LOAD FLOW ANALYSIS OF RADIAL AND WEAKLY MESHED DISTRIBUTION SYSTEM

Thesis submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF ENGINEERING
in
POWER SYSTEMS & ELECTRIC DRIVES

Submitted By
Makwana Nirbhaykumar Navinchandra
(Reg. No. 801041013)

Under the supervision of:

Dr. Sanjay K. Jain
Associate Professor, EIED

ELECTRICAL & INSTRUMENTATION ENGINEERING DEPARTMENT
Thapar University
Patiala-147004
JULY-2012

CERTIFICATE

I hereby certify that the work which is being presented in the Thesis entitled **"LOAD FLOW ANALYSIS OF RADIAL AND WEAKLY MESHED DISTRIBUTION SYSTEM"** in partial fulfillment of requirement for the award of degree of Master of Engineering in ***Power Systems & Electric Drives*** submitted in the Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. Sanjay K. Jain**, Associate Prof., Electrical and Instrumentation Engineering Department.

The matter presented in this Thesis has not been submitted for the award of any other degree of this or any other university.

Makwana Nirbhaykumar Navinchandra

Reg. No. 801041013

It is certified that the above statement made by the student is correct to the best of my knowledge & belief.

Dr. Sanjay K. Jain

Associate Prof., EIED

Thapar University, Patiala

Countersigned by

Dr. Smarajit Ghosh

Professor & Head, EIED

Thapar University, Patiala

Dr. S.K. Mohapatra

Dean of Academic Affairs

Thapar University, Patiala

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Makwana Nirbhaykumar Navinchandra

Reg. No.801041013

Abstract

The distribution system provides the link between bulk power system and consumer. The distributors connect the individual load points to the main feeder. The distribution systems are of two types namely radial and weakly system has closed loops where as radial structure is free from loops. The classical methods like Gauss Seidel and Newton Raphson are inefficient in solving distribution network because of its typical features such as high R/X ratio.

A distinctive load flow solution method is used for analysis of the load flow of radial and weakly meshed network. This method has excellent convergence characteristics for both radial as well as weakly meshed structure. A $BIBC$ (bus injection to branch current) matrix formed to calculate branch currents. This matrix is obtained using Kirchhoff's current law for distribution network. Bus voltages are found by forward sweep of the network. The meshed structure of the distribution system is taken care by $LILC$ (line injection to loop current matrix). The performance has been tested on 33-bus and 69-bus distribution systems.

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CHAPTER-1

INTRODUCTION

1.1. OVERVIEW

The analysis of distribution system is an important area of activity as distribution systems provide the 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.

The power flow is an important tool for power system analysis. For proper planning of expansion and operation of distribution networks, the maximum currents carried by the distribution feeders and associated voltage drops, annual energy loss, and the reliability of supplying consumer demands are to be analyzed. The efficiency of such power flow algorithm is utmost importance as each optimization study requires numerous power flow runs. Unfortunately, many of the inputs forming the basis for these studies such as load forecast, load model coefficients, network parameters, and bus shunts forming are often assessed with some uncertainty. This uncertainty is usually of non statistical type due to practical difficulties in data acquisition in large and complex distribution systems.

Some inherent characteristics of electric distribution systems are (i) Radial or weakly meshed structure (ii) unbalanced operation and unbalanced distributed loads (iii) large number of buses and branches (iv) It has wide range of resistance and reactance values (v) Distribution system has multiphase operation.

The Newton Raphson and the fast decoupled power flow solution techniques and a host of their derivatives have efficiently solved 'well behaved' power systems for more than two decades. However, the shortcomings have been encountered when there algorithms are generally implemented and applied to ill-conditioned and poorly initialized power system. The Gauss Siedel power flow technique, another classical power flow method, although very robust, has shown to be extremely inefficient in solving large power systems.

Distribution networks, due to their wide ranging resistance and reactance values and radial structure, fall into the ill conditioned power systems for the generic Newton Rapson and fast decoupled power flow algorithms. Therefore, the modification in the load flow method is necessary for solving the distribution systems.

1.2 LITERATURE REVIEW

A brief literature review on the distribution system aspects including its load flow is represented herewith.

Stott and Alsac [1] represented that fast decoupled Newton method works well for transmission system, however 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.

Stott [2] compared various numerical techniques for power system load flow calculation using the digital computer. The analytical bases and comparative numerical performances of the methods are discussed.

Kersting and Mendive [3] and Kersting [4] developed the load-flow techniques for solving radial distribution networks with updated voltages and currents during the backward and forward sweeps with the help of ladder-network theory.

Stevens *et al.* [5] showed that the method proposed by Kersting and Mendive [3] and Kersting [4] was the fastest but did not converge in five out of twelve cases studied.

Shirmohammadi *et. al.*, [6] presented, compensation based method and branch numbering scheme to enhance the numerical performance of the solution. The meshes are broken through in order to convert it into a radial network.

Shirmohammadi and Hong [7] presented a method for reconfiguration of distribution networks in order to reduce their resistive line losses under normal operation.

Baran and Wu [8] have obtained the load flow solution for distribution system by iterative solution of three fundamental equations representing real power, reactive power and voltage magnitude. The jacobian matrix is computed using chain rule. The mismatches and jacobian matrix calculation is based on simple algebraic expressions and no trigonometric functions.

Luo and Semlyen [9] used active and reactive powers flow, a tree labeling technique and a solution strategy, to reducing the burden of mismatch calculations. The main disadvantage of this 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.

Chiang and Baran [10] showed the uniqueness of load-flow solution for radial distribution networks. This paper that the load flow solution with feasible voltage magnitude for radial distribution networks always exists and is unique. This method extended to the weak capability of radial distribution networks in meeting the load demands in the sense that different pattern of load demands requires different power supply from the substation.

Goswami and Basu [11] presented an approximate direct solution method for solving radial and meshed distribution networks. The loop branches were broken through break points in order to convert it into the network. However, the main limitation of the method is that a junction is assumed to have only three incoming branches and two outgoing branches.

Das *et al.* [12] proposed a load-flow method using sequential numbering scheme. A number of coding is to be supplied when the lateral and sub laterals exist. For large system this increases the complexity of the computation.

Haque [13] proposed for the analysis of both radial and mesh networks. A mesh network is converted to a radial network by breaking the loops through adding some dummy buses. The power injections at the loop break points (LBP) in the equivalent radial network are computed through a reduced order node impedance matrix. Unlike other methods, the shunt admittances are considered in the proposed load flow algorithm and the effect of load admittances is also incorporated in the calculation of power injections at the LBPs.

Lin and Teng [14] described a phase-decoupled load flow method for distribution networks with radial or weakly-meshed structures. The branch-current-based Newton Raphson method is used. The separate Jacobian matrices are used for each phase.

