OPTIMAL CONDUCTOR SELECTION FOR RADIAL DISTRIBUTION NETWORKS

3.1 Introduction

In recent years, considerable attention has been focused in planning of distribution systems to reduce the capital investment and energy losses and to provide better quality supply to consumers. Recently, improved modeling techniques and certain optimization and programming approaches have been presented to determine the best location, and suitable interconnections between substations to meet the increasing demands more reliably and economically. In these approaches, the type of conductor for each feeder segment is often chosen, based on the current carrying capacity of the optimal feeder configuration [8,9,13-15,24,61]. The work presented in [14] goes one step further i.e., the conductor size is selected based on the need for feeder voltage support as well as the current carrying capacity requirement. Motivation behind this additional step is that it may be required to use a large conductor size in order to maintain the voltage down the feeder at an acceptable level. This especially is the case with rural feeders in some developing countries, where feeders often stretch over long distances to serve even very light loads.

In India, rural distribution feeders are too long and during agricultural season, feeders are heavily loaded, and hence, losses of the feeders are very high and also give rise to poor voltage conditions. To improve these conditions, presently utility engineers in India adopt measures [128] such as:

i) Reconductoring of some branches of the existing feeders.

ii) Rerouting the main line of the feeder by the shortest route.

iii) If rerouting is not possible, then the feeder should be studied for bifurcation at suitable points with the view of transferring loads to lightly loaded feeder.

iv) Shunt compensation on 11 KV feeders, etc..

In this chapter, a method is proposed for selecting the optimal branch conductor for radial distribution networks based on a load flow technique developed in **chapter 2**. The conductors, which are determined by the proposed method, will satisfy not only the maximum current carrying capacity but also maintain acceptable voltage levels of the radial distribution systems. In addition, it will give maximum saving in depreciation on capital cost of conductor and cost of energy losses in radial distribution systems.

The load flow method required for optimal branch conductor selection of radial distribution networks is presented in (section 3.2). The mathematical model and constraint equations are discussed in section 3.3. A proposed algorithm for optimal branch conductor selection is described in section 3.4. The flow chart for the proposed method is given in section 3.5. Two radial distribution networks are considered and the results of these networks are presented in section 3.6. Conclusions of this chapter are presented in section 3.7.

3.2 Load Flow Method for Optimal Branch Conductor Selection

A simple load flow algorithm developed in **Chapter 2** with a little modification is used for the optimal branch conductor size selection of radial distribution feeders.

Fig. 2.2 given shows a single line diagram of distribution network. Branch number, sending end node and receiving end node of this system are given in **Table 2.1.** Consider branch-1, the receiving end node voltage of branch-1 can be written from eqn. (2.8) **(Chapter 2, Section 2.2)** as:

$$|V_{(2,k)}| = [\tfrac{1}{2}[b_{(1,k)} + \{b^2_{(1,k)} - 4\,c_{(1,k)}\}^{1/2}]]^{1/2} \qquad \text{-------(3.1)}$$

Where

$|V_{(2,k)}|$ = voltage magnitude of node 2 with k type conductor of branch-1,

k= 1,2,...., NTYPE

$b_{(1,k)} = |V_{(1,k)}|^2 - 2\,P_{(2)}\,r_{(1,k)} - 2\,Q_{(2)}\,x_{(1,k)}$

$c_{(1,k)} = \{P^2_{(2)} + Q^2_{(2)}\}\,\{r^2_{(1,k)} + x^2_{(1,k)}\}$

$V_{(1,k)}$= substation voltage (constant for all k)

$P_{(2)}$ = Total real power load of all nodes beyond node 2 and plus real power load at node 2 itself plus the sum of the real power losses of all the branches beyond node 2.

$Q_{(2)}$ = Total reactive power load of all nodes beyond node 2 and plus reactive power load at node 2 itself plus the sum of the reactive power losses of all the branches beyond node 2.

$r_{(1,k)}$ = resistance of branch 1 with k type of conductor, k= 1,2.....,NTYPE

$x_{(1,k)}$ = reactance of branch 1 with k type of conductor, k= 1,2,.....,NTYPE

Similarly for branch 2

$$|V_{(3,k)}| = [\tfrac{1}{2}[b_{(2,k)} + \{b^2_{(2,k)} - 4\,c_{(2,k)}\}^{1/2}]]^{1/2} \qquad \text{--------(3.2)}$$

As the substation voltage $V_{(1,k)}$ is known, easily calculate $V_{(2,k)}$ for k= 1,2, ... ,NTYPE from eqn. (3.1).

