PLANNING OF RADIAL DISTRIBUTION SYSTEMS

6.1 Introduction

A systematic approach to distribution system planning is essential to ensure that the growing demand of electricity can be adequately met by distribution system expansion, which is both technically adequate and reasonably economical. Even though considerable work had been reported, employing systematic approach to generation and transmission system planning, very little attention was paid in the case of distribution system planning. In the future, more than in the past, electric utilities need a fast and economical planning tool to evaluate the effectiveness of alternative plans of system expansion and their impact on the rest of the system to provide the necessary economical, reliable and safe electric energy to all consumers.

To make the distribution system-planning problem very simple, very recently, some researchers [82,83,114] have focused their attention to apply heuristic rules in distribution system planning problem. Inclusion of heuristic rules simplified the problem formulations and also takes less solution time. Chen and Hsu [58] have proposed an expert system for load allocation in distribution system planning. The main objective of their work is to transfer some of the loads from the heavily loaded feeder to a main transformer in the new substation by considering heuristic rules. The main drawback of this work is that they have assumed that all the feeders have the same type of conductors. They have also not carried out any load flow analysis during switching operation.

Hsu and Chen [66] have also presented a knowledge-based expert system for distribution substation planning. A basic objective of this study was to find the optimal feeder path and optimum location of substation by considering all the heuristic rules. In this study they have also considered the same type of conductors for all branches. However, they have not presented any procedure for the selection of the tie lines. For open loop system design Glamocanin and Fillipovic [89] have proposed open loop distribution system planning for urban areas considering heuristic rules. Their method is suitable for planning of new feeders but not suitable for transferring load from one feeder to another. They have also considered a uniform conductor for the feeder.

In the planning of distribution system, one is concerned about the determination of proper numbers of feeders, selection of optimum size of branch conductor for each feeder and minimum number of tie lines based on the forecasted loads.

For distribution system, the radial feeder structure, which is simple with inherent advantages of minimal length of feeders and easy coordination of several protective devices, is preferred to supply power to all consumers with more reliability.

However, the system topology must be changed through feeder reconfiguration when one tries to restore the electricity service in unfaulted regions following an outage. Even when all components are normal and the system is in normal operation, feeder reconfiguration is still necessary in order to achieve load balancing and loss reduction. In distribution system when switches are operated manually feeder reconfiguration may be conducted once per week, or once per month or once per season based on the forecasted loads in that particular period. However, feeder reconfiguration may be conducted more frequently, e.g., once per day, in an automated distribution system where the switches are operated via remote control and the section loads are monitored and recorded by computers in the distribution dispatch and control center.

In this chapter, an attempt is made to determine a proper radial distribution feeder configuration with minimum feeder path, optimum selection of conductors of feeder branches and selection of minimum number of the tie lines for open loop design of distribution systems using a systematic approach.

In the next section, the minimum cost algorithm is illustrated with one existing substation emerging with two feeders in section 6.2 The various distribution system planning aspects viz., optimum size of branch conductor, selection of tie lines are discussed in sections 6.3 and 6.4 respectively. The overall distribution system-planning algorithm is presented in section 6.5. This proposed algorithm is illustrated with one example i.e., a 53-node system, which is presented in section 6.6.

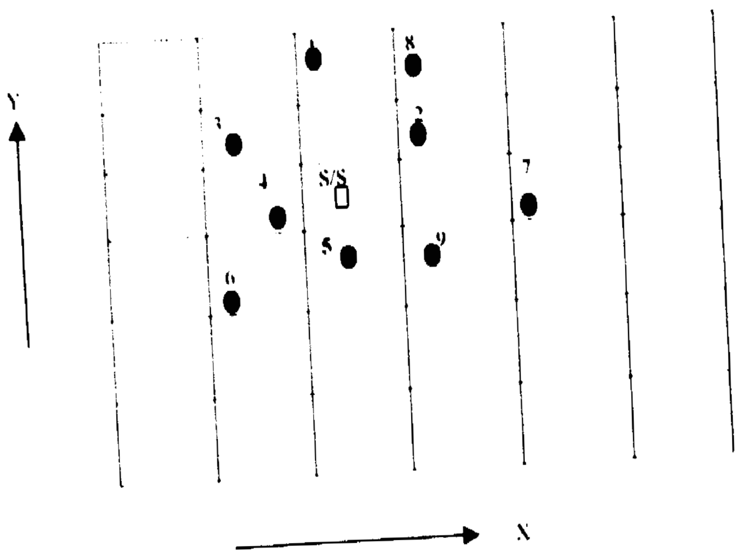
6.2 The Minimum Cost Algorithm of the Feeder with One Existing Substation

For simplicity, to start with, only the investment cost of feeders is compared for each of the proposed distribution systems. This leads to the result that investment cost is proportional to feeder length. Therefore, the problem of minimizing investment cost reduces to that of minimizing feeder length. Minimal path algorithm is extremely suitable for distribution system planning. Taking the nine load points in **Fig. 6.1** as an example whose X and Y coordinates are known, it is logical to start the computation with existing substation. Now, before describing the minimum feeder path algorithm, it is worth mentioning here that all the paths between the nodes are not feasible. For example,

(i) A distribution line is discarded if there is a big pond between the two nodes

(ii) If the line passes through a residential campus, it is discarded

(iii) If the line passes through a commercial area, it is discarded.



Load Point

Fig. 6.1 : Distribution system load points location (taken as an example)

6.2.1 Two Feeders Case

For two-feeder case, it is assumed that only two feeders are emerging from the existing substation. The set of "connected nodes", S contains existing substation (ES) initially. From **fig.6.1** all the load points are in set of unconnected nodes in $\bar{S}$

$$S = \{(ES), (ES)\} \qquad \text{--------(6.1)}$$

$$\bar{S} = \{1,2,3,4,5,6,7,8,9\} \qquad \text{---------(6.2)}$$

First find out two load points closed to existing substation. Say the two nodes are 4 and 5 and the paths from existing substation to these nodes are feasible. Therefore, connect nodes 4 and 5 to existing substation.. There fore set of S and $\bar{S}$ now becomes.