Losi and Russo [15] presented an Object oriented load flow modeling for both radial and weakly meshed distribution system. The algorithm is based on the Newton Raphson technique. In formulation of this method, some approximations to the full Jacobian matrix are introduced and sufficient conditions for convergence are derived.

The load flow algorithm proposed by Zimmerman and Chang [16], It does not require any jacobian matrix construction and factorization but more computation is involved because it solves three fundamental equations representing the real power, reactive power and voltage magnitude.

Ranjan and Venkatesh [17] proposed a load-flow technique using power convergence characteristic. Algorithm can easily accommodate the composite load modeling.

Sivanagaraju, *et al.* [18] described a distinctive load flow solution technique for weakly meshed distribution systems using branch injection branch current matrix (BIBC).which is obtain by applying Kirchhoff's current law. Bus voltages are found by forward sweep of the network.

1.3 OBJECTIVE OF WORK

Objective of the present work is to study and implement the load flow algorithm for both radial and weakly meshed distribution networks. The object is\to use a method that can be applied to both systems with minimum computational efforts.

1.4 ORGANISATION OF THESIS

The work carried out in this Thesis has been summarized in four Chapters. The Chapter 1 highlights the brief introduction, requirements of distribution system and summary of work carried out by various researchers, and the outline of the Thesis. The Chapter 2 explains load flow technique using *BIBC* matrix for radial and weakly meshed distribution network. The Chapter 3 deals with results and discussion pertaining to two test cases, namely 33 bus and 69 bus distribution system. The conclusions and the scope of further work are detailed in Chapter 4.

CHAPTER-2

LOAD FLOW OF WEAKLY MESHED DISTRIBUTION NETWORK

2.1 INTRODUCTION

The load flow of a power network provides the steady state solution through which various parameters of interest like currents, voltages, losses etc can be calculated. The load flow is important for the analysis of distribution system, to investigate the issues related to planning, design and the operation and control. Many classical methods such as Gauss-Seidel, Newton Raphson are used to carry out the load flow of transmission system. The use of these methods for distribution system may not be advantageous because they are mostly based on the general meshed topology of a typical transmission system where as most distribution systems have a radial or tree structure. Further distribution system posses high R/X ratio, which cause the distribution systems to be ill conditioned for conventional load flow methods.

The efficiency of the optimization problem of distribution system depends on the load flow algorithm because load flow solution has to run for many times. Therefore, the load flow solution of distribution system should have robust and time efficient characteristics. A method which can find the load flow solution of radial distribution system directly by using topological characteristic of distribution network is used. To solve the radial distribution network, form *BIBC* (branch injection to branch current) matrix. This matrix is obtained by applying Kirchhoff's current law for the distribution network and the voltage of each node is calculated by forward sweep of the network. In this method multi port compensation technique is used for computation of breakpoint current injections.

2.2 RADIAL DISTRIBUTION NETWORK

The load flow of radial distribution system is carried out using the bus-injection to branch current matrix (BIBC) and equivalent current injections [18]. In this section, the development procedure will be described in detail. For distribution networks, the equivalent current injection based model is more practical. For bus, the complex load S_i is expressed by

$$S_i = P_i + jQ_i \tag{1}$$

Where i =1.2.3……, n

And corresponding equivalent current injection at the k -th iteration of solution is

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = ((P_i + jQ_i)/V_i^k)^* \qquad (2)$$

Where V_i^k and I_i^k are the bus voltage and equivalent current injection of bus at the k -th iteration, respectively. I_i^r and I_i^i are the real and imaginary parts of the equivalent current injection of bus at the k -th iteration, respectively.

2.2.1 Relationship Matrix Development

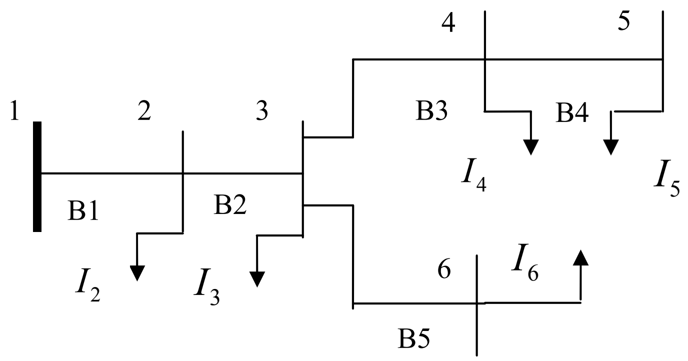

Figure. 2.1. Simple Distribution System

Form equation (2), injected currents are obtained. By applying Kirchhoff's current law (KCL) to the distribution network, the branch current are calculated. A simple distribution system, shown in the figure 2.1, is used as example [18]. 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

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6$$

$$B_3 = I_4 + I_5 \qquad (3)$$

$$B_5 = I_6$$

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

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (4)$$

Equation (4) can be expressed as

$$[B] = [BIBC][I] \quad (5)$$

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

2.2.2. Formation of BIBC Matrix

From equation (4), algorithm for $BIBC$ matrix [20] is as follows :

1) For a distribution system with m-branch section and n-bus, the dimension of the $BIBC$ matrix is $mx(n-1)$.
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 a +1 to the position of the k-th row and the j-th bus column.
3) Repeat procedure (2) until all line sections are included in the $BIBC$ matrix. From equation (4).

2.2.3. Bus Voltage Computation

The receiving end bus voltages are found by a forward sweep through the ladder network using the generalized equations given below.

$$V(m2) = V(m1) - BB(jj)Z(jj) \quad (6)$$

Where $m1, m2$ are the sending and receiving ends, and

jj is the branch number

BB is branch current

The relationship between branch currents and bus voltages can be obtained by below equation. For example, the voltages of bus 2, 3, and 4 are

$$V_2 = V_1 - BB_1 Z_{12}$$

$$V_3 = V_2 - BB_2 Z_{23} \tag{7}$$

$$V_4 = V_3 - BB_3 Z_{34}$$

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

$$P\_loss = \left| BB(jj)^2 \right| R(jj) \tag{8}$$

$$Q\_loss = \left| BB(jj)^2 \right| X(jj) \tag{9}$$

2.3. MODIFIATION FOR WEAKLY MESHED DISTRIBUTION NETWORK

Some distribution feeders serving high-density load areas contain loops created by closing normally open tie-switches. The method discussed for radial distribution system is extended for “weakly-meshed” distribution feeders [18].

