RECONFIGURATION OF RADIAL DISTRIBUTION NETWORKS

5.1 Introduction

The subject of minimizing distribution power losses has gained a great deal of attention due to the high cost of electrical energy and therefore, much of current research on distribution automation has focused on the minimum loss configuration. Besides economic consideration, the effect of electric power loss is that heat energy is dissipated which increases the temperatures of the associated electric components and can result in insulation failure. By minimizing the power losses, the system may acquire longer life span, and has greater reliability. Therefore, loss minimization in distribution systems has become the subject of intensive research.

In Practical systems, the methods employed for reduction of losses are:

- Installation of capacitors, when this is economically justified.
- Network reconfiguration, which is the selection of the proper topological structure of the network for minimum losses.

Most electric distribution feeders are configured radially for effective coordination of their protection systems. By changing the state of network switches, the radiality can always be preserved. The optimal operating condition of distribution networks is obtained when line losses are minimized without any violations of branch loading and voltage limits.

There are two types of switches in the system: one is normally closed switches connecting the line sections called sectionalizing switches and the other is normally open switches on the tie-lines connecting either two primary feeders or two substations, or loop-type laterals called tie switches. The change in network configuration is achieved by closing or opening of these two types of switches in such a way that the 'radiality' of the network is maintained. Distribution lines or line sections show different characteristics as each has a different mixture of residential, commercial and industrial type loads, their corresponding peak times are not coincident. This is due to the fact that some parts of the distribution system become more heavily loaded at certain times of the day and less heavily loaded at other times. Therefore, by shifting the loads in the system, the radial structure of the distribution feeders can be modified from time to time in order to reschedule the load currents more efficiently for loss minimization. During normal operating condition, networks are reconfigured for two purposes: (i) to minimize the system real power losses in the network and to increase network reliability; and (ii) to relieve the over loads in the feeders. The former is referred to as feeder reconfiguration for loss reduction and the latter as load balancing.

Goswami and Basu [85] were of the belief that it was inappropriate to initially represent the distribution network as a meshed network and then open switches until a radial system is obtained. They introduced an algorithm similar to that of Merlin and Back [10] differing in that the distribution network considered one tie-switch at a time. In the method proposed by Goswami and Basu, the opening of another switch to ensure a radial network complements any switch closure. Wagner et al. [73] presented reconfiguration algorithm based on solution of a linear transportation problem.

In this chapter, the problem of reducing power losses in radial distribution networks via feeder reconfiguration is proposed. A simple method for determining the open /- closed states of sectionalizing and tie switches to achieve loss reduction is presented. The performance of proposed method is tested with three different distribution networks i.e. 16, 33 and 69 node networks.

In sections 5.2 and 5.3, it is dealt with problem statement and strategy respectively of the proposed method. The flowchart of the proposed method is given in section 5.4. Three radial networks are considered and the results of these are presented in section 5.5. Conclusions of this chapter are presented in section 5.6.

5.2 Problem Statement

Feeder reconfiguration is performed by opening / closing two types of switches, tie and sectionalizing switches. A whole feeder or part of a feeder may be served from another feeder by closing a tie switch linking the two while an appropriate sectionalizing switch must be opened to maintain radial structure.

In the context of loss reduction, the problem to be addressed in this chapter is to identify tie and sectionalizing switches that should be closed and opened respectively, to achieve maximum reduction in losses. Conceptually it is a straightforward matter to determine whether the new system obtained through a feeder reconfiguration would incur lower losses. The change in the losses can easily be computed from the results of two load flow studies simulating the system configurations before and after the feeder reconfiguration.

The problem is now illustrated using the 3-feeder distribution system shown in **fig 5.1**. The dotted branches (14), (15) and (16) represent tie switches connecting feeders and normally open tie switches are assumed to be present on these branches.