$$S = \{(ES, 4), (ES, 5)\} \qquad \text{---------(6.3)}$$

or $$S = \{S1, S2\} \qquad \text{---------(6.4)}$$

Where

$$S1 = (ES, 4) \qquad \text{--------(6.5)}$$

$$S2 = (ES, 5) \qquad \text{--------(6.6)}$$

and $$\bar{S} = \{1,2,3,6,7,8,9\} \qquad \text{-------(6.7)}$$

Now compare the distances from any node in S1 and S2 (i.e. S) to any node in $\bar{S}$ and find out the feasible shortest path. Say, node 3 in nearest to node 4 (i.e. shortest path is $D_{4,3}$) and node 9 is nearest to node 5 (i.e. shortest path is $D_{5,9}$). Now find out minimum of $D_{4,3}$ and $D_{5,9}$. Say $D_{5,9}$ is minimum. As node 5 belongs to set S2 therefore,

$$S1 = (ES, 4) \qquad \text{--------- (6.8)}$$

$$S2 = (ES, 5, 9) \qquad \text{--------- (6.9)}$$

Connect node 5 to node 9, therefore,

$$\bar{S} = \{1,2,3,5,7,8\} \qquad \text{--------(6.10)}$$

Again, compare the distances from any node in S1 and S2 to any node in $\bar{S}$ and find out the shortest distances. Say node 3 is nearest to node 4 (shortest path is $D_{4,3}$), node 7 is nearest to node 9 (Shortest path is $D_{7,9}$) and node 2 is nearest to node 5 (shortest path is $D_{2,5}$). Find out minimum of $D_{4,3}$, $D_{7,9}$ and $D_{2,5}$. Say $D_{4,3}$ is the minimum. Connect node 4 to node 3. Now node 4 belongs to set S1.

Therefore,

$$S1 = (ES, 4, 3) \qquad \text{---------- (6.11)}$$

$$S2 = (ES, 5, 9) \qquad \text{----------(6.12)}$$

and

$$\bar{S} = \{1,2,6,7,8\} \qquad \text{---------- (6.13)}$$

This process is repeated until all load points are connected, i.e. all the load points are in S (S = {S1, S2}) and $\bar{S}$ = {null}.

Based on the procedure described above, a generalized computer program is developed for any number of feeders emerging from one existing substation with minimal feeder path.

Connect node 5 to node 9, therefore,

$$\bar{S} = \{1,2,3,5,7,8\} \quad \text{--------(6.10)}$$

Again, compare the distances from any node in S1 and S2 to any node in $\bar{S}$ and find out the shortest distances. Say node 3 is nearest to node 4 (shortest path is $D_{4,3}$), node 7 is nearest to node 9 (Shortest path is $D_{7,9}$) and node 2 is nearest to node 5 (shortest path is $D_{2,5}$). Find out minimum of $D_{4,3}$, $D_{7,9}$ and $D_{2,5}$. Say $D_{4,3}$ is the minimum. Connect node 4 to node 3. Now node 4 belongs to set S1.

Therefore,

$$S1 = (ES, 4, 3) \quad \text{---------- (6.11)}$$

$$S2 = (ES, 5, 9) \quad \text{----------(6.12)}$$

and $$\bar{S} = \{1,2,6,7,8\} \quad \text{---------- (6.13)}$$

This process is repeated until all load points are connected, i.e. all the load points are in S ($S = \{S1, S2\}$) and $\bar{S} = \{null\}$.

Based on the procedure described above, a generalized computer program is developed for any number of feeders emerging from one existing substation with minimal feeder path.

6.3 Optimum Type of Branch Conductor

After obtaining the optimum feeder path, it is necessary to obtain the optimum type of branch conductor. The branch conductor optimization algorithm as developed in **Chapter 3**, is used for this purpose.

6.4 Selection of Tie-Lines

It is already mentioned that the system topology must be changed through feeder reconfiguration when one tries to restore the electricity service in unfaulted regions following an outage event in the system. Even when all components are normal and the system is in normal operation, feeder reconfiguration is still necessary in order to achieve load balancing and loss reduction.

In the present work, attempt is made to determine a proper open loop distribution plan with a minimum number of tie-lines, which can meet the need of feeder reconfiguration in normal system operation.

To make feeder reconfiguration possible, an open loop type network structure must be established at the planning stage. Then some of the tie-switches are normally opened in order to achieve radial configuration in normal system operation.

To select the minimum number of tie lines at the planning stage for open loop distribution system design, proposed network reconfiguration algorithm as developed in **Chapter 5** is used. Proposed network reconfiguration algorithm is very much suitable to find out the minimum number of tie lines at the planning stage.

6.5 Distribution System Planning Algorithm

The distribution-planning algorithm is given in three steps:

Step-1: Obtain radial feeder configuration using the proposed feeder path algorithm.

Step-2 :Obtain optimum type of the branch conductor using branch conductor optimization algorithm as developed in **Chapter-3.**

Stpe-3: Select minimum number of tie lines using the proposed network reconfiguration algorithm as developed in **Chapter-5.**

Step-3 is required for open loop design of distribution system or transferring the loads from one feeder to another.

6.6 Illustrative Example

Fig. 6.2 shows a location of existing substation and 53 load points. The data of this example is taken from [127] and is given in **Table E1 (Appendix E)**. Data related to the Conductors that have been used for branch conductor optimization are given in **Table B1 (Appendix B)**.

Now the basic objectives of this problem are:

1. To find out the number of feeders emerging from the existing substation such that cost of the line is minimum.
2. To find out the optimum type of branch conductor.
3. To find out the minimum number of tie lines for open loop design of this distribution system.

It is assumed that all the tie lines are of Raccon type conductor

To get the answers of the above-mentioned objectives, three cases are examined:

(1) two feeders case, (2) three feeders case and (3) four feeders case.

6.6.1 Two feeders Case

In this case, the existing substation has two feeders. Optimal radial network configuration is given in **Fig. 6.3**. By using branch wise conductor algorithm the optimum type of conductor has been selected. The optimal type of conductor for each branch is also shown in **Fig. 6.3**. Total line length is **99.07 Km**. Total real and reactive power losses are **40.37 KW** and **37.76 KVAr** respectively. Minimum voltage occurring at node 33, i.e., V(33) = **0.96142 p.u**. Cost of the line is **Rs.2,94,560 /-.**

Now, in order to obtain optimum open loop configuration, initially 6 tie lines are considered: (11-12), (10-33), (14-28), (43-47), (38-18) and (41-52).

The final choice of the tie lines is obtained using the proposed network reconfiguration (minimum real power loss) as developed in **Chapter 5.** It was found that tie-lines (11-12), (10-33) and (14-28) are suitable for open loop design because these are giving the maximum real power loss reduction after network reconfiguration. **Fig. 6.4** shows the open loop configuration and **Fig. 6.5** shows the optimal results after network reconfiguration. Total **real** and **reactive** power losses after network reconfiguration are **36.25 KW** and **34.00 KVAr** respectively.