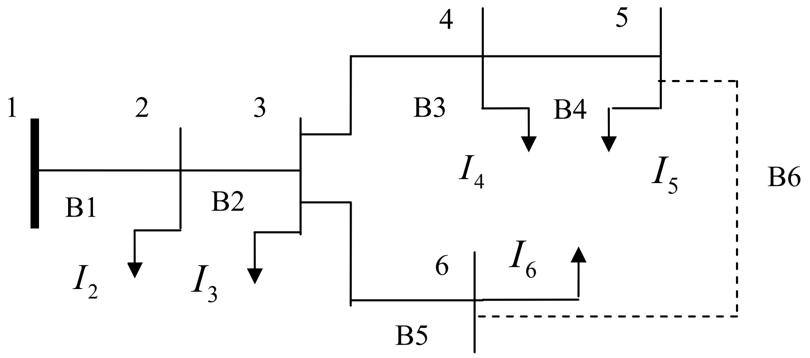

Figure.2.2. Simple Distribution System with One Loop

2.3.1. Modification for BIBC Matrix

Existence of loops in the system does not affect the bus current injections, but new branches will need to be added to the system. Figure 2.2 shows a simple case with one loop [18]. Taking the new branch current into account, the current injections of bus 5 and bus 6 will be

$$
\begin{aligned}
I_5^{'} &= I_5 + B_6 \\
I_6^{'} &= I_6 - B_6
\end{aligned}
\tag{10}
$$

The BIBC matrix will be

$$
\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 + B_6 \\ I_6 - B_6 \end{bmatrix} \tag{11}
$$

Equation (13) can be written as

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} + \begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} B_6 \\ -B_6 \end{bmatrix} \tag{12}$$

Equation (12) can be expressed as

$$[B] = [BIBC][I] + [LILC] + [B'] \tag{13}$$

Current of tie branch '6' can be calculated as

$$B_6 = (V_5 - V_6) / Z_{66} \tag{14}$$

If a new branch B_k makes the system become meshed (the new branch is between bus i and j), copy the elements of the i-th bus column to the k-th column and minus the elements of the j-th bus column. Finally, fill a +1 value to the position of the k-th row and the k-th column.

2.3.2 Algorithm for Load flow of Meshed Distribution Network

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

Step 1) Start

Step 2) Read the system data. Assume the initial voltage at all buses as source bus voltage.

Step 3) From the computed current injection to the each bus

Step 4) Compute the branch current in each branch using *BIBC* matrix

Step 5) For meshed network, $LILC$ matrix is formed from $BIBC$ matrix as given by equation (12).The order of $LILC$ matrix is (number of branches) X (twice the number of tie switches).

Step 6) Compute the mesh current using equation (14).

Step 7) Compute branch current B using equation (13).

Step 8) Compute the voltage magnitude at the receiving end bus of each branch using equation (6).

Step 9) Calculate the difference of bus voltage magnitude in consecutive iterations if the maximum difference $\Delta V \max \leq 0.0001$ otherwise go to step 2.

Step 10) Print load flow solution and stop.

2.2.4. Flow Chart for Meshed Distribution Network

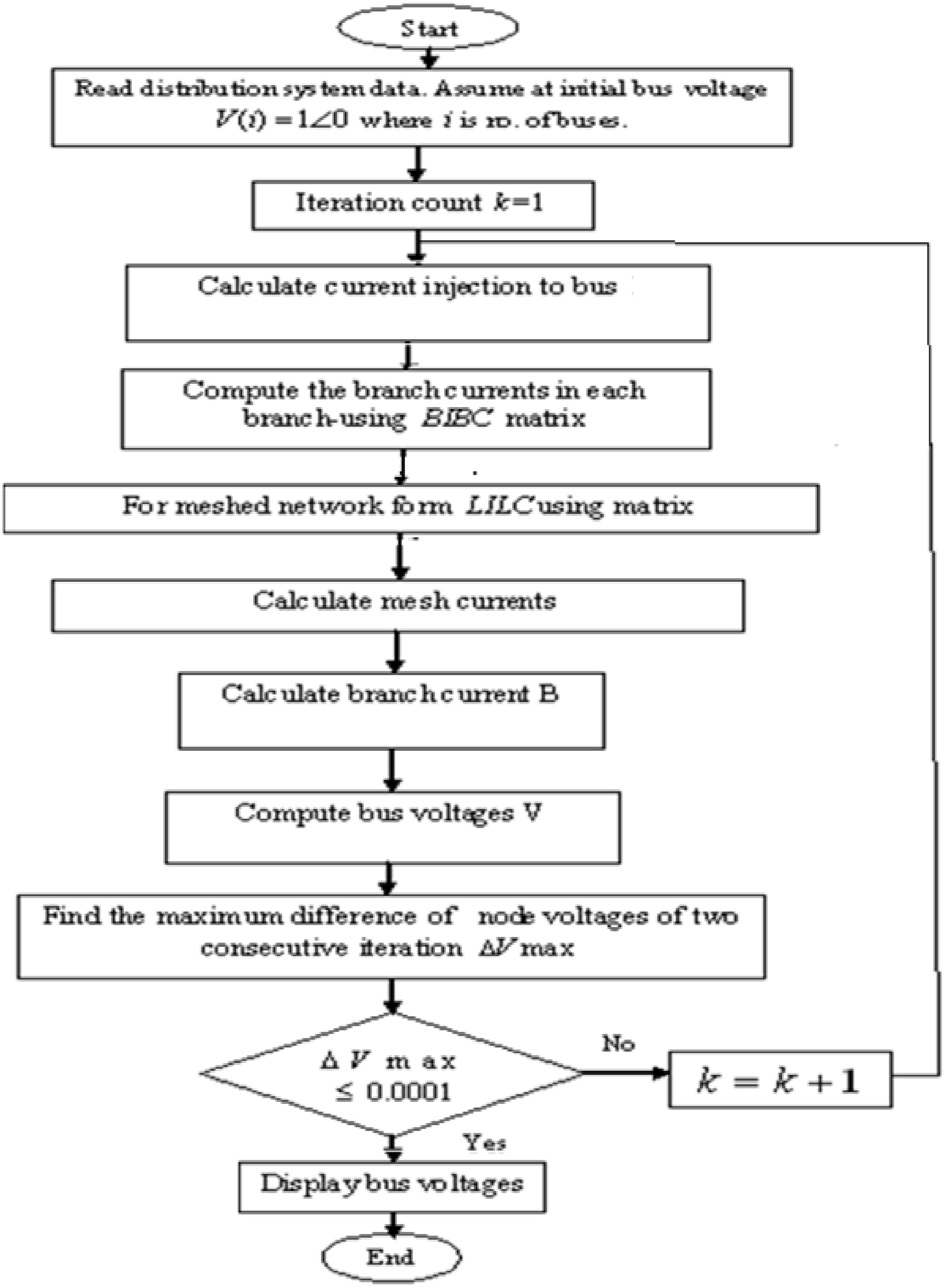

Figure.2.3. Flow Chart for Load Flow Solution of Weakly Meshed Distribution System

CHAPTER-3

RESULTS & DISCUSSION

This chapter contains the results, obtained from the algorithm discussed in Chapter 2, for two cases. The algorithm is tested for the following two systems

- 33-bus distribution system
- 69- bus distribution system

The specification of these networks maintains the radial structures are given in Appendix - A and [19] Appendix - B [8] respectively. The modification arising due to weakly meshed structures are discussed in the respective section.