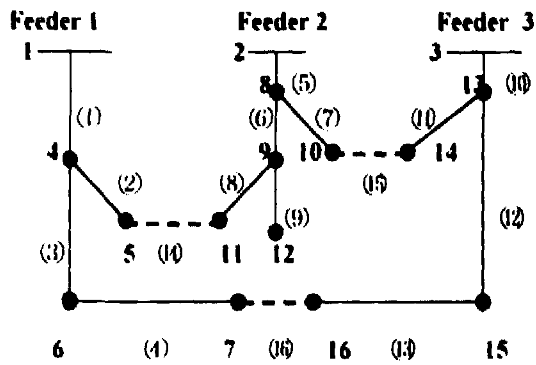
For notational convenience, the corresponding tie numbers are used to identify these tie switches. Without loss of generality and keeping in view of the practical situations, it is assumed for ease of explanation that there are sectionalizing switches on every branch of the system. The corresponding branch numbers will also identify all 13 sectionalizing switches.

The load at node 11 can be transferred to feeder-1 by closing the tie switch (14) and opening the sectionalizing switch (8), similarly the loads at nodes 9, 11 and 12 can be transferred to feeder-1 by closing the tie switch (14) and opening the sectionalizing switch (6). Throughout this chapter, it is considered that feeder reconfiguration by closing a single tie switch and opening a single sectionalizing switch to preserve radiality of the two feeders that are under consideration. The combined pair consisting of a tie and sectionalizing switch will be referred to as a switching option.

5.3 Strategy

The simplicity of the proposed method makes it suitable for on-line control strategy for feeder loss reduction. The strategy for selecting the best switching option is further explained via the example system of **fig. 5.1**. The load-flow results of the above system are tabulated in **Table 5.1**.

When closing the tie switch (10), five options for opening sectionalizing switches (1), (2), (8), (6) and (5) are available. Since $V(11) < V(5)$ transferring loads on Feeder-1 to Feeder-2 is expected to increase losses. Consequently, opening the sectionalizing switch (1) or (2) is regarded as undesirable and need not be considered. Therefore, associated with closing the tie switch (10) are three options, viz., opening the sectionalizing switches (8), (6) and (5), respectively. Similarly, since $V(10) < V(14)$ opening switch (11) or (12) is considered to be undesirable when the tie switch (15) is closed. For a similar reason, transferring loads on Feeder-III to Feeder-I when the tie switch (16) is closed is expected to increase losses; consequently the corresponding switching options are eliminated from further consideration. As a result of this elimination process, the number of switching options to be examined is now eight



1,2,3, ,node numbers,

(1),(2), ...branch numbers

Fig.5.1: Initial configuration of IEEE 16-node network

5.4: Flowchart for Network Reconfiguration

The flowchart for the proposed network reconfiguration of radial distribution network is given in **fig. 5.2**.

