

## A Novel Method for Optimal Conductor Selection of Radial Distribution Feeders Using Fuzzy Evolutionary Programming

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**Abstract:** In this study, a novel method for selecting optimal size of branch conductor of radial distribution feeders based on Fuzzy Evolutionary Programming (FEP) is proposed. The aim of optimal conductor size selection is to select a feeder so as to minimize an objective function, which consists of capital investment and capitalized energy loss costs. A fuzzy based satisfaction parameter is proposed which handles voltage deviation index, power quality index and cost function. The proposed parameter is used to generate different combinations of conductors to obtain optimal solution vector. The effectiveness of the proposed method is illustrated with two examples consisting of 32 bus and 26 bus radial distribution systems.

**Key words:** FEP, radial distribution, proposed parameter, optimal solution vector

### INTRODUCTION

A distribution system is one from which the power is distributed to various users through feeders, distributors and service mains. Feeders are conductors of large current carrying capacity, carrying the current in bulk to the feeding points. Power losses in the lines account for the major portion of the distribution system losses. These power losses mainly depend on the type of the conductor and its resistance, size and length. These power losses can be minimized by grading the conductors instead of using a uniform conductor throughout the length of the feeder. Many mathematical models using mixed integer programming have been presented for distribution system planning (Adams and Laughton, 1974; Ponnavaiko *et al.*, 1986; Ponnavaiko and Rao, 1981).

Number of researches have published different approaches for optimal distribution system planning through conductor grading (Kiran and Alder, 1982; Funk, 1955; Ponnavaiko and Rao, 1982). In Ponnavaiko and Rao (1982) dynamic programming is used to obtain the optimal solution of RDS in which no laterals are considered. In Tram and Wall (1988) an algorithm for optimal selection of conductors of radial distribution feeders is developed. They have also explored the possibilities of using voltage regulator instead of reconductoring of the feeder segment to resolve the low voltage problem.

This study presents a novel method based on fuzzy logic approach for design of radial distribution systems, which selects the optimal size of branch conductor. The size of conductor, which is determined by this method, maintains acceptable voltage level at each bus of a radial distribution system. In addition, it gives maximum saving in capital cost of conductor material and cost of energy losses. The proposed method is easy and simple to implement for any size of radial distribution system with laterals.

**Procedure to determine the voltage at each bus:** The vector based distribution load flow method (Das *et al.*, 1994) is used to calculate the voltage at each bus and total real and reactive power losses.

One branch of a radial distribution system can be represented by a single equivalent circuit as shown in Fig. 1.

The voltage at bus  $i+1$ ,  $|V_{i+1}|$  is calculated as

$$|V_{i+1}| = \sqrt{(P_{i+1} \times R_j + Q_{i+1} \times X_j - 0.5 \times |V_i|^2) - (R_j^2 + X_j^2) \times (P_{i+1}^2 + Q_{i+1}^2) - (P_{i+1} \times R_j + Q_{i+1} \times X_j - 0.5 \times |V_i|^2)^{1/2}} \quad (1)$$

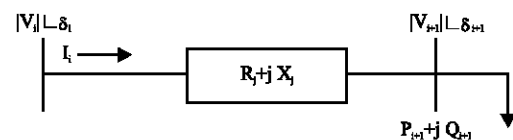


Fig. 1: Single line equivalent circuit

Where,

I=1,2,... number of buses.  
j=1,2,... number of branches.

In order to have better voltage profile for load conditions at all buses, the voltage at each bus should be between specific limits of  $V_{min}$  and  $V_{max}$ . The objective function is formulated as follows,

$$\text{Min. } F = \text{Ploss}_{(j,k)} ((K_p + K_e \times \text{Lsf} \times 8760)) + (\alpha \times A_{(k)} \times \text{cost}_{(k)} \times \text{len}_{(j)}) \quad (2)$$

Where,

$\text{Ploss}_{(j,k)}$  = Real power loss of branch jj with k type of conductor in kW

