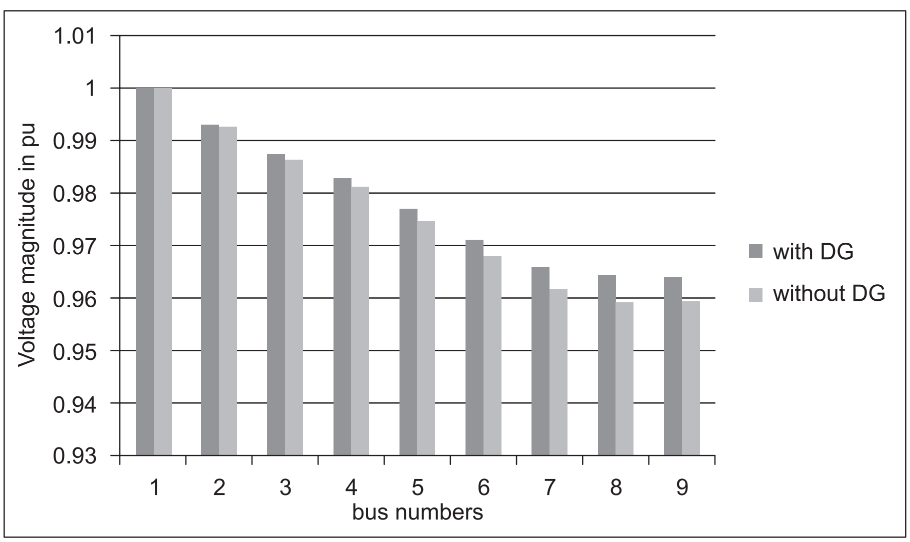

Figure 4: Load flows of 9 bus radial distribution system

Example 2: IEEE 15 bus test system shown in Figure 5 and results are tabulated in Table 2.

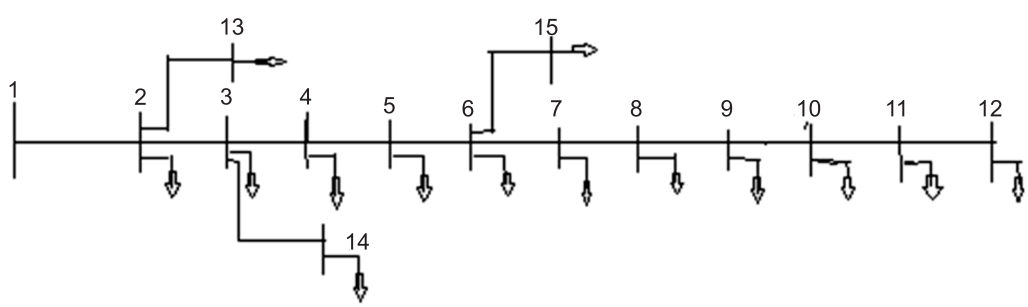

Figure 5: Flow Chart of power flow algorithm

Table 2
Load flow results of 15 bus radial distribution system

Br. No.	*From*	*To*	*Voltage magnitude without DG(pu)*	*Voltage magnitude with DG(pu)*	*Real power loss without DG(pu)*	*Real power loss with DG(pu)*	*Reactive power loss with out DG(pu)*	*Reactive power loss with DG(pu)*
1	1	2	0.9994	0.9995	0.0031	0.0022	0.0013	0.0009
2	2	3	0.9989	0.9991	0.0024	0.0015	0.001	0.0006
3	3	4	0.9982	0.9986	0.0027	0.0015	0.0011	0.0006
4	4	5	0.9971	0.9975	0.004	0.0035	0.0017	0.0015
5	5	6	0.9968	0.9973	0.001	0.0008	0.0004	0.0003
6	6	7	0.9965	0.997	0.0008	0.0006	0.0003	0.0003
7	7	8	0.9954	0.996	0.0033	0.0028	0.0009	0.0008
8	8	9	0.9941	0.9948	0.0035	0.0028	0.001	0.0008
9	9	10	0.9934	0.9941	0.0018	0.0018	0.0005	0.0005
10	10	11	0.9932	0.9939	0.0005	0.0005	0.0001	0.0001
11	11	12	0.9931	0.9938	0	0	0	0
12	2	13	0.9537	0.9538	0.0429	0.0429	0.0274	0.0274
13	3	14	0.8559	0.8561	0.1355	0.1355	0.0865	0.0865
14	6	15	0.9555	0.956	0.0099	0.0099	0.0063	0.0063

The results are shown in Figure 6

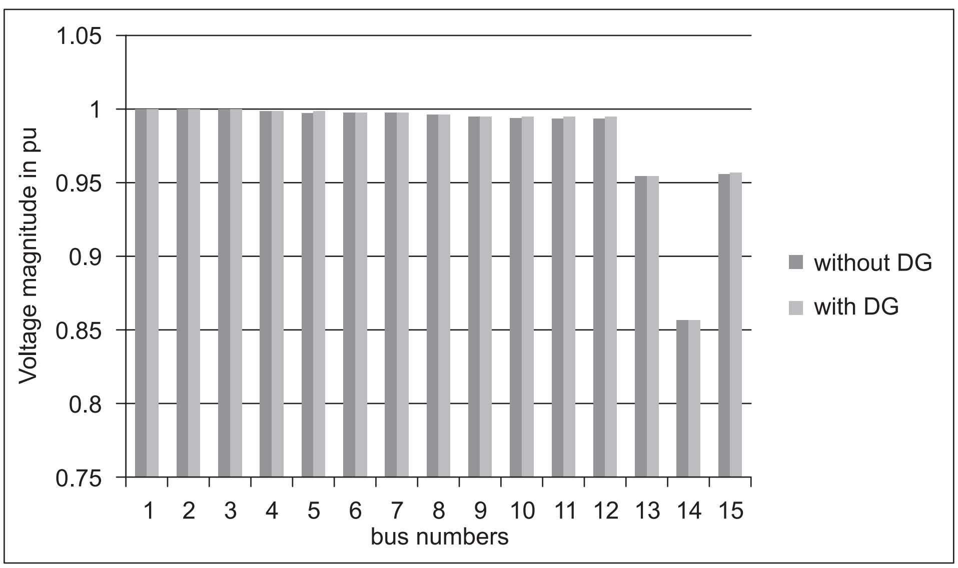

Figure 6: Load flows of 15 bus radial distribution system

The number of iterations and execution time required for converge of different systems by proposed method is shown in Table 3.

Table 3
Load flow details for different systems

System	*Iteration*	*Total real power loss without DG(pu)*	*Total real power loss with DG(pu)*	*Execution time (sec) without DG*	*Execution time (sec) with DG*
9 bus	3	0.1333	0.1138	0.043036	0.040635
15 bus	6	0.2114	0.2063	0.104783	0.094536

6. CONCLUSION

In this paper, a direct approach power flow algorithm for radial distribution system solution is proposed. LIBC matrix is developed from the topological characteristics of radial distribution network and is used to solve power flow problem. This topological structure analysis based forward backward power flow method is used to solve IEEE 9 bus and 15 bus radial distribution network and the results have been observed as ,by placing DG at different locations in the distribution network the voltage profile of the system is improved, total real power loss has reduced and also execution time. Thus this method can be useful tool to solve complex distribution system with Distributed generation.

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