Cost of the line for open loop configuration = cost of the line for radial configuration + cost of the tie lines = **Rs2,98,515 /-.**

After network reconfiguration (**fig. 6.5**), minimum voltage occurring at node 3, i.e., V (3) = **0.96884 p.u.**

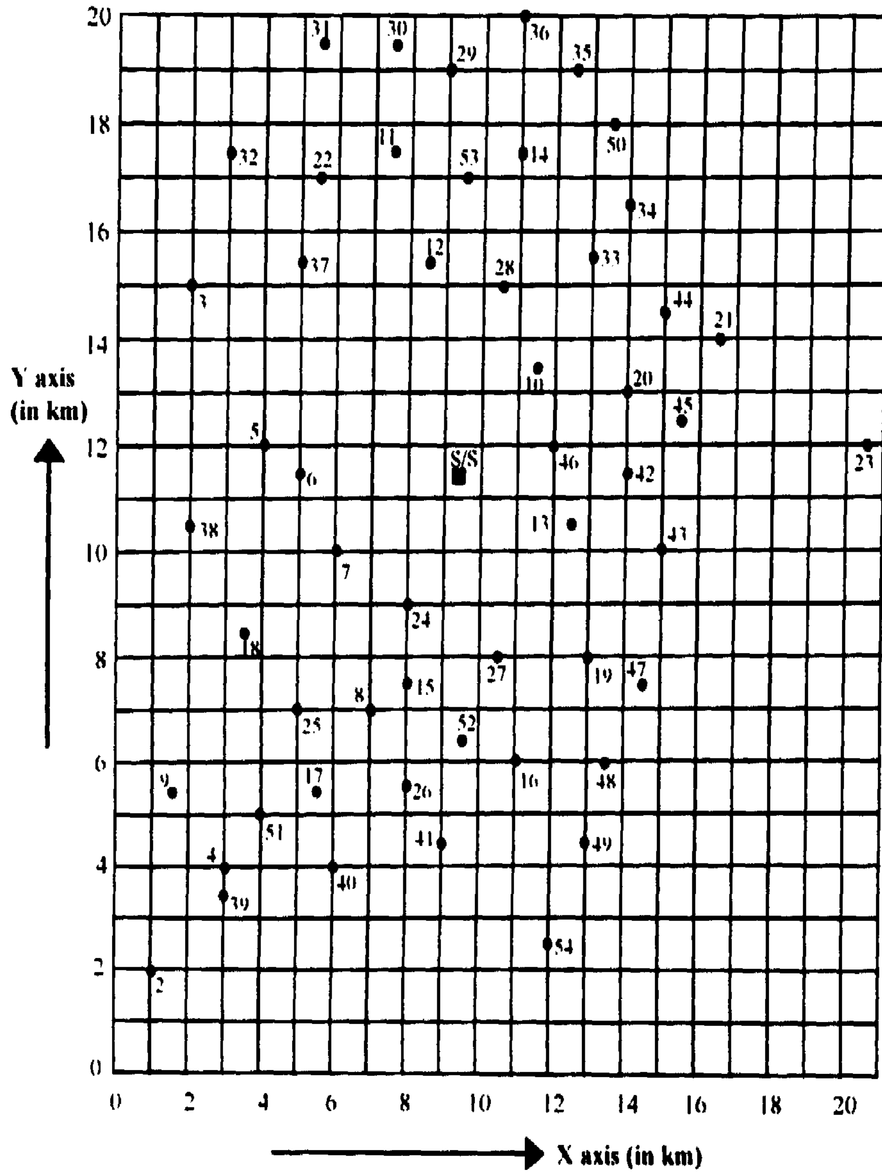


Fig 6.2: Load points and Substation location

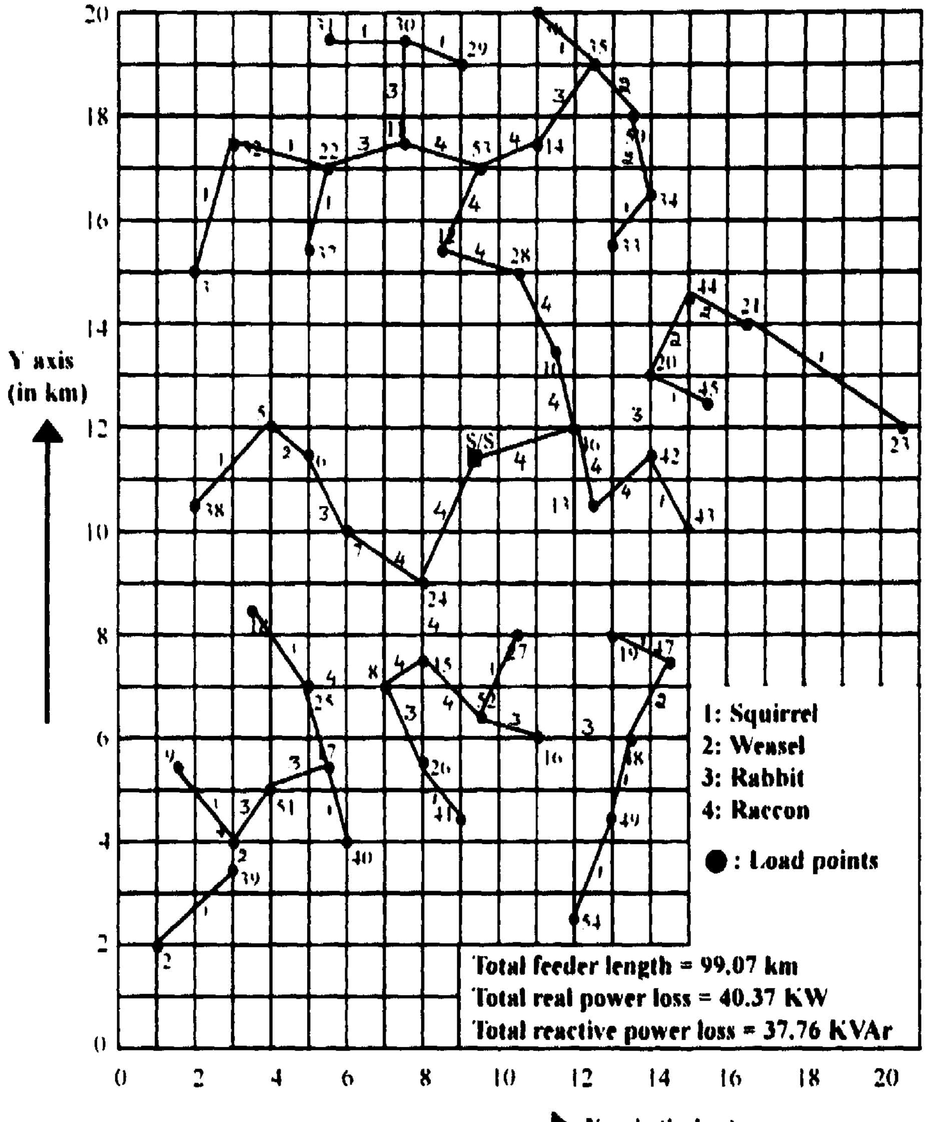


Fig 6.3: Optimal radial feeder configuration (two feeders case)