Once $V_{(2,k)}$ is known, then easily calculate $V_{(3,k)}$ for k= 1,2,....,NTYPE from eqn. (3.2). Similarly voltage of nodes 4,5,---,NB can be calculated for k= 1,2,....,NTYPE . Therefore, a generalized equation of receiving end voltage can be written as

$$|V_{(m2,k)}| = [\tfrac{1}{2}[b_{(jj,k)} + \{b^2_{(jj,k)} - 4\,c_{(jj,k)}\}^{1/2}]]^{1/2} \qquad \text{-------(3.3)}$$

Eqn. (3.3) can be evaluated for m2=2.3,4...NB with different type of conductors.

The expression for current flowing through branch jj with k type of conductor is given as

$I_{(jj,k)}=(P_{(m2)}-j\,Q_{(m2)})/V^*_{(m2,k)}$ -------(3.4)

Eqn. (3.4) clearly shows that as the node voltages are different for different type of conductors; branch currents are also different for different type of conductors.

Detailed load flow calculation procedure has been described in **Section-2.4** of **Chapter 2**.Real and reactive power loss of branch jj with k type conductors are given by:

$LP_{(jj,k)}= I^2_{(jj,k)}\, r_{(jj,k)}$ ------(3.5)

$LQ_{(jj,k)}= I^2_{(jj,k)}\, x_{(jj,k)}$ ------(3.6)

The total real power loss (TLP) and reactive power loss (TLQ) can be calculated as

$TLP=\sum_{jj=1}^{LN1} LP_{(jj,k)}$ -------(3.7)

$TLQ=\sum_{jj=1}^{LN1} LQ_{(jj,k)}$ --------(3.8)

3.3 Objective Function

The basic problem is selection of conductor size for each branch of a radial distribution network, which will minimize the sum of the depreciation cost on capital investment and the cost of energy losses while maintaining an acceptable voltage level.

The objective function for optimal selection of conductor size for branch jj with k type conductor is

Min. $F_{(jj,k)}=CL_{(jj,k)}+CC_{(jj,k)}$ --------(3.9)

(i)Cost of energy losses (CL)

The annual cost of the energy loss in branch jj with k type conductor is

$CL_{(jj,k)}= LP_{(jj,k)}[\,Kp+ Ke \times Lsf \times T\,]$ --------(3.10)

In eqn. (3.10), loss factor is used, because $LP_{(jj,\,k)}$ is peak real power loss of branch jj with k type conductor and the product $Lsf \times LP_{(jj,\,k)}$ gives the average real power loss of branch jj with k type conductor.

(ii) Depreciation on capital investment (CC)

The annual depreciation on capital cost for branch jj with k type conductor is,

$$CC_{(jj,\,k)} = \alpha\,[cost_{(k)} \times len_{(jj)}] \qquad \text{--------(3.11)}$$

In this method, optimal selection of conductor size is obtained by branch wise minimization technique using the load flow method is described **in Section 3.2.**

3. 3.1 Constraint Equations

The constraint equations for the optimal selection of conductor for a branch jj are:

i) Feeder voltage: The feeder voltage at every node in the feeder must be above the acceptable voltage level.

i.e., $|V_{(m2,k)}| > V\,min$, for $m_2=2,3,\ldots\ldots,NB$. ---------(3.12)

ii) Maximum current carrying capacity: Current flowing through branch jj should be less than the maximum current carrying capacity of k type conductor **$Imax_{(k)}$**

i.e., $|I_{(jj,k)}| < Imax_{(k)}$, for all branches jj=1,2,….., NL1. -------(3.13)

3.4 Algorithm for Optimum Branch Conductor Selection

Some of the variables used in the optimal branch conductor selection algorithm are

$TYPE_{(jj,\,k)}$= optimal type of conductor for branch jj

$LLP_{(jj,\,k)}$= optimal real power loss of branch jj with $TYPE_{(k)}$ conductor

$LLQ_{(jj,\,k)}$= optimal reactive power loss of branch jj with $TYPE_{(k)}$ conductor

