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# 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

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

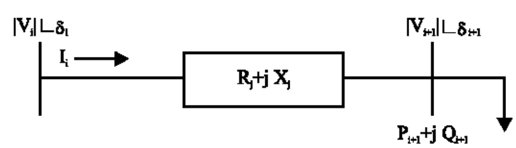


Fig. 1: Single line equivalent circuit

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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,

$$\text{Min. } F = Ploss_{(jj,k)}\,((K_p+K_e\times Lsf\times 8760)) + (a\times A_{(k)}\times cost_{(k)}\times len_{(jj)}) \quad (2)$$

Where,

$Ploss_{(jj,k)}$ = Real power loss of branch jj with k type of conductor in kW
$K_p$ = Aannual demand cost of power loss in Rs $kW^{-1}$
$K_e$ = Annual cost of energy loss in Rs. $kWh^{-1}$
Lsf = Loss factor = $0.8\times(Lf)^2+0.2\times Lf$
Lf = Load factor
$\alpha$ = Interest and depreciation factor
$A_{(k)}$ = Cross sectional area of k type of conductor in $mm^2$
$cost_{(k)}$ = Cost of k type conductor in Rs/ $mm^2$ /km
$len_{(jj)}$ = Length of branch jj in km

**Procedure to generate optimal set of conductor combinations:** Let the vector X= [$X_1$, $X_2$, $X_3$,….., $X_{NC}$ ] 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:

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

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

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

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$^{th}$ 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$^{th}$ interval be referred as $I^i_{VD}$ (X). In order to compute a voltage-deviation index value attributable to the entire solution X, the following is defined,

$$v(X) = \sum_{i=1}^{NL}\{I^i_{VD}(X)\} \quad (7)$$

Where
NL = Number of time intervals

Considering all the solutions [$X_1$, $X_2$, $X_3$,…., $X_{2NC}$ ] and evaluating them using Eq. (7) we obtain the corresponding voltage-deviation indices as [v($X_1$), v($X_2$), v($X_3$),…., 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 $X_1, X_2, \ldots, X_{NC}$

**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 $X_{NC+1}, X_{NC+2}, \ldots, X_{2NC}$ using Eq. (3)

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

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

**Step 9:** If K < Maximum go to step 4

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

**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 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.

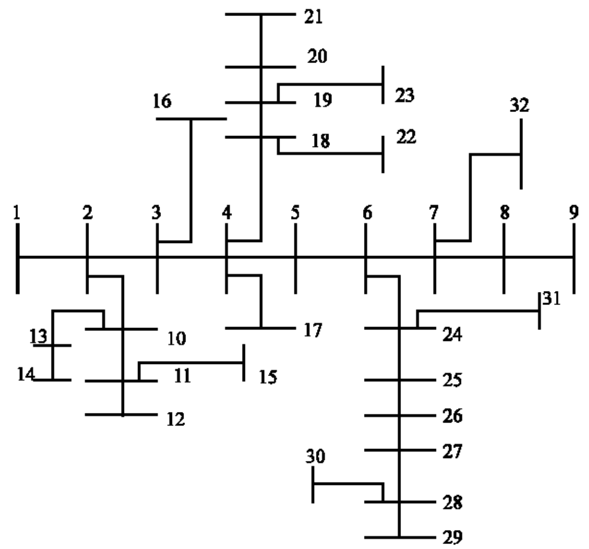


Fig. 2: Single line diagram of 32 bus RDS

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 |

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

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

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

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 ($\Omega$ km$^{-1}$) | Reactance ($\Omega$ km$^{-1}$) | Area of cross section (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$^{th}$ 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 h as 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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