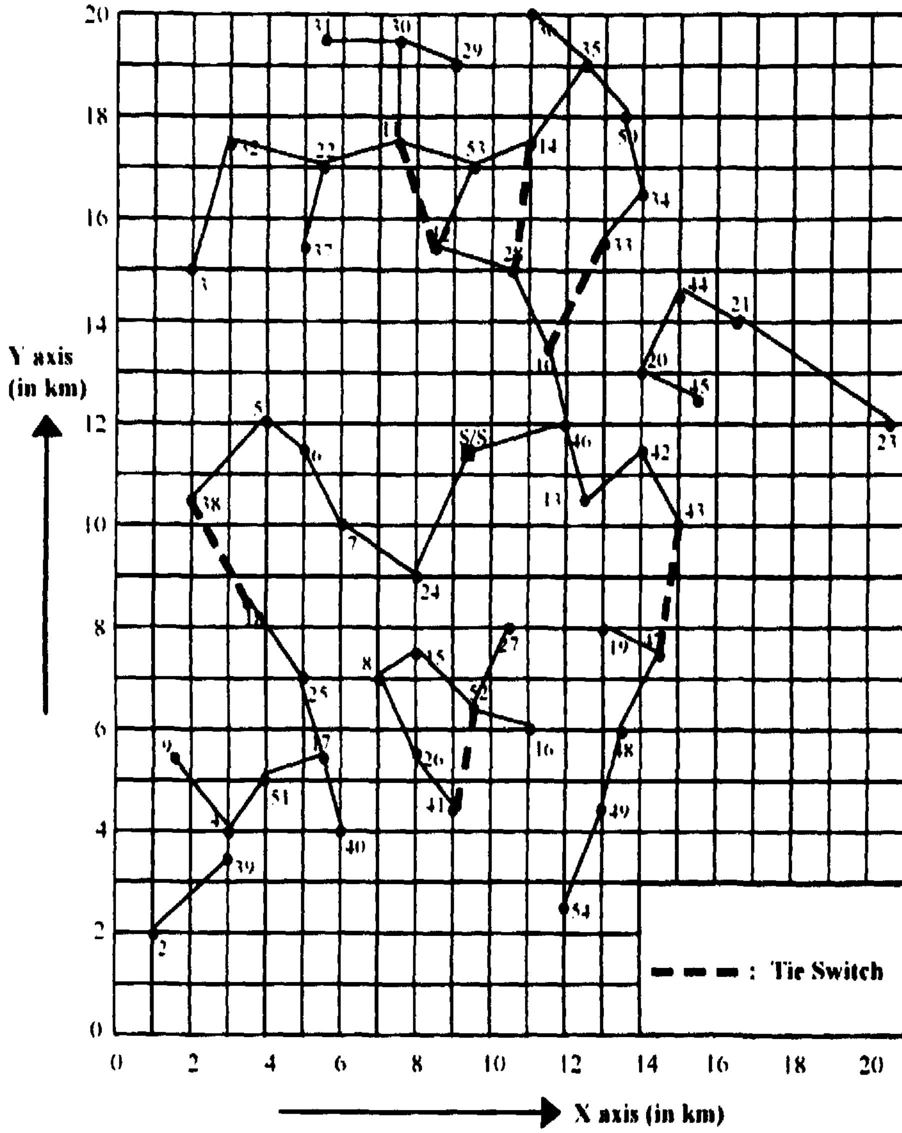


Fig 6.4: Optimal open loop configuration (two feeders case)

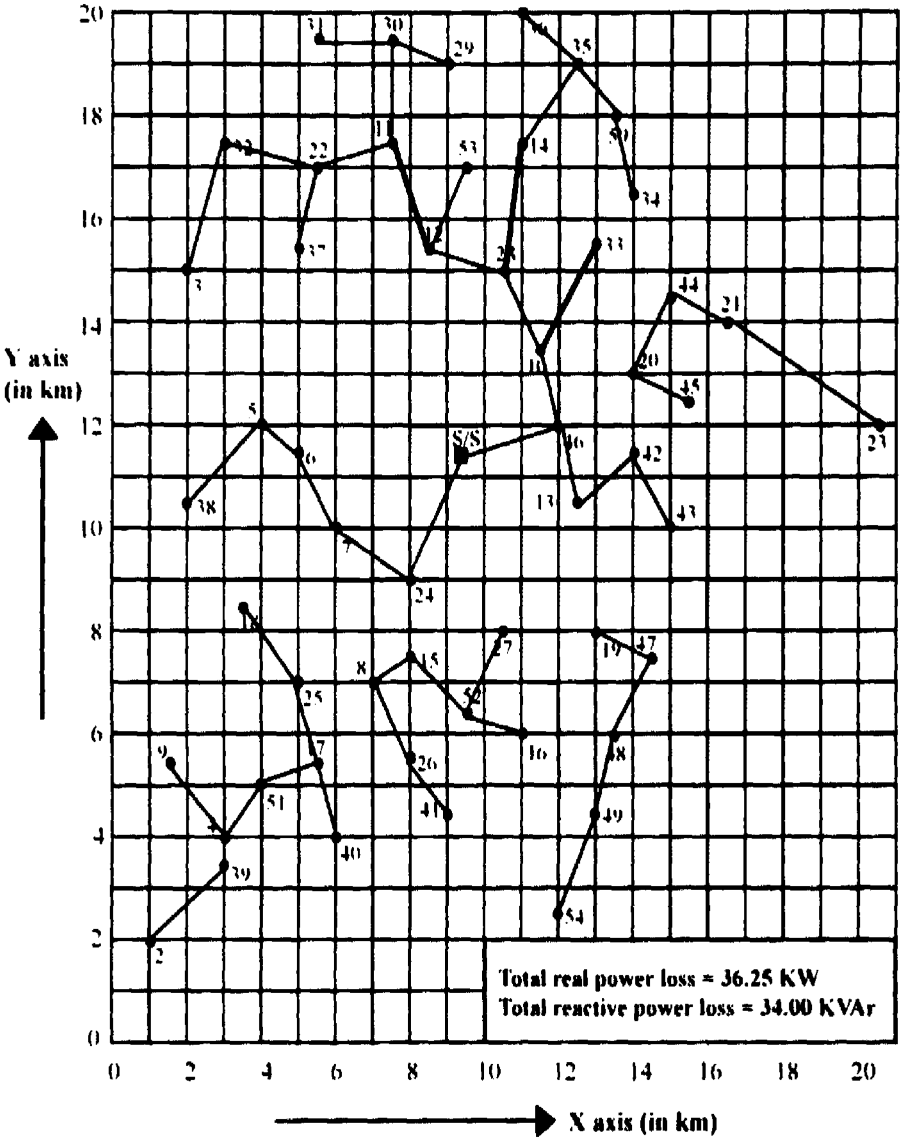


Fig 6.5: Optimal circuit after network reconfiguration (two feeders case)

6.6.2 Three feeders Case

In this case the existing substation has three feeders. Optimal radial network configuration is given in **fig. 6.6.** The optimal type of conductor for each branch is also shown in **fig. 6.6**. Results are summarized below.

