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# A LOOP BASED LOAD FLOW METHOD FOR WEAKLY MESHED DISTRIBUTION NETWORK

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**ABSTRACT**

A distinctive load flow solution technique is proposed for the analysis of weakly meshed distribution systems. The special topological characteristics of distribution networks have been fully exploited to make the solution possible. A branch-injection to branch-current matrix is formed (BIBC). This matrix is obtained by applying Kirchhoff's current law for the distribution network. Using the same matrix a solution for weakly meshed distribution network is proposed. Bus voltages are found by forward-sweep of the network. Test results of 33-bus and 69-bus systems are given to illustrate the performance of the proposed method.

**Keywords:** load flow, weakly meshed distribution network, radial.

## 1. INTRODUCTION

The analysis of distribution system is an important area of activity as distribution systems provide the final link between the bulk power system and consumers. A distribution circuit normally uses primary or main feeders and lateral distributors. A main feeder originates from the substation and passes through the major load centers. Lateral distributors connect the individual load points to the main feeder and are defined as radial distribution systems. Radial systems are popular because of their simple design and low cost.

Even though the Fast decoupled Newton method [1] works well for transmission system, its convergence performance is poor for most radial distribution systems due to their high R/X ratios which deteriorate the diagonal dominance of the jacobian matrix. For these reasons, several non-Newton types of methods [2-5], that consist of forward/backward sweeps on a ladder system have been proposed. Recent research proposed some new ideas on how to deal with the special topological characteristics of distribution systems, but these ideas require new data format or some data manipulations. In [3], the author proposed a compensation-based technique to solve distribution load flow problems. They have developed a branch numbering scheme to enhance the numerical performance of the solution of the solution method and broke the interconnected grid into number of break points in order to convert it into a radial network by direct application of Kirchhoff's voltage and current laws. They have computed the break point currents by using muti-port compensation technique. Branch power flows rather than branch currents were later used in the improved version and presented in [4]. However, the main disadvantage of their method is that the branch and node-numbering scheme and data preparation are highly involved. Another difficulty of their method is that if new branch is inserted, numbering of branch of that part of network is necessary. Baran and Wu [6] have obtained the load flow solution for distribution system by iterative solution of three fundamental equations representing real power, reactive power and voltage magnitude. They computed system jacobian matrix by using chain rule. In their method, the mismatches and jacobian matrix calculation involve only the evaluation of simple algebraic expressions and no trigonometric functions. Chaing [7] has proposed decoupled and fast-decoupled distribution load flow algorithm. Very fast-decoupled load flow algorithm proposed by Chaing is very attractive. It does not require any jacobian matrix construction and factorization but more computation be involved because it solves three fundamental equations representing the real power, reactive power and voltage magnitude. Goswami and basu [8] have presented an approximate direct solution method for solving radial and meshed distribution networks. They have also broken the loop branches (break points) in order to convert it into a radial network similar to that of shirmohamadi, *et al.* [3]. However, the main limitation of their method is that no node in the network is a junction of more than three branches, i.e., one in coming and two outgoing branches.

Literature survey on distribution load flow as mentioned above shows that most of the authors have concentrated on solving radial distribution networks. Only shirmohammadi, et al. and Goswami and basu have made an attempt to solve meshed distribution networks. Their methods have some limitations as discussed above and are not computationally faster.

The main objective of this study was to present a new method of load flow solution for meshed distribution networks. Here, multi-port compensation technique is used for computation of break point current injections. The effectiveness of the proposed method is tested with two test systems.

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## 2. LOAD FLOW SOLUTION OF RADIAL DISTRIBUTION NETWORK

The proposed method is developed based on a derived matrix bus-injection to branch current matrix and equivalent current injections. In this section, the developed procedure will be described in detail. For distribution networks, the equivalent current injection based model is more practical [3]. For bus-i, the complex load $S_I$ is expressed as

$S_i = P_i + jQ_i \quad i = 1,2\ldots n$ ------(1)

and the corresponding equivalent current injection at the $k^{th}$ iteration of solution is

$I_i^k = ((P_i + jQ_i)/V_i^k)^*$ -------(2)

Where $V_i^k$ and $I_i^k$ are the bus voltage and equivalent current injection of bus-i at the $k^{th}$ iteration, respectively.