Now the optimal branch conductor selection algorithm for radial distribution feeders will be described. Initially a flat voltage start is assumed for all k type of conductors and compute $V_{(m2,\ k)}$ using eqn. (3.3) for m2=2,3,...., NB and k= 1,2,....,NTYPE. First consider branch jj=1, then set $m1=IS_{(jj)}= IS_{(1)}$ and $m2= IR_{(jj)}= IR_{(1)}$ and compute $V_{(2,k)}$ using eqn. (3.1) and then evaluate $I_{(jj,\ k)}= I_{(1,\ k)}$ using eqn. (3.4) and after that compute $LP_{(jj,\ k)} = LP_{(1,\ k)}$ and $LQ_{(jj,\ k)}= LQ_{(1,\ k)}$ using eqns. (3.5) and (3.6) for k= 1,2,...., NTYPE.

Now evaluate $CL_{(jj,\ k)} = CL_{(1,\ k)}$ and $CC_{(jj,\ k)} = CC_{(1,\ k)}$ using eqns. (3.10) and (3.11) for given constant values and then evaluate $F_{(jj,\ k)} = F_{(1,\ k)}$ using eqn. (3.9) for k= 1,2,...,NTYPE. Once $F_{(1,\ k)}$ for all k is computed, arrange $F_{(1,k)}$ in ascending order and this is necessary because to select the minimum value of $F_{(1,k)}$ which does not violate any constraints. If constraints are not satisfied with the lowest value, then second lowest value of $F_{(1,k)}$ should be considered and check for the constraints and so on till the lowest value of $F_{(1,k)}$, which satisfies all the constraints is determined. The process is terminated when all constraints are satisfied and the corresponding objective function is optimal and the type of conductor is chosen.

From the above discussions, it is clear that the type of conductor for each branch is selected based on minimum value of the objective function and at the same time constraints are also satisfied. If the constraints are not satisfied then the second best value of the objective function is considered to satisfy the constraints.

Similarly the same process is repeated for the remaining branches (i.e., jj=2,3,4,...., LN1) and this will complete one iteration and $LLP_{(jj,\ k)}$ and $LLQ_{(jj,\ k)}$ are the real and reactive power losses with $TYPE_{(jj,\ k)}$ conductor for jj= 1,2,....,LN1. After that calculate the node voltages and repeat the same procedure. The proposed method takes 2-3 iterations to converge. The convergence criterion is same as that presented in **Chapter 2**.

3.5 Flowchart for Optimal Branch Conductor Selection

The flowchart of the proposed optimal branch conductor size selection for a radial distribution network is shown in **fig.3.1**