Total line length	=	**100.67 Km**
Total real power loss	=	**33.72 KW**
Total reactive power loss	=	**31.25 KVAr**
Minimum voltage	=	**V(33)=0.97018 p.u**
Cost of the line	=	**Rs.2,57,843 /.**

In order to obtain optimum open loop configuration, initially same 6 tie lines as mentioned for two feeders case (**Case- 1**) are considered. The final choice of tie lines is obtained using the proposed network reconfiguration (minimum power loss) as developed in **Chapter 5.** It was also found that tie-lines (11-12), (10-33) and (43-47) are suitable for open loop design because these are giving maximum reduction of real power loss after network reconfiguration. **Fig. 6.7** shows the open loop configuration and **fig. 6.8** shows the optimal results after network reconfiguration. Total **real** and **reactive** power losses after network reconfiguration are **27.54 KW** and **26.41 KVAr** respectively. **Cost** of the line for open loop configuration is **Rs.2,60,948 /-**. After network reconfiguration (**Fig. 6.8**), minimum voltage occurring at node 2, i.e. **V (2)=0.97832 p.u.**

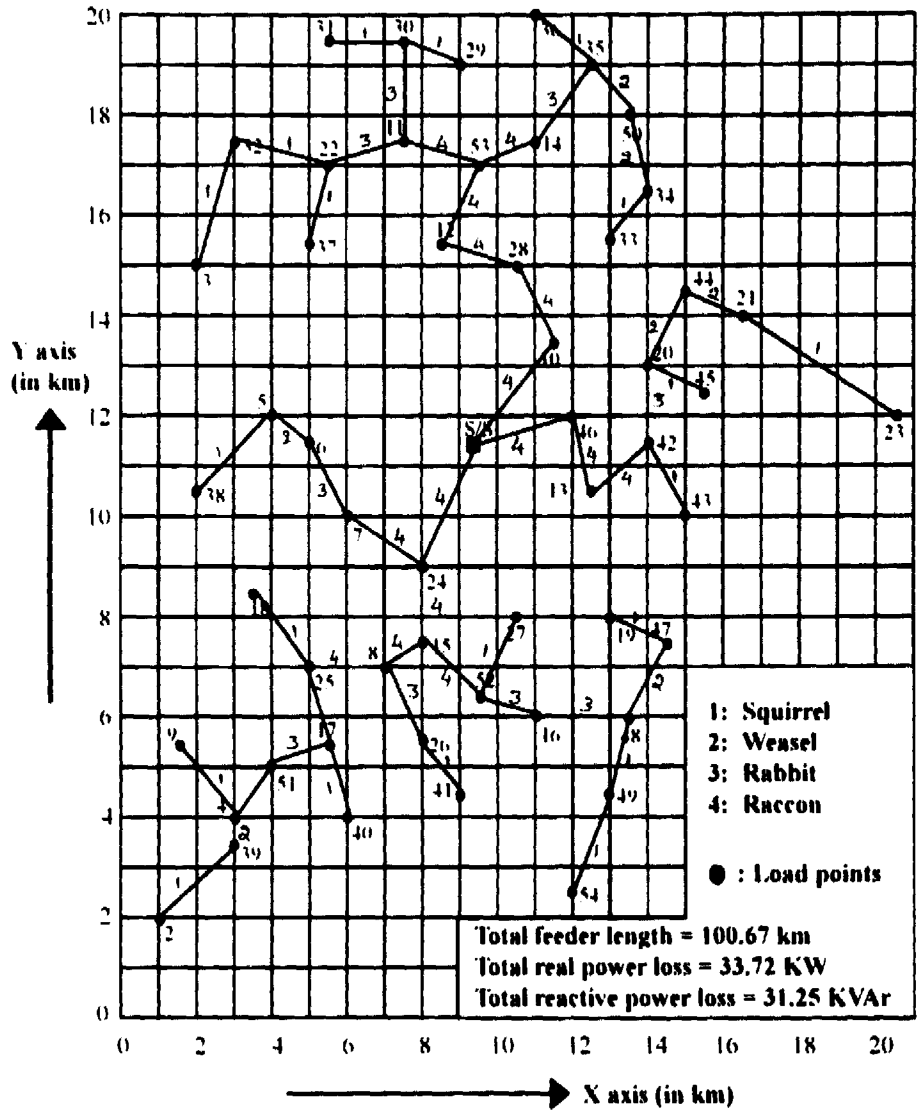


Fig 6.6: Optimal radial feeder configuration (three feeders case)