### 2.1. BIBC Matrix development

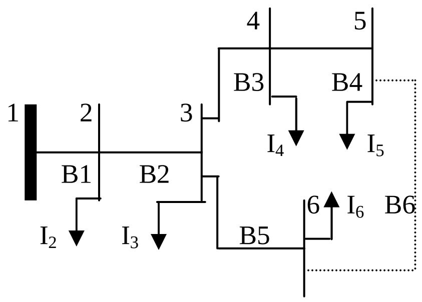


**Figure-1.** Simple distribution system.

A simple distribution network shown in Figure-1 is used as an example. The current injections are obtained from eq. (2), the relationship between the bus current injections and branch currents can be obtained by applying Kirchhoff's current law (KCL) to the distribution network. Using the algorithm of finding nodes beyond all branches proposed by Ghosh *et al.* The branch currents can then be formulated as functions of equivalent current injections. For example, the branch currents $B_1$, $B_3$ and $B_5$, Can be expressed as

$$\left.\begin{aligned} B_1 &= I_2 + I_3 + I_4 + I_5 + I_6 \\ B_3 &= I_4 + I_5 \\ B_6 &= I_6 \end{aligned}\right\} \text{----------(3)}$$

Therefore, the relationship between the bus current injections and branch currents can be expressed

$$\begin{bmatrix} B1 \\ B2 \\ B3 \\ B4 \\ B5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2 \\ I3 \\ I4 \\ I5 \\ I6 \end{bmatrix} ----(4)$$

Eq. (4) can be expressed in general form as

[B] = [BIBC][I] -------(5)

Where BIBC is bus injection to branch current matrix, the BIBC matrix is a upper triangular matrix and contains values of 0 and +1 only.

The receiving end bus voltages are found by a forward sweep through the ladder network using the generalized equation as

V (m2) = V (m1) – I (jj) Z (jj) ---- (6)

Where m1, m2 are the sending and receiving ends
jj is the branch number

The real and reactive power loss of branch jj are given by

$P\_LOSS = |I(jj)|^2 R(jj)$ ---------(7)

$Q\_LOSS = |I(jj)|^2 X(jj)$ ---------(8)

## 3. LOAD FLOW SOLUTION OF MESHED DISTRIBUTION NETWORK

Some distribution feeders serving high-density load areas contain loops created by closing normally switches. The proposed method for radial is extended for weakly meshed distribution feeders. Existence of loops in the system does not affect the bus current injections, but new branches need to be added to the system. Fig.3 shows a simple case with a one loop. Taking the new branch current into account, the current injections of bus 5 and bus 6 will be

$I^1_5 = I_5 + B_6$
$I^1_6 = I_6 - B_6$

Modification of equation (4) we have

$$\begin{bmatrix} B1 \\ B2 \\ B3 \\ B4 \\ B5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2 \\ I3 \\ I4 \\ I5+B6 \\ I6-B6 \end{bmatrix} ------(9)$$

Eq. (9) can be rewritten as

$$\begin{bmatrix} B1 \\ B2 \\ B3 \\ B4 \\ B5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2 \\ I3 \\ I4 \\ I5 \\ I6 \end{bmatrix} + \begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} B6 \\ -B6 \end{bmatrix}$$

**LILC Matrix**

Current of tie branch '6' can be calculated as

$B_6 = V_5 - V_6 / Z_{66}$ ------- (10)

## 4. ALGORITHM OF PROPOSED METHOD FOR MESHED NETWORK

The computational steps involved in solving the load flow problem of a single source network by the proposed method are given as under:

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(i) Read the system data. Construct the tree and number the branches. Assume the initial voltage at all buses as source bus voltage.
(ii) Compute current injections at each bus using eq. (2).
(iii) From the computed current injections; compute the branch currents in each branch-using BIBC matrix from eq. (4).
(iv) For meshed network, LILC matrix is formed from BIBC matrix as given by eq.(9).The order of LILC matrix is (number of branches)X(twice the number of tie switches)
(v) Compute the current injections at tie line nodes using eq. (10)
(vi) Using LILC matrix currents are injected in to the tie-switch nodes in opposite directions.
(vii) Compute the voltage magnitude at the receiving end bus of each branch using eq.(6).
(viii) Once currents are injected using LILC matrix, branch currents are updated and again radial load flow is run which completes one mesh iteration.
(ix) Repeat steps (ii) to (viii) till the max. magnitude of voltage difference between consecutive iterations is less than 0.0001 p.u