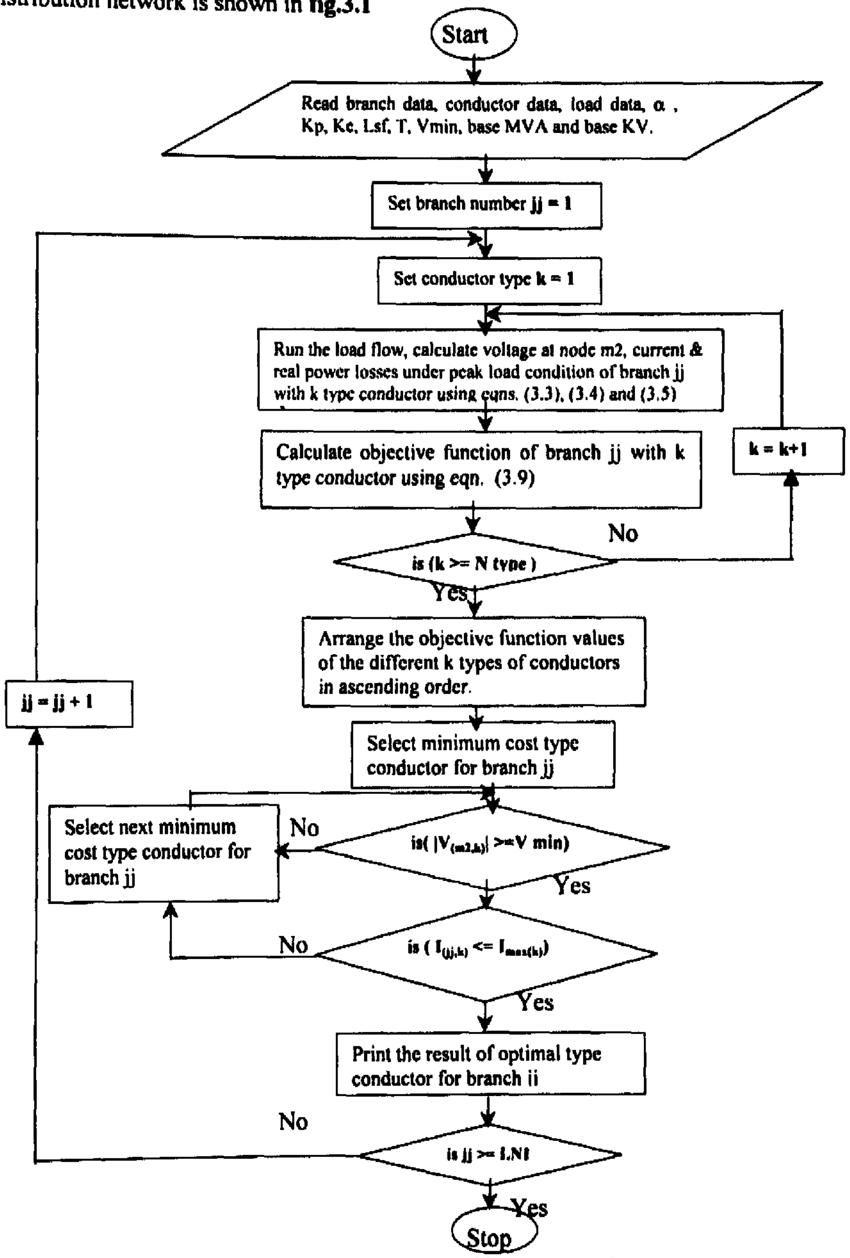


Fig. 3.1: Flowchart for selecting optimal type of branch conductor

3.6 Illustrative Examples

In this section, effectiveness of the proposed algorithm is demonstrated through two examples. Common conductor data for the examples are given in **Appendix B1.**

3.6.1 Example-1

Fig.3.2 shows an existing 26-node radial distribution network in ANANTAPUR, from Anantapur town to Vidyuthnagar. The basic objective is to examine whether branch conductors of this system is properly selected or not.

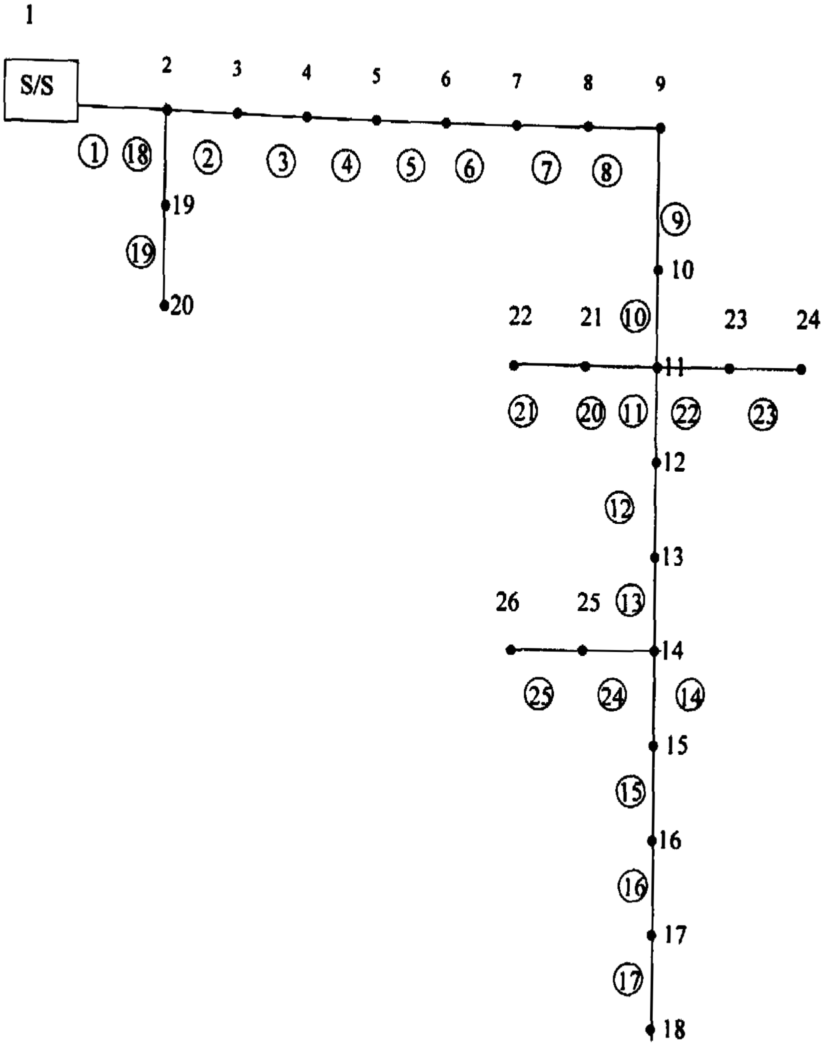
Before analyzing the results, it is worth mentioning that presently in India, utilities are using three or four different types of conductors for distribution feeders. The line and load data of 26-node radial distribution network are given in **Appendix B2.** First a base caseload flow study is carried out using the data given **Appendix B2.** Results of this base case run are given in **Table 3.1.**