3.1. 33 - BUS DISTRIBUTION SYSTEM

Following are the characteristics for 33-bus radial distribution system in figure 3.1.

Number of buses = 33

Number of lines = 32

Slack Bus No =1

Base Voltage=12.66 kV

Base MVA=100 MVA

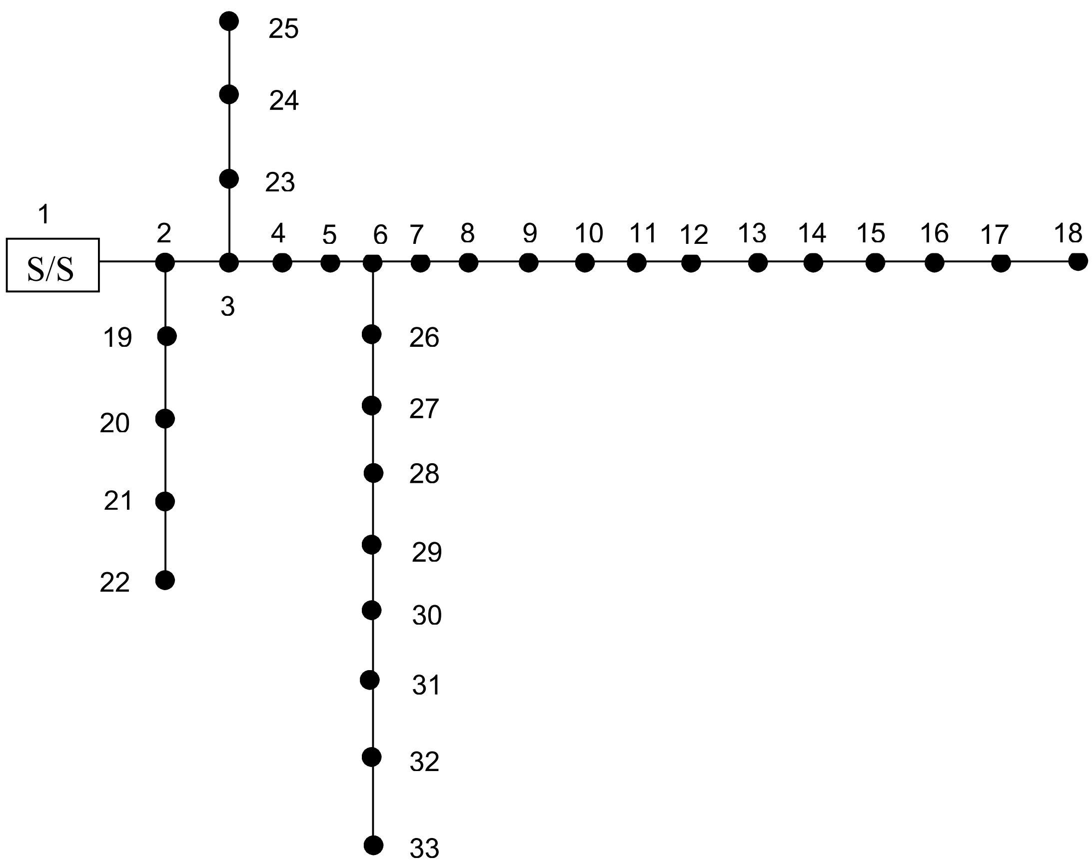

Figure 3.1. Representation of 33-Bus Distribution System

Bus injection to branch current ($BIBC$) matrix for 33- bus distribution system is represented as below. The size of the $BIBC$ matrix is (32X32).

BIBC =

[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1
0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1]

The load flow of the distribution system is obtained using the Algorithm discussed in Chapter 2. Load flow solution of 33-bus distribution system for radial network is summarized in Table 3.1. This solution convergence is resulted in 5 iterations.

Table 3.1. Voltage Magnitude and Phase Angle from 33-Bus Radial Distribution System Load Flow Solution

Bus Number	Voltage Magnitude in p.u.	Angle in Degree
1	1.000000	0
2	0.997015	0.0136
3	0.982883	0.0959
4	0.975373	0.1620
5	0.967948	0.2292
6	0.949470	0.1350
7	0.945946	-0.0966
8	0.932291	-0.2500
9	0.925960	-0.3245
10	0.920255	-0.3932
11	0.919386	-0.3858
12	0.917872	-0.3741
13	0.911697	-0.4672
14	0.909408	-0.5475
15	0.907981	-0.5859
16	0.906599	-0.6096
17	0.904552	-0.6885
18	0.903938	-0.6983
19	0.996486	0.0028
20	0.992909	-0.0642
21	0.992204	-0.0835
22	0.991567	-0.1039
23	0.979297	0.0649
24	0.972625	-0.0239
25	0.969300	-0.0676
26	0.947541	0.1745
27	0.944976	0.2307
28	0.933534	0.3137
29	0.925315	0.3916
30	0.921756	0.4969
31	0.917594	0.4125
32	0.916679	0.3894
33	0.916395	0.3817

The total active and reactive power loss in radial distribution load flow is 210.8420 kW and 143.1137 kVAr respectively.