## 5. RESULTS AND ANALYSIS

The effectiveness of the proposed method is illustrated with two different cases as follows:

**Case-I.** Illustrates the 33-bus radial distribution system and mesh distribution sytem.

**Case-II.** Illustrates the 69-bus radial distribution system and mesh distribution system.

**Case-I.** Figure-2 shows a 33-bus distribution system. The line, load and tie switch data are given in [10]. The load flow results of radial and meshed systems as case ‘a’ and case ‘b’ are given in Table-1.

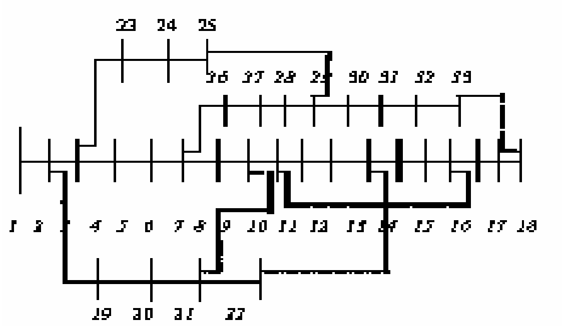

**Figure-2.** Single line diagram of a 33-bus network with 5-tie lines.

**Table-1.** Load flow results of 33 bus system.

| Bus No. | Case (a) \|V\| (p.u) | Case (b) \|V\| (p.u) |
|---|---|---|
| 1 | 1.00000 | 1.00000 |
| 2 | 0.99703 | 0.99756 |
| 3 | 0.98295 | 0.98804 |
| 4 | 0.97548 | 0.98361 |
| 5 | 0.96809 | 0.97931 |
| 6 | 0.94972 | 0.96869 |
| 7 | 0.94626 | 0.96686 |
| 8 | 0.94626 | 0.96434 |
| 9 | 0.94142 | 0.96110 |
| 10 | 0.93515 | 0.95810 |
| 11 | 0.92934 | 0.95766 |
| 12 | 0.92848 | 0.95688 |
| 13 | 0.92698 | 0.95374 |
| 14 | 0.92088 | 0.95257 |
| 15 | 0.91862 | 0.95184 |
| 16 | 0.91720 | 0.95114 |
| 17 | 0.91584 | 0.95010 |
| 18 | 0.91381 | 0.94979 |
| 19 | 0.91321 | 0.99636 |
| 20 | 0.99650 | 0.98680 |
| 21 | 0.99293 | 0.98471 |
| 22 | 0.99222 | 0.98281 |
| 23 | 0.99158 | 0.98486 |
| 24 | 0.97937 | 0.97895 |
| 25 | 0.97270 | 0.97601 |
| 26 | 0.96938 | 0.96750 |
| 27 | 0.94780 | 0.96592 |
| 28 | 0.94524 | 0.95887 |
| 29 | 0.93381 | 0.95381 |
| 30 | 0.92560 | 0.95161 |
| 31 | 0.92205 | 0.94905 |
| 32 | 0.91789 | 0.94849 |
| 33 | 0.91697 | 0.94832 |

**Case-II.** This case Illustrates with 69 bus system. The line, load and tie switch data are given in ref[6]. The Load flow results of 69 bus radial distribution system are given in Table-2. The Load flow results of 69 bus meshed distribution system are given in Table-3.The voltage magnitude at the root bus was considered to be 1.0 p.u. It was found that the voltage magnitudes in the case of mesh distribution system are higher than that of radial distribution system because of the inclusion of tie lines.

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**Table-2.** Load flow results of 69 bus radial distribution system.