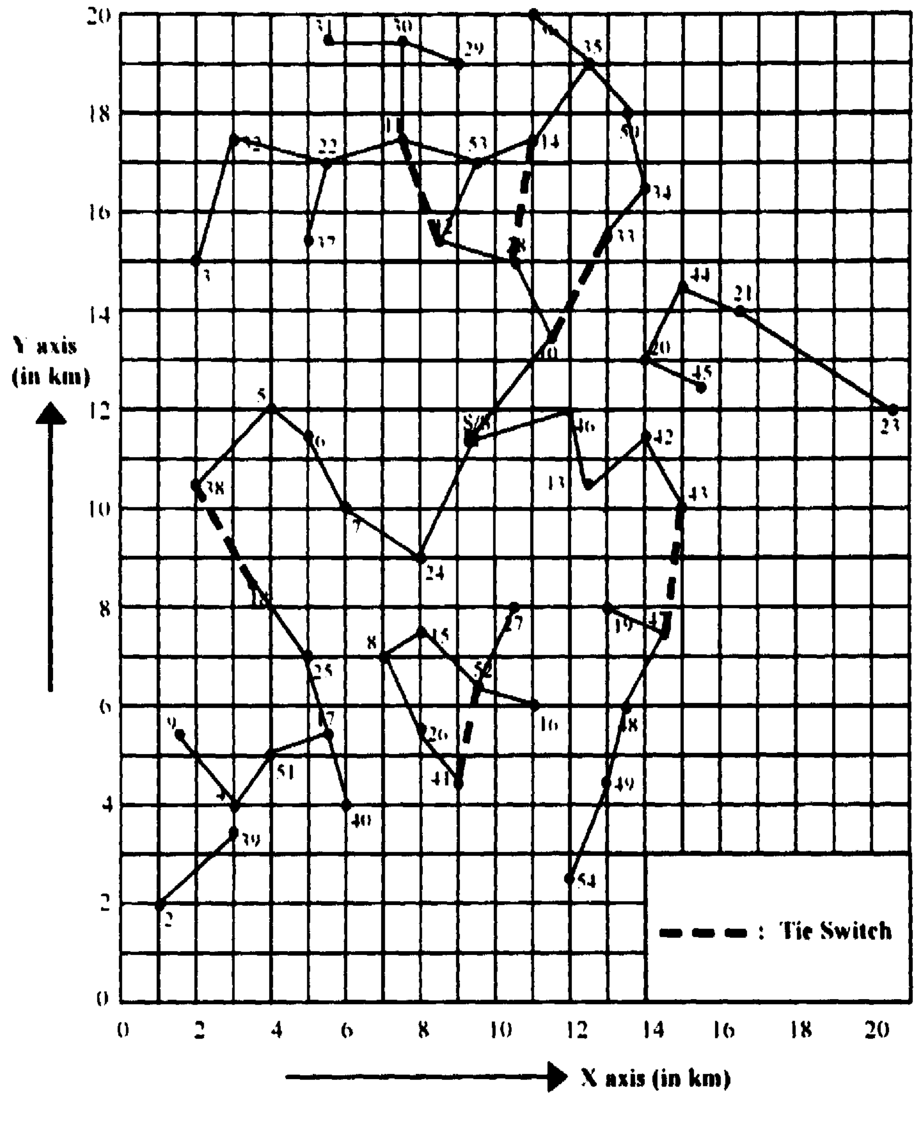


Fig 6.7: Optimal open loop configuration (three feeders case)

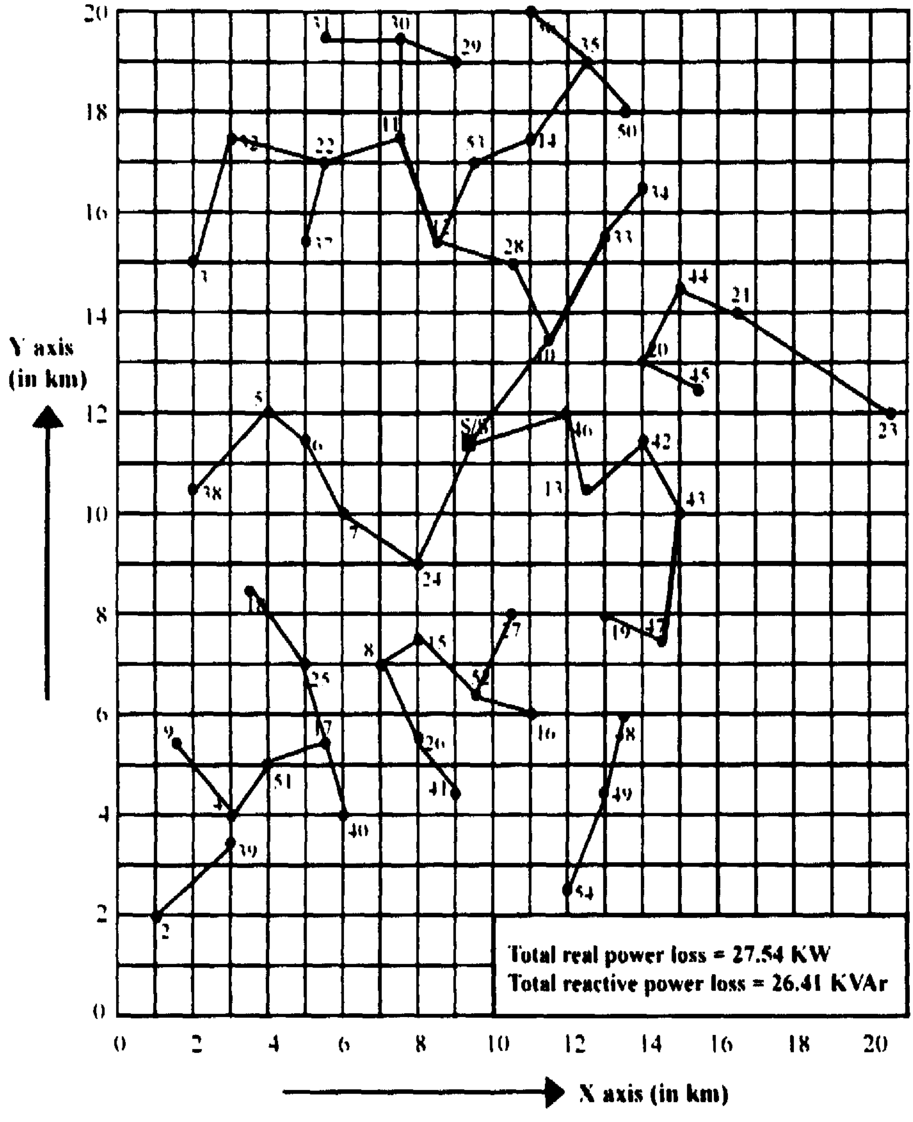


Fig 6.8: Optimal circuit after network reconfiguration (three feeders case)

6.6.3 Four feeders Case

In this case, the existing substation has four feeders. Optimal radial configuration is given in **fig. 6.9**. Optimal results for radial configuration are summarized below.

Total line length	=	**102.49 Km**
Total real power loss	=	**33.05 KW**
Total reactive power loss	=	**30.50 KVAr**
Minimum voltage	=	**V (33)=0.97018 p.u.**
Cost of the line	=	**2,53,630 /-**

For obtaining optimum open loop configuration, initially, same 6 tie lines as mentioned for two feeders case (**Case-1**) are considered. It was found that tie-lines (11-12), (10-33), (14-28) and (43-47) are suitable for reduction of real power loss after network reconfiguration. **Fig. 6.10** shows the optimal open loop configuration and **fig. 6.11** shows the optimal results after network reconfiguration.