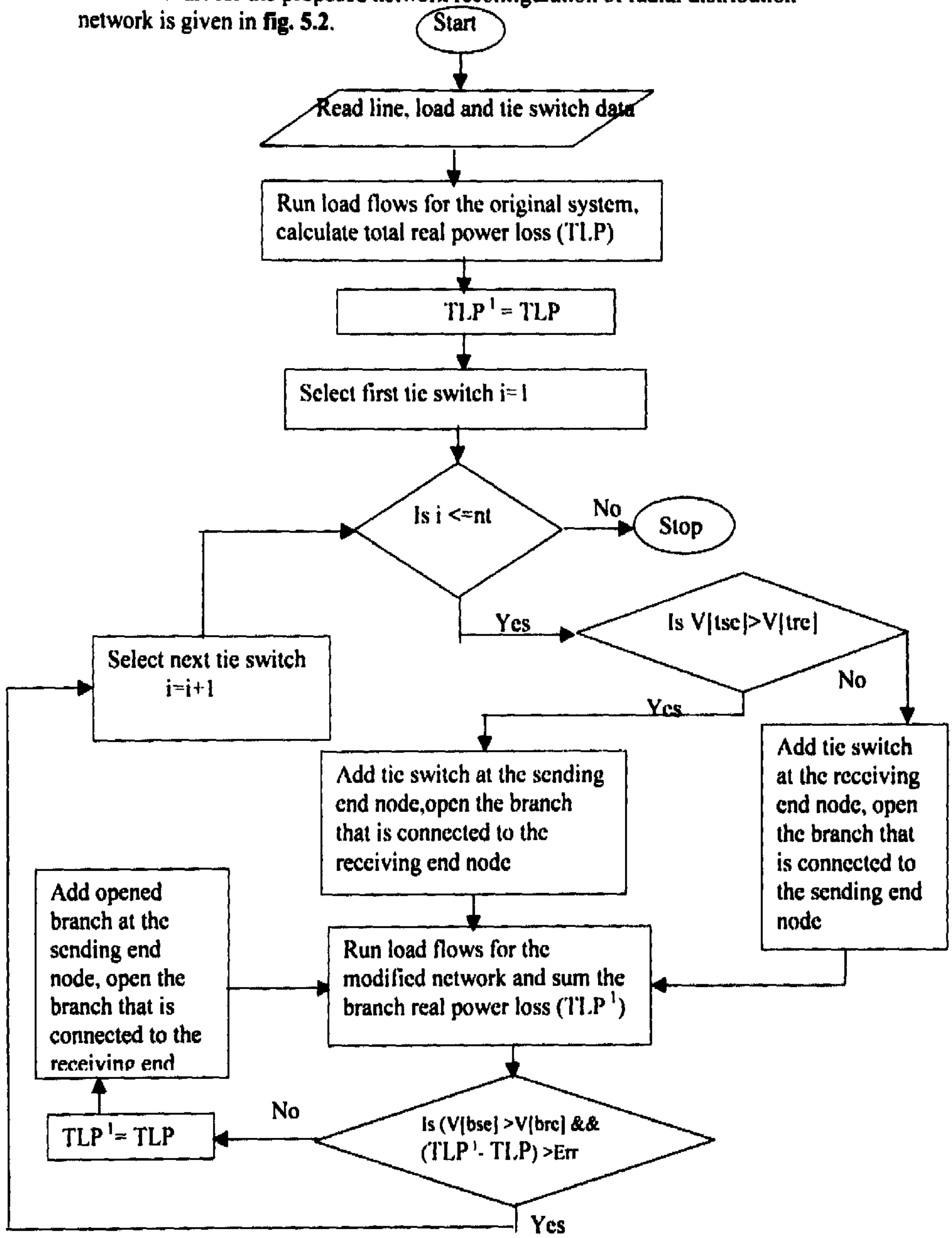


Fig. 5.2: Flowchart for network reconfiguration

5.5 Illustrative Examples

In this section the effectiveness of the proposed method is demonstrated through three examples

5.5.1 Example- 1

Consider the IEEE 16-node network [51] as shown in **fig.5.1** The line, load and tie switch data of the network is given in **Appendix D1**

5.5.1.1 Case-I: Without End node Capacitor

Initially the load flow solution obtained **(explained in chapter 2)** for the original system, which gives the node voltages, and total real power loss (TLP) as obtained are shown in 1st column of **Table 5.1**. Select first tie-switch (10). Voltages of two nodes of tie switch, i.e., '5' and '11' are compared. From 1st column of **Table 5.1**, it is observed that V(5) is greater. So tie switch is connected at the node '5' and the branch that is connected in between the nodes '11' and '9' i.e. sectionalizing switch (8) is open. The resultant network is shown in **fig.5.3**

Now, the load flow solution for the above network is obtained. The results of load flow are shown in 2nd column of **Table 5.1**. From these results the voltage at the nodes '11' and '9' of the tie switch (8) are compared. Here, V(11) is greater than V(9). Hence, it is possible to connect the branch (8) and open the branch that is connected in between the nodes '9' and '8' i.e. sectionalizing switch (6), which is towards the source. It is observed that the total power loss is increased and hence the switching option is not effective. Hence the final position of open switch (8) is between nodes 11 and 9. The modified network is as shown in **fig.5.4**.