For the optimization of branch conductors, four different types of conductors are used (**Appendix B1**). Same load data as given in **Appendix B2** is used for the purpose of comparison. Limit of minimum voltage is taken as **0.90 p.u.**

Results of conductor optimization are depicted in **Table 3.2 and Table 3.3. Table 3.4** gives the comparison of the results.

From **Table 3.2**, it is seen that reconductoring is necessary for some of the branches and **Table 3.3** shows the load flow results after modifications. **Table 3.4** shows the comparison of the results.

Conductor optimization results of this network clearly shows that branch conductors of this network were not properly selected during its planning and one must optimize the branch conductors for better feeder voltage profiles and low power loss.



1,2,….,26 node numbers

①,②,…. ,㉕ branch numbers

Fig. 3.2: 26-node radial distribution network

Table. 3.1: Base case load flow results of 26-node network

Node number	Voltage magnitude (KV)
1	11.000000
2	10.809421
3	10.760314
4	10.714064
5	10.647388
6	10.540805
67	10.520404
8	10.500914
9	10.463762
10	10.428446
11	10.394971
12	10.342766
13	10.306397
14	10.272819
15	10.265121
16	10.254972
17	10.248321
18	**10.242344**
19	10.806766
20	10.805881
21	10.393130
22	10.392210
23	10.387604
24	10.386684
25	10.269327
26	10.268162

Table. 3.2: Reconductoring of various branches for 26-node network

Branch number	Existing feeder	Modification of feeder
	From	To
1 to 16	Weasel	Raccon
18	Weasel	Rabbit
19	Weasel	Squirrel
20	Weasel	Rabbit
21	Weasel	Squirrel
22	Weasel	Rabbit
23	Weasel	Squirrel
24	Weasel	Raccon
25	Weasel	Squirrel

Table. 3.3: Load flow results of 26-node network after modification of conductor size

Node number	Voltage magnitude (KV)
1	11.000000
2	10.901784
3	10.876518
4	10.852744
5	10.818488
6	10.763743
7	10.753266
8	10.743261
9	10.724195
10	10.706076
11	10.688906
12	10.662161
13	10.643530
14	10.626330
15	10.622387
16	10.617190
17	10.613784
18	10.242344
19	10.870218
20	10.720731
21	10.592997
22	10.124387
23	10.589281
24	10.116468
25	10.624539
26	**9.945420**

Table. 3.4: Comparison of the results for 26-node network

Case	**Minimum voltage node (KV)**	**Total real power loss (KW)**
Base case load flow results	$V_{(18)}$=10.242344	33.69
Load flow results after modification of conductor type	$V_{(26)}$= 9.945420	13.14
Net real power loss reduction= (33.69-13.14) = 20 .55 KW		

3.6.2 Example -2

Fig. 3.3 shows a 32-node radial distribution network [87]. Basic objective of this problem is to find out the optimal branch conductors using the proposed conductor optimization algorithm. Line and load data of this system are given in **Appendix B3**.

In India, during agricultural season, rural distribution feeders are heavily loaded and power factor of the load is very poor because of agricultural motor pumpsets. **Table 3.5 and Table 3.7** give the load flow results before and after selecting the optimal branch conductor. The comparisons of results are presented in **Table 3.6 and Table 3.8**, which conforms the effectiveness of the proposed method.