Total **real** and **reactive power** losses after network reconfiguration are **26.97 KW and 25.38 KVAr** respectively. **Cost** of the line for open loop configuration is **Rs.2,62,181/-**. After network reconfiguration (**fig. 6.11**), minimum voltage occurring at node 2, i.e., **V (2)=0.97532 p.u.**

The results for radial and open loop configuration are summarized in **Tables 6.1** and **6.2.** From **Table 6.1**, it is seen that cost of the line for two feeders case is much higher, voltage condition is very poor and real and reactive power losses are very high. However, there is not much choice between three and four feeders cases for optimal radial configuration.

Table 6.2 shows the comparison of the results for open loop configuration. Once again two feeders case is not acceptable, due to high cost, and higher real and reactive power losses. In fact three feeders case is the best choice for open loop design because cost is less and real power losses are nearly equal as compared to four feeders case after network reconfiguration.

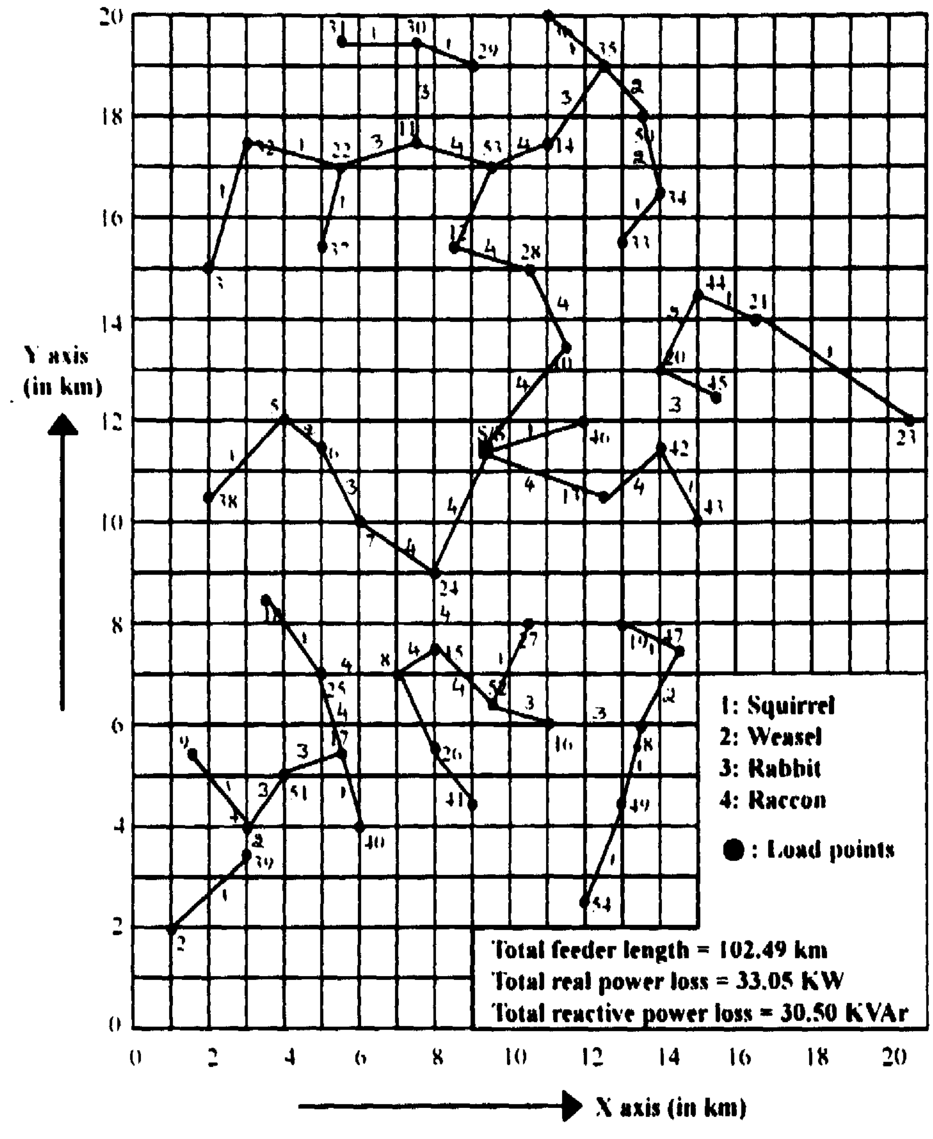


Fig 6.9: Optimal radial feeder configuration (four feeders case)