Similarly for remaining tie switches (15) and (16), the results are obtained. The summary of results and reconfigured network are given in **Table 5.2** and **fig.5.5** respectively. The test results shows that the total real power loss is **7.7% less** than that of initial configuration due to the improvement of voltage from **0.95310 p.u.** to **0.95679 p.u.**

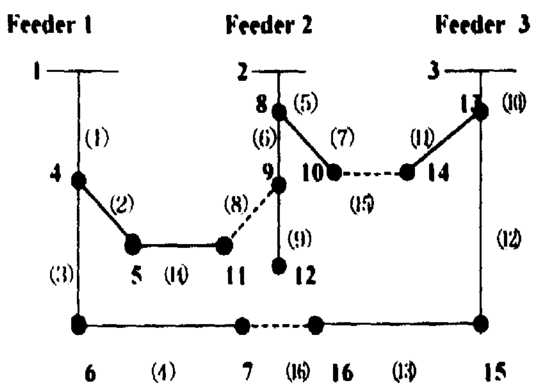


Fig.5.3: Reconfiguration network with tie switch (14) is connected and sectionalizing switch (8) is open

Table 5.1: The load flow results of IEEE-16 node network (Case-I)

Original System		Tie switch 5-11 C		Branch 11-9 C		Tie switch 10-14 C		Branch 10-8 C		Tie switch 7-16 C	
V[1]	1.00000	V[1]	1.00000	V[1]	1.00000	V[1]	1.00000	V[1]	1.00000	V[1]	1.00000
V[2]	1.00000	V[2]	1.00000	V[2]	1.00000	V[2]	1.00000	V[2]	1.00000	V[2]	1.00000
V[3]	1.00000	V[3]	1.00000	V[3]	1.00000	V[3]	1.00000	V[3]	1.00000	V[3]	1.00000
V[4]	0.98852	V[4]	0.98796	V[4]	0.97473	V[4]	0.98796	V[4]	0.98796	V[4]	0.98526
V[5]	0.98447	V[5]	0.98331	V[5]	0.95600	V[5]	0.98331	V[5]	0.98331	V[5]	0.98061
V[6]	0.98175	V[6]	0.98118	V[6]	0.96786	V[6]	0.98118	V[6]	0.98118	V[6]	0.97467
V[7]	0.98067	V[7]	0.98010	V[7]	0.96676	V[7]	0.98010	V[7]	0.98010	V[7]	0.97232
V[8]	0.97319	V[8]	0.97402	V[8]	0.99061	V[8]	0.97619	V[8]	0.89778	V[8]	0.97619
V[9]	0.95908	V[9]	0.96055	V[9]	0.93269	V[9]	0.96275	V[9]	0.88311	V[9]	0.96275
V[10]	0.97107	V[10]	0.97191	V[10]	0.98853	V[10]	0.98399	V[10]	0.92373	V[10]	0.98746
V[11]	0.95829	V[11]	0.98303	V[11]	0.94956	V[11]	0.98303	V[11]	0.98303	V[11]	0.98033
V[12]	0.95310	V[12]	0.95457	V[12]	0.92653	V[12]	0.95679	V[12]	0.87660	V[12]	0.95679
V[13]	0.99057	V[13]	0.99057	V[13]	0.99057	V[13]	0.98846	V[13]	0.96190	V[13]	0.99191
V[14]	0.98884	V[14]	0.98884	V[14]	0.98884	V[14]	0.98475	V[14]	0.93399	V[14]	0.98821
V[15]	0.98508	V[15]	0.98508	V[15]	0.98508	V[15]	0.98296	V[15]	0.95624	V[15]	0.98984
V[16]	0.98384	V[16]	0.98384	V[16]	0.98384	V[16]	0.98172	V[16]	0.95497	V[16]	0.96854
TPL 649.58KW		TPL 626.69KW		TPL 909.19KW		TPL 599.56KW		TPL 1813.27 KW		TPL 630.23 KW	
Volt min 0.95310		Volt min 0.95457		Volt min 0.92653		Volt min 0.95679		Volt min 0.87660		Volt min 0.95679	
		Loss redn 22.89 KW		THIS BRANCH CONNECTION IS NOT USEFUL		Loss reduc 50.02 KW		THIS BRANCH CONNECTION IS NOT USEFUL		THIS TIE SWITCH CONNECTION IS NOT USEFUL	