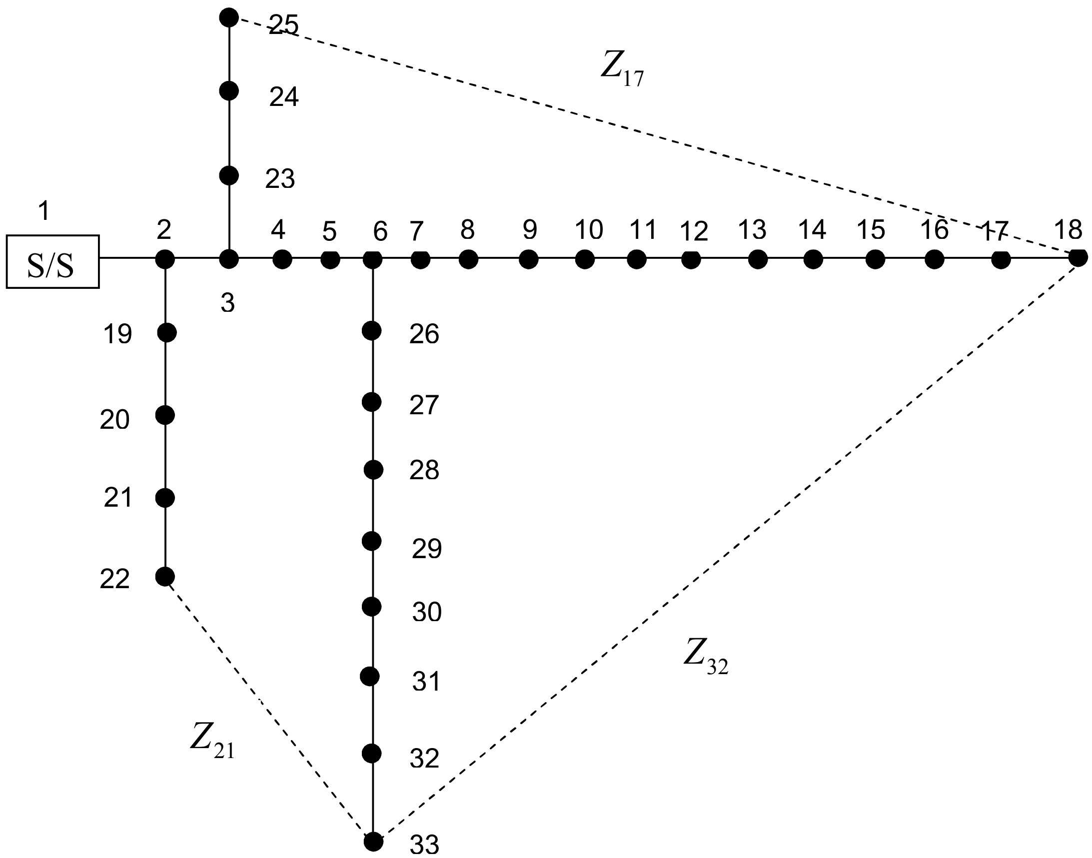

Figure.3.2. Meshed Network of 33- Bus Distribution System

The Meshed Network of 33- bus distribution system is shown in figure 3.2. The three meshes shown in figure 3.2 are given below.

1st mesh loop ---- 22↔ 33

2nd mesh loop---- 33↔ 18

3rd mesh loop---- 18↔ 25

Their impedances are taken as Z_{21}, Z_{32} and Z_{17} respectively. The dimension of $LILC$ matrix is (32X6).Considering all these three meshed loops, the load flow solution are summarized in Table 3.3. The number of iteration expanded for this meshed load flow is 2.

Table 3.2. Voltage Magnitude and Phase angle for 33-Bus Meshed Distribution System Load Flow Solution

Bus Number	Voltage Magnitude in p.u.	Angle in Degree
1	1.000000	0
2	0.997178	0.0125
3	0.983909	0.0883
4	0.976958	0.1494
5	0.970103	0.2112
6	0.953070	0.1247
7	0.949844	-0.0893
8	0.937348	-0.2350
9	0.931584	-0.3056
10	0.926399	-0.3706
11	0.925608	-0.3644
12	0.924230	-0.3546
13	0.918641	-0.4419
14	0.916577	-0.5154
15	0.915291	-0.5508
16	0.914045	-0.5730
17	0.912206	-0.6450
18	0.911653	-0.6542
19	0.996654	0.0017
20	0.993106	-0.0650
21	0.992407	-0.0843
22	0.991776	-0.1045
23	0.980424	0.0581
24	0.973948	-0.0283
25	0.970726	-0.0709
26	0.951293	0.1617
27	0.948936	0.2142
28	0.938413	0.2951
29	0.930860	0.3702
30	0.927602	0.4682
31	0.923778	0.3928
32	0.922936	0.3721
33	0.922675	0.3652

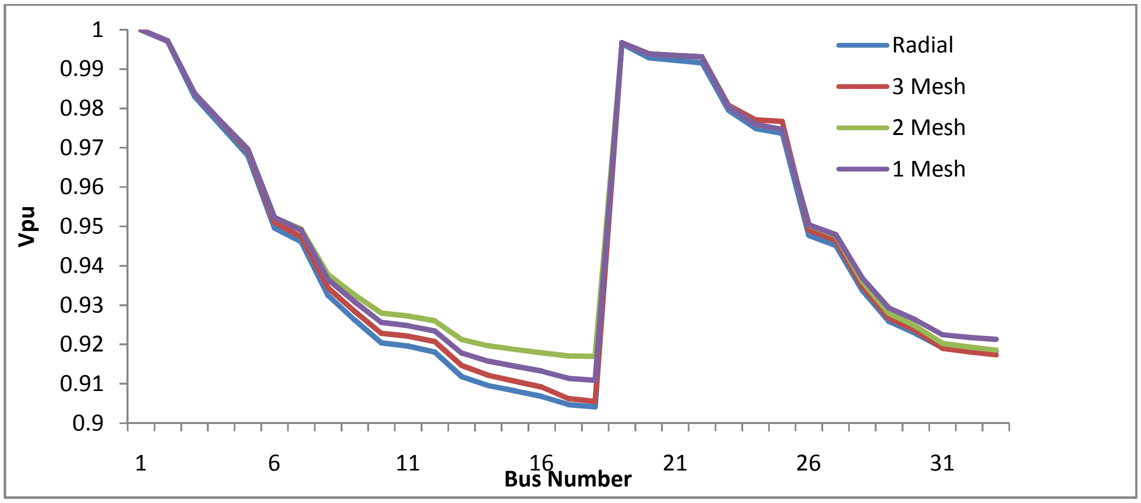

Figure 3.3. Comparison of Voltage Magnitude for 33 -bus Radial and Meshed Distribution Systems

The performance for 1 mesh (22-23), 2 mesh (22-33, 18-33) and 3 mesh (22-33, 18-33, 18-25) are shown in figure 3.3. Voltage magnitude at each buses increase in meshed distribution network load flow as compare to the radial distribution network.

Similarly for 69- Bus distribution system, radial and meshed load flow results are given below.

3.2. 69 - BUS DISTRIBUTION SYSTEM

Following are the characteristics for 69 bus radial distribution system in figure 3.4