$K_p$  = Annual demand cost of power loss in Rs kW<sup>-1</sup>

$K_e$  = Annual cost of energy loss in Rs. kWh<sup>-1</sup>

$\text{Lsf}$  = Loss factor =  $0.8 \times (\text{Lf})^2 + 0.2 \times \text{Lf}$

$\text{Lf}$  = Load factor

$\alpha$  = Interest and depreciation factor

$A_{(k)}$  = Cross sectional area of k type of conductor in mm<sup>2</sup>

$\text{cost}_{(k)}$  = Cost of k type conductor in Rs/ mm<sup>2</sup>/km

$\text{len}_{(j)}$  = Length of branch jj in km

**Procedure to generate optimal set of conductor combinations:** Let the vector  $X = [X_1, X_2, X_3, \dots, X_{NC}]$  refer NC different combinations of conductors initially chosen for the branches in RDS. In the proposed algorithm, these initial combinations are considered as a starting guess to generate NC more combinations  $X_{NC+1}$  to  $X_{2NC}$  through a random process. The combination  $X_{NC+j}$  in the set of NC combinations  $X_{NC+1}$  to  $X_{2NC}$  is generated as follows:

$$X_{NC+j} = \frac{2(r) - r_M}{r_M} \times (X_{MAX} - X_{MIN}) \times \frac{\mu_X^{MAX}}{\mu_X^1} + X_j \quad (3)$$

Where,

NC refer to number of combinations

r is a random number between 0 to  $r_M$

$\mu_X^j$  is satisfaction parameter value of combination  $X_j$

$X_{MIN}$  and  $X_{MAX}$  are the combinations of X that yields minimum and maximum satisfaction parameter values, respectively

$\mu_X^{MAX}$  is maximum satisfaction parameter value

**Procedure to determine satisfaction parameter value:** In order to obtain optimal solution for a radial distribution system the main considerations are power losses and voltages. In the proposed algorithm, a satisfaction parameter is used which takes voltages and the cost function into account. The satisfaction parameter value is computed as follows (Venkatesh and Ranjan, 2006)

$$\mu_X(X) = \min (\mu_f(F(X)), \mu_v(v(X))) \quad (4)$$

Where,

$\mu_f(F(X))$  is the membership function of an objective function

$$\mu_f(F(X)) = (F(X) - F_{MIN}) / (F_{MAX} - F_{MIN}) \quad (5)$$

Where,

$F_{MAX}$  and  $F_{MIN}$  are the maximum and minimum values among the set of objective functions  $F(X)$ .

$\mu_v(v(X))$  is the membership function of voltage index

$$I_{VD} = \sqrt{\frac{B_{NV}}{n-1} \sum_{n=1}^n (V_n - V_n^{LIM})^2} \quad (6)$$

Where,

$I_{VD}$  is the voltage deviation index.

$B_{NV}$  is the number of buses that violate the prescribed voltage limits.

$V_n^{LIM}$  is the upper limit of the n<sup>th</sup> bus voltage if there is an upper-limit violation or lower-limit if there is a lower limit violation.

N is the number of buses in the system.

Let the  $I_{VD}$  associated with any solution's i<sup>th</sup> interval be referred as  $I_{VD}^i(X)$ . In order to compute a voltage-deviation index value attributable to the entire solution X, the following is defined,

$$\begin{aligned} &NL \\ &v(X) = \sum \{I_{VD}^i(X)\} \\ &i = 1 \end{aligned} \quad (7)$$

Where

NL = Number of time intervals

Considering all the solutions  $[X_1, X_2, X_3, \dots, X_{2NC}]$  and evaluating them using Eq. (7) we obtain the corresponding voltage-deviation indices as  $[v(X_1), v(X_2), v(X_3), \dots, v(X_{2NC})]$ . The membership function of voltage index is given by,

$$\mu_v(v(X)) = (v_{MAX} - v(X)) / (v_{MAX} - v_{MIN}) \quad (8)$$

Where

$v_{MAX}$  and  $v_{MIN}$  are the maximum and minimum values among the set of permissible values of v.

### Basic FEP algorithm for optimal conductor selection in RDS

**Step 1:** Read line and load data.

**Step 2:** Run the load flow for the base system and compute the voltage at each bus, total real and reactive power losses of the system.