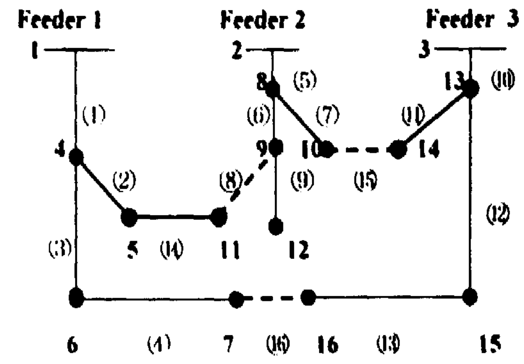


Fig.5.4: Reconfiguration network with tie switch (14) is connected and sectionalizing switch (8) is opened

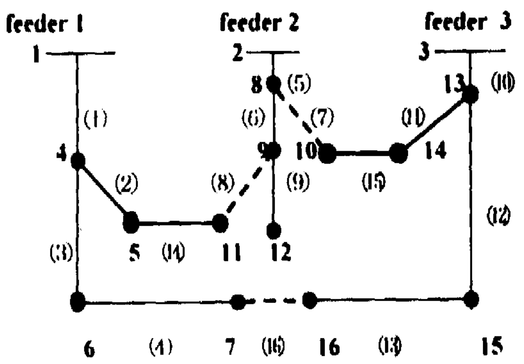


Fig.5.5: final reconfiguration network

5.5.1.2 Case-II: With End Node Capacitor

In this case also above study is carried out with end node capacitors. The final reconfigured network is same as shown in **fig.5.5** and the results are given in **Table 5.3** The total real power loss is **8.91%** less than that of initial configuration due to the improvement of voltage from **0.96982 p.u** to **0.97208 p.u.**

Table 5.2: Summary of test results for IEEE-16 node network (Case-I)

Network Configuration	Open tie switches	System power loss (KW)	Minimum voltage (p.u)
Initial	(11), (15), (16)	649.58	0.95310
Final	(8), (7), (16)	599.56	0.95679

Table 5.3: Summary of test results for IEEE-16 node network (Case-II)

Network Configuration	Open tie switches	System power loss (KW)	Minimum voltage (p.u)
Initial	(11), (15), (16)	505.05	0.96982
Final	(8), (7), (16)	460.06	0.97208

5.5.2 Example- 2

Fig.5.6 shows a 33-node, 12.66 KV radial distributions network [56]. The line, load and tie switch data is given in **Appendix D2**. Load flow results before network reconfiguration are given in **Table 5.4**, total real power loss is **202.4 KW**. **Fig.5.7** shows the final reconfiguration network obtained from the proposed method. Load flow results by applying the proposed method after reconfiguration are presented in **Table 5.5** and the total real power loss is **141.04** KW. The summary of test results is given in **Table 5.6**. The total real power loss is **30.33%** less than that of initial configuration due to the improvement of voltage from **0.91311 p.u** to **0.93784 p.u.**

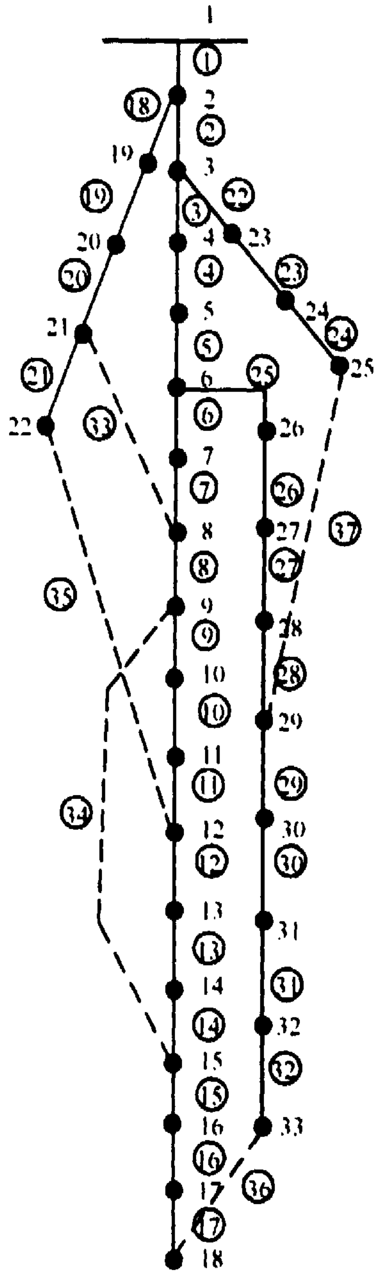


Fig. 5.6: Initial configuration of 33 - node radial network with five tie-switches