Number of buses = 69

Number of lines = 68

Slack Bus No =1

Base Voltage=12.66 kV

Base MVA=100 MVA

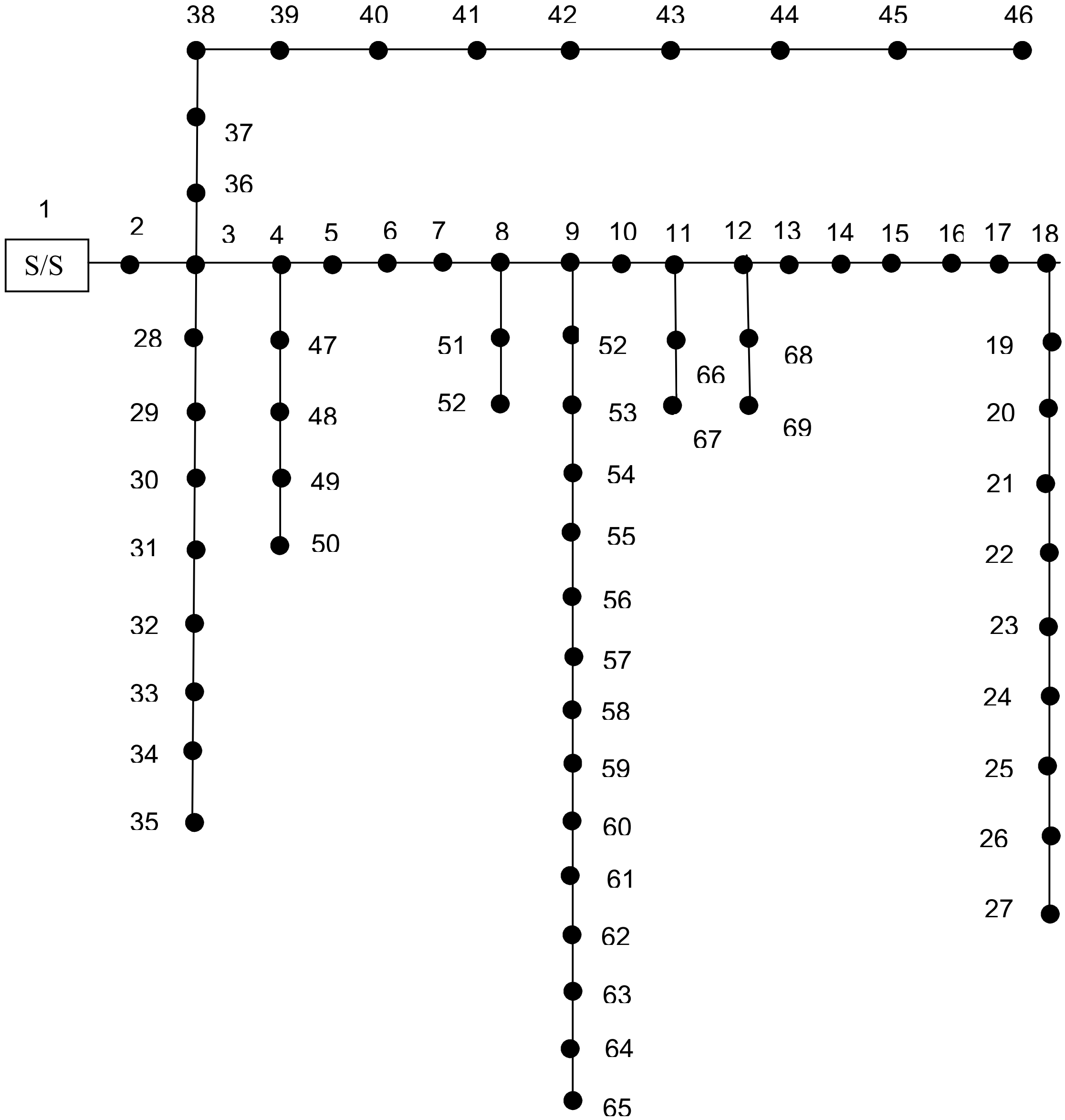

Figure 3.4. Representation of 69 – Bus Distribution System

Load flow solution of 69- Bus Distribution System for radial network is summarized in Table 3.3. The convergence is also achieved in 5 iterations.

Table.3.3 Voltage Magnitude and Phase Angle from 69-Bus Radial Distribution System Load Flow Solution

Bus Number	Voltage Magnitude in p.u.	Angle in Degree
1	1.000000	0
2	0.999966	-0.0013
3	0.999932	-0.0025
4	0.999839	-0.0060
5	0.999083	-0.0212
6	0.990131	0.0464
7	0.980821	0.1180
8	0.978601	0.1351
9	0.977465	0.1439
10	0.972428	0.2287
11	0.971318	0.2475
12	0.968140	0.3002
13	0.965222	0.3464
14	0.962336	0.3932
15	0.959472	0.4392
16	0.958939	0.4478
17	0.958060	0.4620
18	0.958051	0.4621
19	0.957586	0.4707
20	0.957288	0.4762
21	0.956807	0.4851
22	0.956800	0.4852
23	0.956728	0.4865
24	0.956571	0.4895
25	0.956402	0.4926
26	0.956333	0.4939
27	0.956313	0.4943
28	0.999926	-0.0027
29	0.999859	-0.0047
30	0.999766	-0.0020
31	0.999750	-0.0016
32	0.999668	0.0008
33	0.999472	0.0064
34	0.999217	0.0137
35	0.999168	0.0152

36	0.999916	-0.0034
37	0.999703	-0.0155
38	0.999478	-0.0224
39	0.999413	-0.0243
40	0.999410	-0.0244
41	0.998253	-0.0662
42	0.997960	-0.0708
43	0.997922	-0.0714
44	0.997913	-0.0716
45	0.997815	-0.0734
46	0.997814	-0.0734
47	0.999789	-0.0078
48	0.998543	-0.0526
49	0.994698	-0.1917
50	0.994153	-0.2115
51	0.978566	0.1354
52	0.978556	0.1356
53	0.974679	0.1658
54	0.971436	0.1915
55	0.966963	0.2270
56	0.962594	0.2620
57	0.940121	0.6585
58	0.929062	0.8611
59	0.924784	0.9421
60	0.919760	1.0466
61	0.912363	1.1156
62	0.912074	1.1183
63	0.911686	1.1220
64	0.909786	1.1398
65	0.909211	1.1452
66	0.909151	1.1465
67	0.909150	1.1465
68	0.908799	1.1534
69	0.908798	1.1534

The total active and reactive power loss in radial distribution load flow is 225.2161 kW and 102.5553 kVAr respectively.