**Step 3:** Generate randomly NC combination of solution vectors  $X_1, X_2, \dots, X_{NC}$

**Step 4:** Set the iteration count  $K=1$

**Step 5:** Evaluate the objective function value for each of these combinations  $X^j$  for  $j = 1$  to  $NC$

**Step 6:** Generate NC more combinations  $X_{NC+1}, X_{NC+2}, \dots, X_{2NC}$  using Eq. (3)

**Step 7:** Choose the best NC solution vectors amongst the set of  $2NC$  solution vectors  $X_1, X_2, \dots, X_{2NC}$  with lower values of objective function and designate the chosen set as of NC solution vectors as  $X_1, X_2, \dots, X_{NC}$

**Step 8:** Increment the iteration count,  $K=K+1$ .

**Step 9:** If  $K < \text{Maximum}$  go to step 4

**Step 10:** Choose the best solution amongst the NC solution sets  $X_1, X_2, \dots, X_{NC}$

**Step 11:** Determine the reduction in total real power loss and net saving by using objective function (Eq. 2).

**Step 12:** Print results.

**Step 13:** Stop.

### RESULTS AND DISCUSSION

The proposed method is illustrated with two radial distribution systems of 32 buses and 26 buses given below.

**Example:** Consider 32-bus practical radial distribution system in India. The line and load data is given in Appendix and also the single line diagram is shown in Fig. 2. First base case load flow study is carried out and then for optimization of branch conductor, four different types of conductors are used. The electrical properties of conductors are given in appendix.

A radial distribution system has several branches. When these branches are reconductored, it alters the flow of power and it changes the resulting power losses and

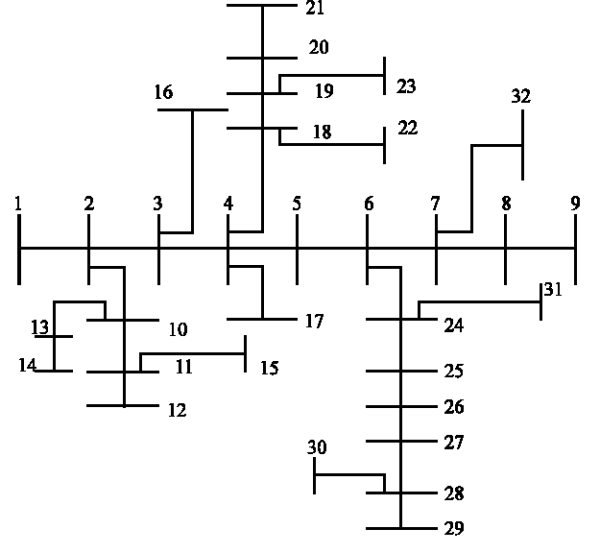


Fig. 2: Single line diagram of 32 bus RDS

Table 1: Comparison of results

	Minimum voltage (pu)	Real power loss (kW)	Total cost (Rs)
Base case	0.9825	25.4	90598
After conductor grading	0.9901	10.4	44004
Net power loss reduction after conductor grading = 15 Kw			
Net savings after conductor grading = Rs 46594			

Table 2: Modifications in the feeder conductor type after conductor grading

Branch no.	Existing feeder (from 8th year)	Modification (to 9th year)
10	3	4
13	3	2
14	2	4
15	3	2
19-20	2	3
22	2	3
27	2	3
28-29	1	2
31	3	2

voltage profile. The reconductored branches require capital investment. The proposed algorithm to select the best conductor type for each branch of the RDS, such that the resulting RDS requires the least reconductoring costs, yields the minimum power losses and gives best voltage profile.

The comparison of results for base case and after conductor grading are shown in Table 1.