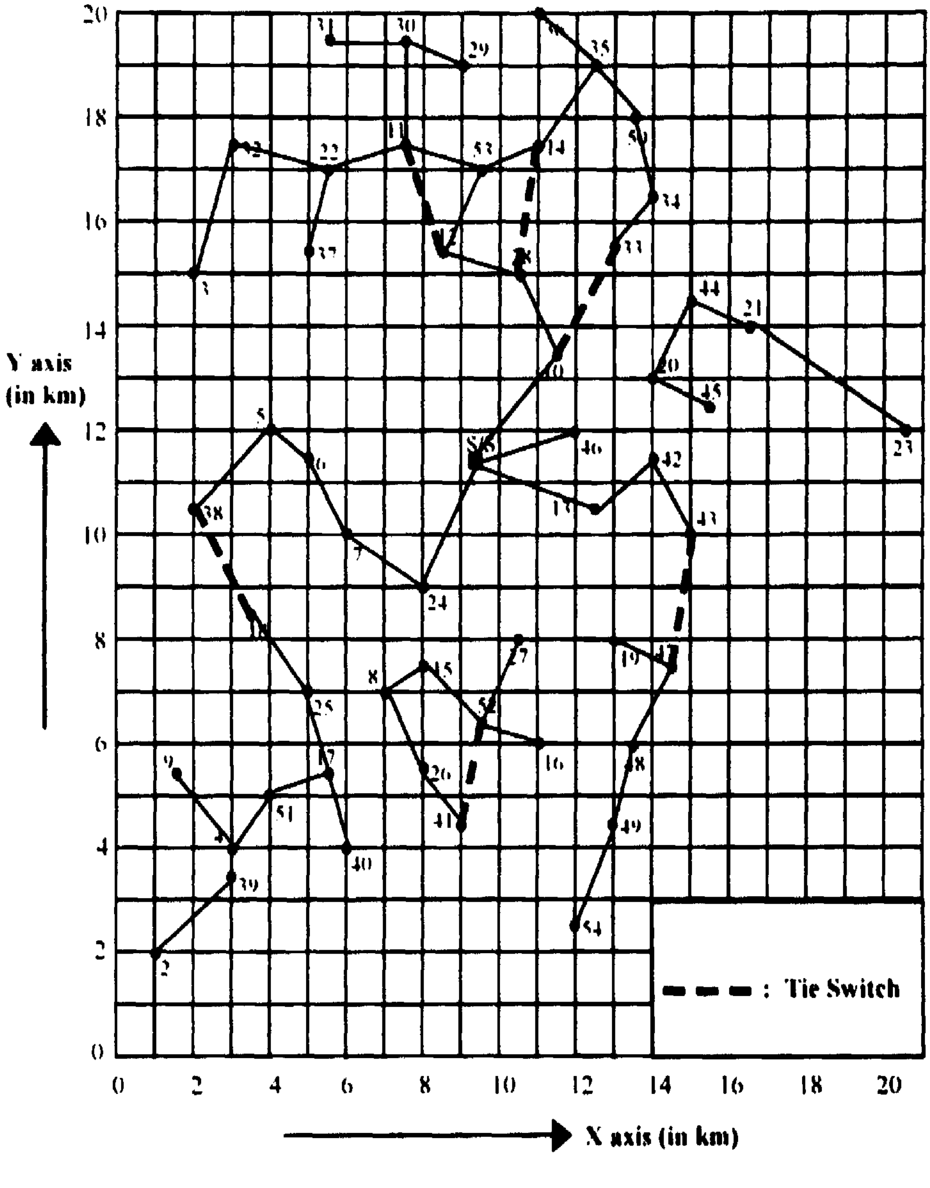


Fig 6.10: Optimal open loop configuration (four feeders case)

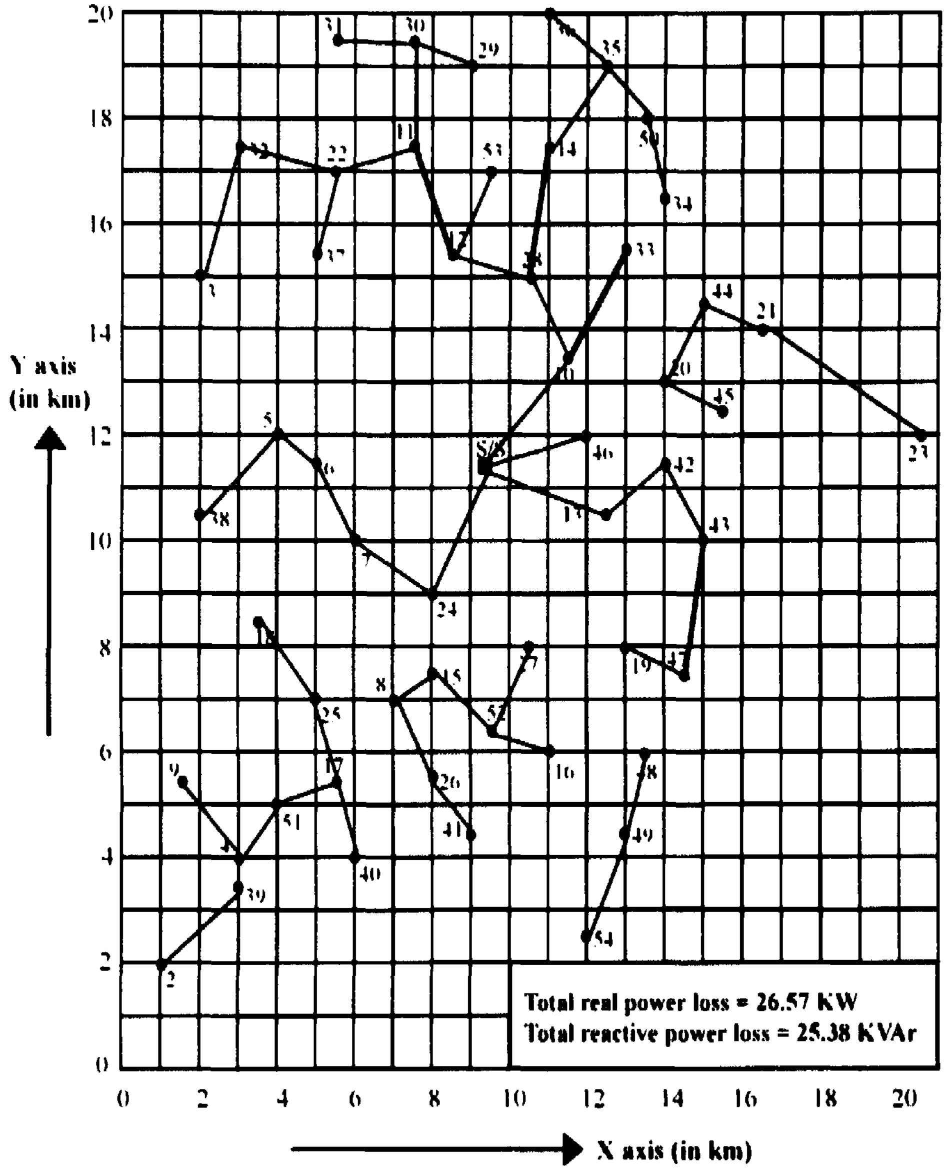


Fig 6.11: Optimal circuit after network reconfiguration (four feeders case)

Table6.1: Comparison of results for radial configurations

Radial Feeder Variables	Number of Feeders		
	2 Feeders	3 Feeders	4 Feeders
Total Length (Km)	99.07	100.67	102.49
Total Cost (Rs.)	2,94,560 /-	2,57,843 /-	2,53,630 /-
Total Real Power Loss (KW)	40.37	33.72	33.05
Minimum voltage magnitude (p.u)	V(33)= 0.96142	V(33)= 0.97018	V(33)= 0.97018

Table 6.2: Comparison of results for open loop configurations

Open Loop Variables	Number of Feeders		
	2 Feeders	3 Feeders	4 Feeders
Total Length (Km)	101.28	102.51	105.45
Total Cost (Rs.)	2,98,515/-	2,60,948/-	2,62,181/-
Real Power Loss (KW)	36.25	27.54	26.97
Minimum voltage after network reconfiguration (p.u)	V(3)=0.96884	V(2)=0.97832	V(2)=0.97532

6.7 Conclusions

In this chapter, distribution system planning problem is divided into three sub problems: (1). The radial feeder planning, (2) selection of optimum type of branch conductor and (3) selection of tie lines for open loop design of distribution systems. The following specific conclusions can be made based on the results from this work:

i) A simple procedure has been suggested for selecting the number of feeders emerging from an existing substation based on the cost of the line, minimum real power loss and minimum system voltage.

ii) Optimum type of branch conductor has been obtained using a branch conductor optimization algorithm.

iii) For the purpose of feeder reconfiguration, the feeder network must be planned as open loop structure. In order to obtain open loop design of distribution system, final choice of tie lines has been selected based on network reconfiguration algorithm. Power loss optimization leads to minimal distribution system variable cost.