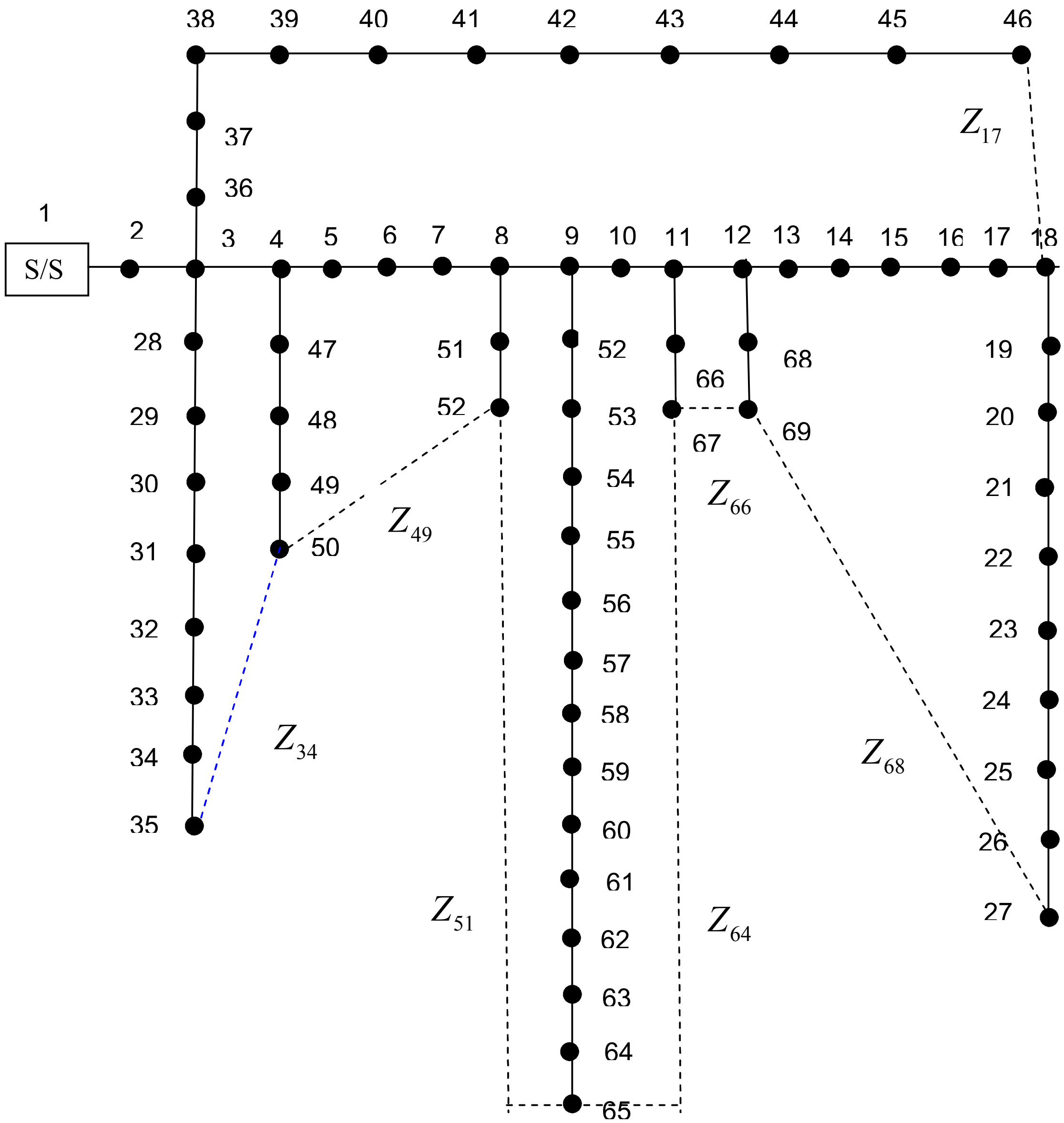

Figure.3.5. Meshed Network of 69-Bus Distribution System

The Meshed Network of 69- bus distribution system is shown in figure 3.5. The figure consists of seven meshes described below.

1st mesh loop-----35↔ 50

2nd mesh loop----50↔52

3rd mesh loop----52↔65

4th mesh loop----65↔67

5th mesh loop-----67↔69

6th mesh loop-----69↔ 27

7th mesh loop-----18↔46

Their impedances of these branches are taken as $Z_{34}, Z_{49}, Z_{51}, Z_{64}, Z_{66}, Z_{68}$ and Z_{17} respectively. Considering these all meshed branches, the load flow solution of 69- bus distribution system for meshed network summarized in Table 3.4. The number of iteration in meshed load flow is 2.

Table.3.4. Voltage Magnitude and Phase angle from 69-Bus Meshed Distribution System Load Flow Solution

Bus Number	Voltage Magnitude in p.u.	Angle in Degree
1	1.000000	0
2	0.999968	-0.0012
3	0.999935	-0.0024
4	0.999846	-0.0056
5	0.999140	-0.0192
6	0.990827	0.0508
7	0.982183	0.1248
8	0.980123	0.1425
9	0.979072	0.1516
10	0.974266	0.2349
11	0.973207	0.2533
12	0.970179	0.3052
13	0.967390	0.3507
14	0.964634	0.3967
15	0.961897	0.4421
16	0.961389	0.4505
17	0.960549	0.4644
18	0.960540	0.4646
19	0.960097	0.4730
20	0.959813	0.4784
21	0.959353	0.4871
22	0.959346	0.4872
23	0.959278	0.4885
24	0.959129	0.4914
25	0.958968	0.4945
26	0.958901	0.4957
27	0.958882	0.4961
28	0.999929	-0.0026
29	0.999862	-0.0045
30	0.999769	-0.0019

31	0.999753	-0.0014
32	0.999671	0.0010
33	0.999476	0.0065
34	0.999220	0.0139
35	0.999171	0.0153
36	0.999919	-0.0033
37	0.999707	-0.0153
38	0.999483	-0.0222
39	0.999418	-0.0242
40	0.999414	-0.0243
41	0.998260	-0.0660
42	0.997969	-0.0707
43	0.997930	-0.0713
44	0.997922	-0.0714
45	0.997823	-0.0732
46	0.997823	-0.0733
47	0.999797	-0.0074
48	0.998560	-0.0522
49	0.994745	-0.1913
50	0.994204	-0.2111
51	0.980089	0.1428
52	0.980079	0.1430
53	0.976532	0.1745
54	0.973575	0.2011
55	0.969501	0.2382
56	0.965525	0.2747
57	0.945136	0.6589
58	0.935103	0.8546
59	0.931223	0.9326
60	0.926672	1.0326
61	0.919948	1.1032
62	0.919685	1.1059
63	0.919334	1.1096
64	0.917610	1.1279
65	0.917090	1.1334
66	0.917035	1.1346
67	0.917035	1.1346
68	0.916717	1.1412
69	0.916716	1.1412

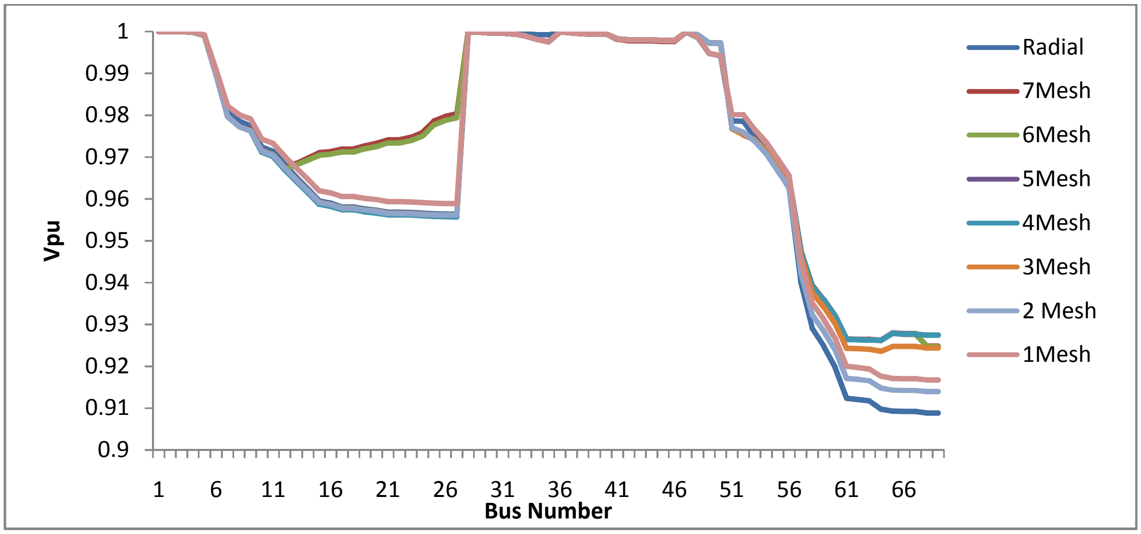

Figure 3.6. Comparison of Voltage Magnitude for 69 -bus Radial and Meshed Distribution Systems

The voltage profile with various meshes is shown in figure 3.6. The number of meshes, in the order from 1st Mesh to 7th Mesh, are considered during the study. The Voltage magnitude at each buses increase in meshed distribution network load flow as compare to the radial distribution network.