**Optimal conductor selection for future growth:** If the load is varying in future, then the optimal conductor selection can be determined as follows:

$$P_L = P_{L0} \times (1 + g)^n \quad (9)$$

$$Q_L = Q_{L0} \times (1 + g)^n \quad (10)$$

Table 3: Summary of results after modification

	Base case			After conductor grading		
	Minimum voltage(pu)	Real power loss(kw)	Total cost(Rs)	Minimum voltage(pu)	Real power loss(kw)	Total cost(Rs)
n=8	0.9696	76.5	263060	0.9829	31.1	113770
n=9	0.9674	87.8	301490	0.9820	35.4	129130

Table A.1: Electrical properties of various conductors used for 11 kV distribution systems

S.No	Type of conductor	Resistance ( $\Omega \text{ km}^{-1}$ )	Reactance ( $\Omega \text{ km}^{-1}$ )	Area of cross section ( $\text{mm}^2$ )
1	Squirrel	1.3760	0.3896	12.90
2	Weasel	0.9108	0.3797	19.35
3	Rabbit	0.5441	0.3673	32.26
4	Raccon	0.3657	0.3579	48.39

Table A.2: Line data of 32 bus Practical RDS

Branch	Conductor type	From bus	To bus	Length (km)
1	Weasel	1	2	0.3837
2	Weasel	2	3	0.1936
3	Weasel	3	4	0.1428
4	Weasel	4	5	0.4231
5	Weasel	5	6	0.0968
6	Weasel	6	7	0.1944
7	Weasel	7	8	0.0133
8	Weasel	8	9	0.0511
9	Weasel	2	10	0.4477
10	Weasel	10	11	0.1080
11	Weasel	11	12	0.0222
12	Weasel	10	13	0.0802
13	Weasel	13	14	0.2268
14	Weasel	11	15	0.3379
15	Weasel	3	16	0.0140
16	Weasel	4	17	0.2065
17	Weasel	4	18	0.1396
18	Weasel	18	19	0.0450
19	Weasel	19	20	0.0866
20	Weasel	20	21	0.1761
21	Weasel	18	22	0.1322
22	Weasel	19	23	0.0265
23	Weasel	6	24	0.0514
24	Weasel	24	25	0.1392
25	Weasel	25	26	0.2538
26	Weasel	26	27	0.2426
27	Weasel	27	28	0.2443
28	Weasel	28	29	0.1979
29	Weasel	28	30	0.1006
30	Weasel	24	31	0.0964
31	Weasel	7	32	0.2045

Where

$P_L, Q_L$  = Real and reactive power load for n years

$P_{L0}, Q_{L0}$  = Real and reactive power load at base condition

n = number of years

g = growth rate at 7%

The results of modification in branch conductors for future load expansion for 32 bus RDS is shown in Table 2.

It is observed that, the optimal conductor selection is obtained by the proposed method is sufficient to maintain voltage profile and reduction in power loss up to 8 years. From 9<sup>th</sup> year the obtained optimal selection is not suitable to obtain maximum net savings, so, it is need to change some of the conductors by other type of conductors (Table 2).

Table A.3: Load data of 32 bus practical RDS

Bus no.	P(kW)	Q (kV Ar)
1	0	0
2	80	60
3	0	0
4	0	0
5	80	60
6	0	0
7	0	0
8	80	60
9	80	60
10	0	0
11	0	0
12	80	60
13	80	60
14	80	60
15	80	60
16	80	60
17	80	60
18	0	0
19	0	0
20	80	60
21	80	60
22	80	60
23	80	60
24	0	0
25	80	60
26	80	60
27	80	60
28	0	0
29	80	60
30	80	60
31	80	60
32	80	60

The summary of results after modification of the conductors is shown in Table 3.

It is observed from Table 3, the power loss reduction is reduced from 76.5 kW to 31.1 kW and net saving is increased to Rs.149290/- for the 8th year. Similarly for the 9th year the power loss reduction is 52.4 kW and net saving is increased to Rs 272360/- with minimum modifications in the selection of conductors.

## CONCLUSION

In this study, a novel method has been presented for selecting the optimal size of branch conductor using Fuzzy Evolutionary Programming. This method maintains the voltages at all buses of the RDS within the limits, therefore it results better voltage regulation. In addition the proposed algorithm reduces the total power losses, which maximize the net savings of the system. The proposed algorithm has been tested for several radial distribution networks and an example consisting of 32-bus system is presented. The results obtained in this method that there is a net saving in energy losses and cost of conductor with good voltage profile.

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