Table 5.4: Load flow solution for initial configuration of 33-node network

Node number	Voltage magnitude (p.u)
1	1.00000
2	0.99704
3	0.98296
4	0.97548
5	0.96808
6	0.94968
7	0.94620
8	0.94135
9	0.93508
10	0.92927
11	0.92841
12	0.92691
13	0.92080
14	0.91853
15	0.91712
16	0.91575
17	0.91372
18	**0.91311**
19	0.99651
20	0.99293
21	0.99223
22	0.99159
23	0.97939
24	0.97272
25	0.96940
26	0.94775
27	0.94519
28	0.93375
29	0.92553
30	0.92197
31	0.91781
32	0.91690
33	0.91661

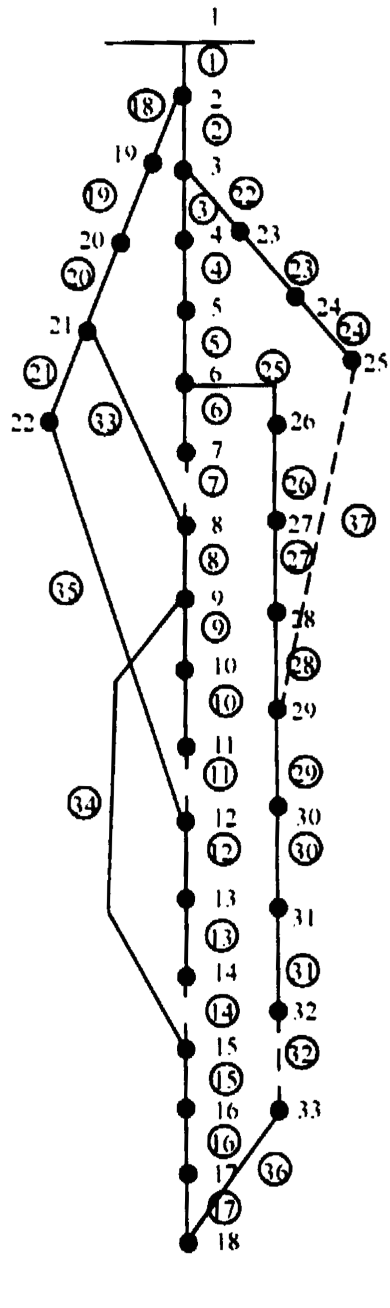


Fig. 5.7: Final reconfiguration of 33 - node radial distribution network

Table 5.5: Load flow solution for final configuration of 33-node network

Node number	Voltage magnitude (p.u)
1	1.00000
2	0.99708
3	0.98701
4	0.98249
5	0.97818
6	0.96734
7	0.96669
8	0.96052
9	0.95619
10	0.95523
11	0.95516
12	0.96586
13	0.96329
14	0.96250
15	0.95012
16	0.94835
17	0.94543
18	0.94440
19	0.99508
20	0.97822
21	0.97358
22	0.97092
23	0.98346
24	0.97682
25	0.97350
26	0.96556
27	0.96320
28	0.95268
29	0.94514
30	0.94194
31	0.93851
32	**0.93784**
33	0.94407

Table 5.6:Summary of test results for 33 node network

Network Configuration	Open tie switches	System power loss (KW)	Minimum voltage (p.u)
Initial	33 34 35 36 37	202.4	0.91311
Final	7 11 11 32 37	141.04	0.93784