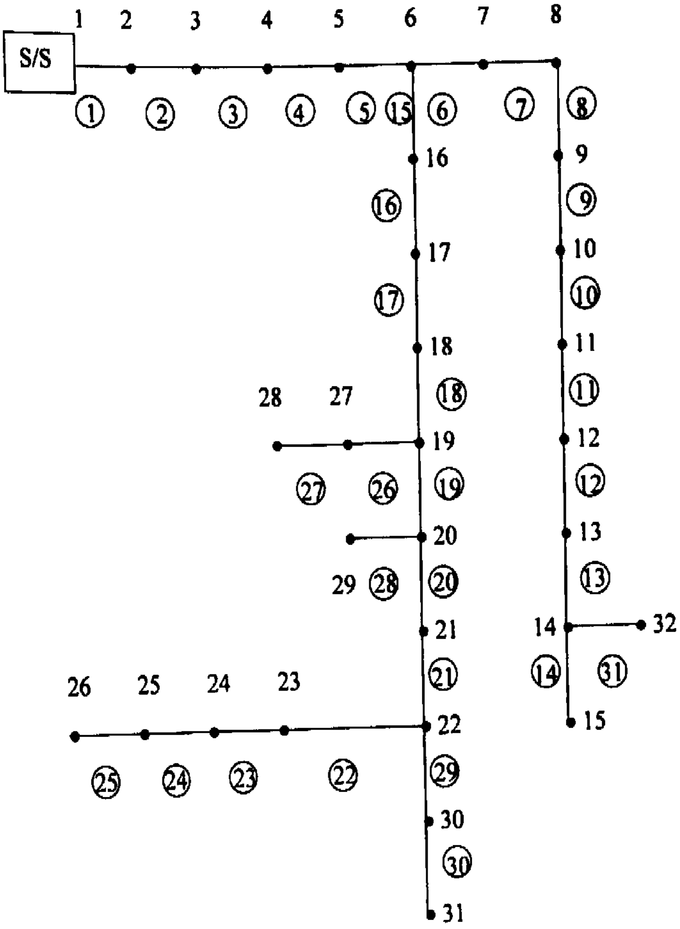


Fig. 3.3: 32-node radial distribution network

Table. 3.5: Base case load flow results of 32-node distribution network

Node number	**Voltage magnitude (KV)**
1	11.000000
2	10.918906
3	10.839014
4	10.669851
5	10.437507
6	10.356462
7	10.329853
8	10.281162
9	10.265569
10	10.209586
11	10.144878
12	10.126750
13	10.112507
14	10.086626
15	10.075238
16	10.305944
17	10.285466
18	10.265689
19	10.108257
20	10.075831
21	10.053753
22	10.046553
23	10.032209
24	10.013555
25	10.008293
26	**9.991540**
27	10.100669
28	10.078223
29	10.071082
30	10.043219
31	10.041791
32	10.080687

Table. 3.6: Reconductoring of various branches for 32-node network

Branch number	Existing feeder	Modification of feeder
	From	To
1 to 12	Rabbit	Raccon
15to21	Rabbit	Raccon
22	Weasel	Raccon
23 to 25	Weasel	Rabbit
26 to27	Weasel	Raccon
28 to31	Weasel	Rabbit

Table. 3.8: Load flow results of 32-node network after modification of conductor size

Node number	Voltage magnitude (KV)
1	11.000000
2	10.938443
3	10.877817
4	10.749491
5	10.573301
6	10.511877
7	10.491691
8	10.454757
9	10.442932
10	10.400490
11	10.351464
12	10.337735
13	10.326951
14	10.086851
15	10.075462
16	10.473622
17	10.458122
18	10.443157
19	10.324121
20	10.299619
21	10.282940
22	10.277502
23	10.270082
24	10.024401
25	10.020799
26	10.009336
27	10.320186
28	10.308547
29	10.072982
30	10.044699
31	**10.043720**
32	10.082780

Table3.9: Comparison of the results for 32-node network

Case	Minimum voltage node (KV)	Total real power loss (KW)
Base case load flow results	V (26)= 9.991540	39.23
Load flow results after modification of conductor type	V (31)= 10.043720	25.67
Net real power loss reduction= (39.23 - 25.67) = **13.56 KW**		

3.7 Conclusions

An efficient algorithm for optimal branch conductor selection to provide better feeder voltage support while recognizing feeder-loading requirements has been presented in this chapter. The total interest and depreciation on capital cost of conductor material and cost of energy losses have been minimized. The effectiveness of this proposed algorithm has been illustrated with two different distribution networks.