| Bus | \|V\| (p.u) | Bus | \|V\| (p.u) |
|---|---|---|---|
| 1 | 1.00000 | 35 | 0.99916 |
| 2 | 0.99996 | 36 | 0.99981 |
| 3 | 0.99993 | 37 | 0.99964 |
| 4 | 0.99983 | 38 | 0.99948 |
| 5 | 0.99900 | 39 | 0.99944 |
| 6 | 0.99005 | 40 | 0.99944 |
| 7 | 0.98074 | 41 | 0.99874 |
| 8 | 0.97852 | 42 | 0.99845 |
| 9 | 0.97818 | 43 | 0.99841 |
| 10 | 0.97319 | 44 | 0.99840 |
| 11 | 0.97209 | 45 | 0.99830 |
| 12 | 0.96894 | 46 | 0.99830 |
| 13 | 0.96602 | 47 | 0.99978 |
| 14 | 0.96313 | 48 | 0.99854 |
| 15 | 0.96026 | 49 | 0.99470 |
| 16 | 0.95973 | 50 | 0.99415 |
| 17 | 0.95885 | 51 | 0.97700 |
| 18 | 0.95884 | 52 | 0.97214 |
| 19 | 0.95838 | 53 | 0.96934 |
| 20 | 0.95808 | 54 | 0.96609 |
| 21 | 0.95760 | 55 | 0.96160 |
| 22 | 0.95759 | 56 | 0.95721 |
| 23 | 0.95752 | 57 | 0.93471 |
| 24 | 0.95737 | 58 | 0.92361 |
| 25 | 0.95720 | 59 | 0.91931 |
| 26 | 0.95713 | 60 | 0.91426 |
| 27 | 0.95711 | 61 | 0.90682 |
| 28 | 0.99992 | 62 | 0.90653 |
| 29 | 0.99985 | 63 | 0.90614 |
| 30 | 0.99976 | 64 | 0.90423 |
| 31 | 0.99974 | 65 | 0.90365 |
| 32 | 0.99965 | 66 | 0.97204 |
| 33 | 0.99945 | 67 | 0.97204 |
| 34 | 0.99922 | 68 | 0.96861 |
| | | 69 | 0.96861 |

TP = 238.541 kW
TQ =106.972 kVAr
**No of iterations: 3**

**Table-3.** Load flow results of 69 bus mesh distribution system.

| Bus | \|V\| (p.u) | Bus | \|V\| (p.u) |
|---|---|---|---|
| 1 | 1.00000 | 35 | 0.99917 |
| 2 | 0.99997 | 36 | 0.99982 |
| 3 | 0.99994 | 37 | 0.99918 |
| 4 | 0.99986 | 38 | 0.99852 |
| 5 | 0.99940 | 39 | 0.99832 |
| 6 | 0.99442 | 40 | 0.99831 |
| 7 | 0.98925 | 41 | 0.99422 |
| 8 | 0.98801 | 42 | 0.99253 |
| 9 | 0.98786 | 43 | 0.99230 |
| 10 | 0.98566 | 44 | 0.99225 |
| 11 | 0.98518 | 45 | 0.99168 |
| 12 | 0.98379 | 46 | 0.99168 |
| 13 | 0.98252 | 47 | 0.99981 |
| 14 | 0.98125 | 48 | 0.99857 |
| 15 | 0.98000 | 49 | 0.99473 |
| 16 | 0.97976 | 50 | 0.99419 |
| 17 | 0.97938 | 51 | 0.98710 |
| 18 | 0.97937 | 52 | 0.98420 |
| | | 53 | 0.98253 |
| 19 | 0.97917 | 54 | 0.98059 |
| 20 | 0.97904 | 55 | 0.97791 |
| 21 | 0.97883 | 56 | 0.97529 |
| 22 | 0.97883 | 57 | 0.96186 |
| 23 | 0.97880 | 58 | 0.95524 |
| 24 | 0.97873 | 59 | 0.95267 |
| 25 | 0.97865 | 60 | 0.94966 |
| 26 | 0.97862 | 61 | 0.94523 |
| 27 | 0.97862 | 62 | 0.94505 |
| 28 | 0.99994 | 63 | 0.94482 |
| 29 | 0.99987 | 64 | 0.94368 |
| 30 | 0.99977 | 65 | 0.94334 |
| 31 | 0.99975 | 66 | 0.98515 |
| 32 | 0.99967 | 67 | 0.98515 |
| 33 | 0.99947 | 68 | 0.98365 |
| 34 | 0.99924 | 69 | 0.98365 |

TP = 238.541 kW
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## 6. CONCLUSIONS

An efficient load flow method for solving weakly meshed distribution systems has been developed. The application of the proposed method is simple and straightforward. However, for a meshed network, a loop matrix LILC is used in finding currents flowing in each loop formed by each tie-switch. This method can also be easily extended for different load models.

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