5.5.3 Example- 3

Fig.5.8 shows a single line diagram of 69-node, 12.66 KV radial distribution network [54] with tie switches. The line, load and tie switch data is given in **Appendix D3**. Load flow results before network reconfiguration are given in **Table 5.7**, total real power loss is **224.99 KW**. **Fig.5.9** shows the final reconfiguration network obtained from the proposed method. Load flow results by applying the proposed method after reconfiguration are presented in **Table 5.8** and the total real power loss is **106.38 KW**. The summary of test results is given in **Table 5.9**. The total real power loss is **52.72%** less than that of initial configuration due to the improvement of voltage from **0.90918 p.u** to **0.94831 p.u.**

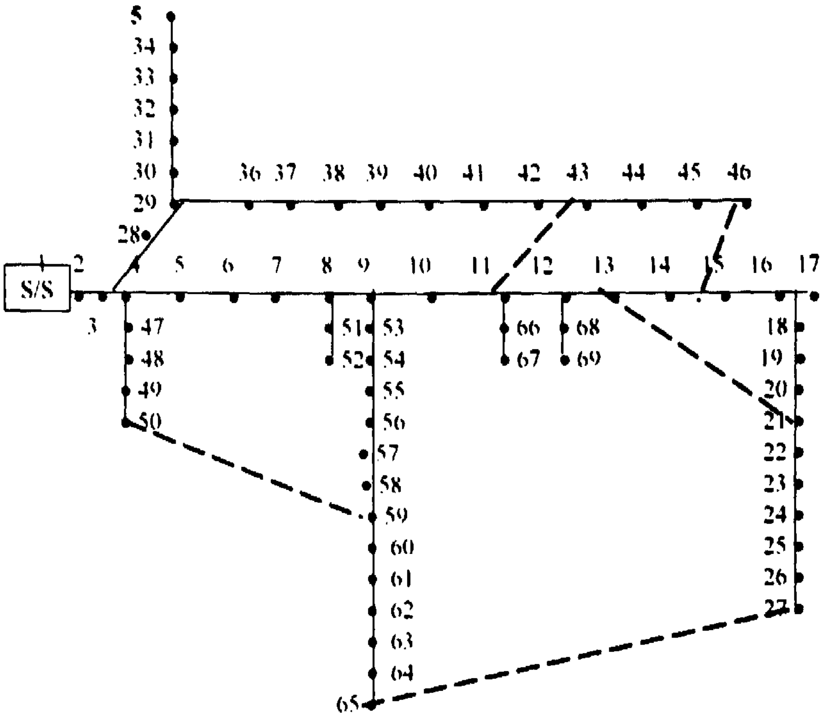


Fig.5.8: Initial configuration of 69-node radial distribution network

Table 5.7: Load flow solution for initial configuration of 69-node network

Node number	Voltage magnitude (p.u)	Node number	Voltage magnitude (p.u)
1	1.00000	36	0.99992
2	0.99997	37	0.99975
3	0.99993	38	0.99959
4	0.99984	39	0.99954
5	0.99902	40	0.99954
6	0.99009	41	0.99884
7	0.98079	42	0.99855
8	0.97858	43	0.99851
9	0.97744	44	0.99850
10	0.97245	45	0.99841
11	0.97134	46	0.99840
12	0.96818	47	0.99979
13	0.96526	48	0.99854
14	0.96236	49	0.99470
15	0.95950	50	0.99415
16	0.95896	51	0.97854
17	0.95808	52	0.97853
18	0.95808	53	0.97466
19	0.95761	54	0.97141
20	0.95731	55	0.96694
21	0.95683	56	0.96257
22	0.95682	57	0.94010
23	0.95675	58	0.92904
24	0.95660	59	0.92476
25	0.95643	60	0.91973
26	0.95636	61	0.91234
27	0.95634	62	0.91205
28	0.99993	63	0.91166
29	0.99985	64	0.90976
30	0.99973	**65**	**0.90918**
31	0.99971	66	0.97129
32	0.99961	67	0.97129
33	0.99935	68	0.96785
34	0.99901	69	0.96785
35	0.99895		