CHAPTER-4

CONCLUSION & FUTURE SCOPE

4.1. CONCLUSION

In this thesis work an efficient method is used for load-flow analysis of radial and weakly meshed distribution system. This method is based on the formation of branch injection to branch current matrix ($BIBC$) and line injection to loop current matrix ($LILC$). The effectiveness of the developed algorithm is tested for 33- bus and 69- bus distribution networks. The following conclusions are drawn from the study

- Method is effective for both radial and weakly meshed structure.
- The voltage profile is improved due to meshed structure.
- The load flow of the weakly meshed distribution network typically converges in few iterations.

4.2. SCOPE FOR FUTURE WORK

In this thesis work, a balance distribution load flow analysis is discussed. The scope is identified as –

- The investigations may be extended to unbalance and multiphase distribution system.
- Load has been assumed constant in the analysis. The study can be extended to analyze varying loads that can be modeled by fuzzy membership.

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APPENDIX A

Table (A.1) Line data of 33- Bus Radial Distribution System

Branch No.	Sending end Bus	Receiving end Bus	Branch Resistance(Ω)	Branch Reactance (Ω)
1	1	2	0.0922	0.0477
2	2	3	0.4930	0.2511
3	3	4	0.3660	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	1.7114	1.2351
8	8	9	1.0300	0.7400
9	9	10	1.0040	0.7400
10	10	11	0.1966	0.0650
11	11	12	0.3744	0.1238
12	12	13	1.4680	1.1550
13	13	14	0.5416	0.7129
14	14	15	0.5910	0.5260
15	15	16	0.7463	0.5450
16	16	17	1,2890	1.7210
17	17	18	0.7320	0.5740
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	08980	0.7091
24	24	25	0.8960	0.7011
25	6	26	0.2030	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9630
31	31	32	0.3105	0.3619
32	32	33	0.3410	0.5302

Table (A.2) Load Data of 33-Bus Radial Distribution System

Bus Number	P(KW)	Q(KVAR)
1	0	0
2	100	60
3	90	40
4	120	80
5	60	30
6	60	20
7	200	100
8	200	100
9	60	20
10	60	20
11	45	30
12	60	35
13	60	35
14	120	80
15	60	10
16	60	20
17	60	20
18	90	40
19	90	40
20	90	40
21	90	40
22	90	40
23	90	50
24	420	200
25	420	200
26	60	25
27	60	25
28	60	20
29	120	70
30	200	600
31	150	70
32	210	100
33	60	40

APPENDIX B

Table (B.1) Line data of 69 - Bus Radial Distribution System

Branch No.	Sending end Bus	Receiving end Bus	Branch Resistance(Ω)	Branch reactance(Ω)
1	1	2	0.0005	0.0012
2	2	3	0.0005	0.0012
3	3	4	0.0015	0.0036
4	4	5	0.0215	0.0294
5	5	6	0.366	0.1864
6	6	7	0.381	0.1941
7	7	8	0.0922	0.047
8	8	9	0.0493	0.0251
9	9	10	0.819	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.03	0.34
13	13	14	1.044	0.34
14	14	15	1.058	0.3496
15	15	16	0.1966	0.065
16	16	17	0.3744	0.1238
17	17	18	0.0047	0.0016
18	18	19	0.3276	0.1083
19	19	20	0.2106	0.069
20	20	21	0.3416	0.1129
21	21	22	0.014	0.0046
22	22	23	0.1591	0.0526
23	23	24	0.3463	0.1145
24	24	25	0.7488	0.2475
25	25	26	0.3089	0.1021
26	26	27	0.1732	0.0572
27	3	28	0.0044	0.0108
28	28	29	0.064	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.351	0.116
32	32	33	0.839	0.2816
33	33	34	1.708	0.5646
34	34	35	1.474	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.064	0.1565
37	37	38	0.1053	0.123
38	38	39	0.0304	0.0355
39	39	40	0.0018	0.0021
40	40	41	0.7283	0.8509
41	41	42	0.31	0.3623
42	42	43	0.041	0.0478

43	43	44	0.0092	0.0116
44	44	45	0.1089	0.1373
45	45	46	0.0009	0.0012
46	4	47	0.0034	0.0084
47	47	48	0.0851	0.2083
48	48	49	0.2898	0.7091
49	49	50	0.0822	0.2011
50	8	51	0.0928	0.0473
51	51	52	0.3319	0.114
52	9	53	0.174	0.0886
53	53	54	0.203	0.1034
54	54	55	0.2842	0.1447
55	55	56	0.2813	0.1433
56	56	57	1.59	0.5337
57	57	58	0.7837	0.263
58	58	59	0.3042	0.1006
59	59	60	0.3861	0.1172
60	60	61	0.5075	0.2585
61	61	62	0.0974	0.0496
62	62	63	0.145	0.0738
63	63	64	0.7105	0.3619
64	64	65	1.041	0.5302
65	65	66	0.2012	0.0611
66	66	67	0.0047	0.0014
67	67	68	0.7394	0.2444
68	68	69	0.0047	0.0016

Table (B.2) Load Data of 69-Bus Radial distribution System

Bus Number	P(KW)	Q(KVAR)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	2.6	2.2
7	40.4	30
8	75	54
9	30	22
10	28	19
11	145	104
12	145	104
13	8	5
14	8	5
15	0	0
16	45	30
17	60	35
18	60	35
19	0	0
20	1	0.6
21	114	81
22	5	3.5
23	0	0
24	28	20
25	0	0
26	14	10
27	14	10
28	26	18.6
29	26	18.6
30	0	0
31	0	0
32	0	0
33	10	10
34	14	14
35	4	4
36	26	18.55
37	26	18.55
38	0	0
39	24	17
40	24	17
41	102	1
42	0	0
43	6	4.3
44	0	0

45	39.22	26.3
46	39.22	26.3
47	0	0
48	79	56.4
49	384.7	274.5
50	384.7	274.5
51	40.5	28.3
52	3.6	2.7
53	4.35	3.5
54	26.4	19
55	24	17.2
56	0	0
57	0	0
58	0	0
59	100	72
60	0	0
61	1244	888
62	32	23
63	0	0
64	227	162
65	59	42
66	18	13
67	18	13
68	28	20
69	28	20