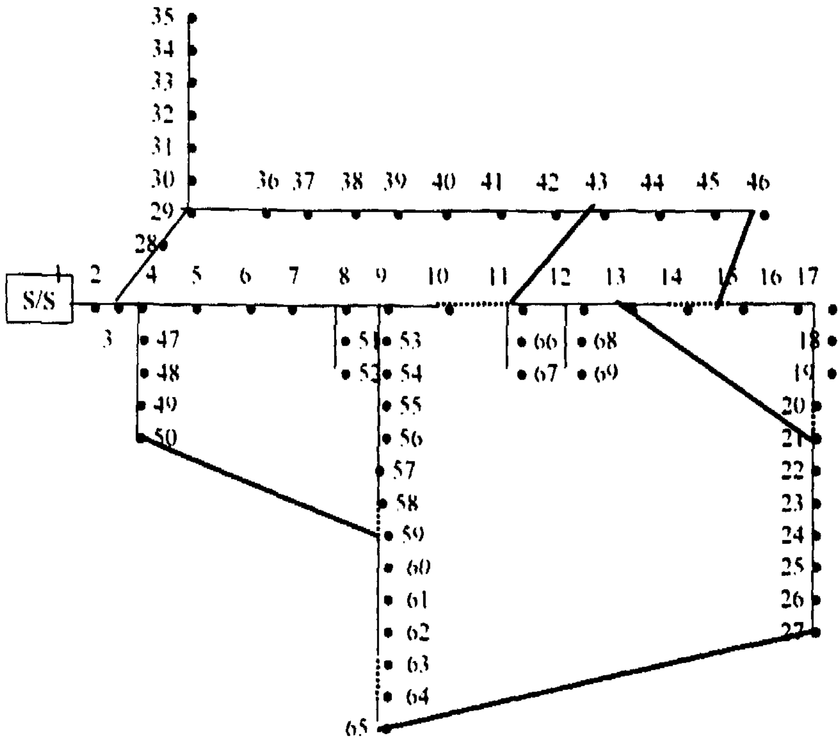


Fig.5.9: Final reconfiguration of 69-node radial distribution network

Table 5.8: Load flow solution for final configuration of 69-node network

Node number	Voltage magnitude (p.u)	Node number	Voltage magnitude (p.u)
1	1.00000	36	0.99984
2	0.99997	37	0.99852
3	0.99993	38	0.99710
4	0.99987	39	0.99669
5	0.99979	40	0.99667
6	0.99893	41	0.98725
7	0.99804	42	0.98324
8	0.99786	43	0.98272
9	0.99781	44	0.98269
10	0.99763	45	0.98239
11	0.97797	46	0.98238
12	0.97412	47	0.99973
13	0.97019	48	0.99635
14	0.97012	49	0.98525
15	0.98100	50	0.98267
16	0.98075	51	0.99782
17	0.98041	52	0.99781
18	0.98041	53	0.99773
19	0.98041	54	0.99764
20	0.98040	55	0.99758
21	0.96763	56	0.99758
22	0.96759	57	0.99758
23	0.96715	58	0.99758
24	0.96620	59	0.95810
25	0.96431	60	0.95415
26	0.96353	61	0.94834
27	0.96311	**62**	**0.94831**
28	0.99993	63	0.94831
29	0.99986	64	0.95849
30	0.99973	65	0.96058
31	0.99971	66	0.97792
32	0.99961	67	0.97792
33	0.99935	68	0.97379
34	0.99901	69	0.97379
35	0.99895		

Table 5.9: Summary of test results for 69 node network

Network Configuration	Open tie switches	System power loss (KW)	Minimum voltage (p.u)
Initial	(69) (70) (71) (72) (73)	224.99	0.90918
Final	(10) (70) (11) (58) (63)	106.38	0.94831

5.6 Conclusions

A network reconfiguration method for loss reduction of radial distribution systems is presented. From the studies, the following important observations can be concluded :

1. The power losses of distribution systems can be effectively reduced by proper feeder reconfiguration.
2. In addition to power-loss reduction, the voltage profile can also be improved by the proposed method.
3. The effectiveness of the proposed method is tested with and without shunt capacitors and the results are presented.