# Capacitor Location and Size Determination to Reduce Power Losses of a Distribution Feeder by Firefly Algorithm

Meysam soleymani, Sadegh soleymani, Hadi Zayandehroodi, Mahdiyeh eslami, Alimorad khajehzadeh

**Abstract-** Increasing application of capacitor banks on distribution networks is the direct impact of development of technology and the energy disasters that the world is encountering. To obtain these goals the resources capacity and the installation place are of a crucial importance. Line loss reduction is one of the major benefits of capacitor, amongst many others, when incorporated in the power distribution system. The quantum of the line loss reduction should be exactly known to assess the effectiveness of the distributed generation. In this paper, a new method is proposed to find the optimal and simultaneous place and capacity of these resources to reduce losses, improve voltage profile too the total loss of a practical distribution system is calculated with and without capacitor placement and an index, quantifying the total line loss reduction is proposed. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on actual power network of Kerman Province, Iran and the simulation results are presented and discussed.

**Keywords-** Distribution systems, Loss reduction index, Capacitor placement, Firefly Algorithm

## 1. Introduction

The loss minimization in distribution systems has assumed greater significance recently since the trendtowards distribution automation will require the most efficient operating scenario for economic viabilityvariations. The power losses in distribution systems correspond to about 70% of total losses in electricpower systems (2005).To reduce these losses, shunt capacitor banks are installed on distribution primaryfeeders. The advantages with the addition of shunt capacitors banks are to improve the power factor, feedervoltage profile, Power loss reduction and increases available capacity of feeders. Therefore it is importantto find optimal location and sizes of capacitors in the system to achieve the above mentioned objectives.Since, the optimal capacitor placement is a complicated combinatorial optimization problem, manydifferent optimization techniques and algorithms have been proposed in the past. Alavi, A.H. and Gandomi, A.H. (2011)proposed Firefly algorithms for multimodal optimizationYang XS (2009) proposed Firefly algorithms for multimodal optimization. In: Stochastic algorithms. However, considered only the losses in the lines and the quantification were defined for the line losses only. These indices, therefore, do not indicate the loss reduction of the system itself. A practical distribution system consists of several distribution transformers, supplying consumers at low voltage on the secondary side. The losses occurring in these transformers and the line losses of the secondary low voltage distribution system should also be considered to arrive at the overall loss reduction of the system.

In this paper, a new method is proposed to find the optimal and simultaneous place and capacity of these resources to reduce losses, improve voltage profile too the total loss of a practical distribution system is calculated with and without capacitor placement and an index, quantifying the total line loss reduction is proposed. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on actual power network of Kerman Province, Iran and the simulation results are presented and discussed.

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## 2. Objective Function

The objective of capacitor placement in the distribution system is to minimize the annual cost of the system, subjected to certain operating constraints and load pattern. For simplicity, the operation and maintenance cost of the capacitor placed in the distribution system is not taken into consideration. The three-phase system is considered as balanced and loads are assumed as time invariant. Mathematically, the objective function of the problem is described as:

$$Minimize f = Min\ (COST)$$

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Where cost includes the cost of power loss and the capacitor placement. The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$V_{min} \leq |V_i| \leq V_{max}$$

Where│Vi│ is the voltage magnitude of bus i, $V_{min}$ and $V_{max}$ are bus minimum andmaximum voltagelimits, respectively.

## 3. Formulation

The power flows are computed by the following set of simplified recursive equations derived from thesingle-line diagram depicted in Figure. 1.

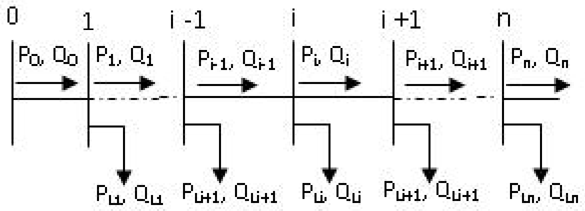


Figure 1: Single line diagram of main feeder

$$P_{i+1} = P_i - P_{Li+1} - R_{ij+1}\frac{P_i^2 + Q_i^2}{|V_i|^2}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{ij+1}\frac{P_i^2 + Q_i^2}{|V_i|^2}$$

$$|V_i|^2 = |V_i|^2 - 2(R_{ij+1}P_i + X_{ij+}Q_i) + (R_{ij+1}^2 + X_{ij+1}^2) \times \frac{P_i^2 + Q_i^2}{|V_i|^2}$$



Where Pi and Qi are the real and reactive powers flowing out of bus i, and $P_{Li}$and $Q_{Li}$are the real andreactive load powers at bus i. The resistance and reactance of the line section between buses i and i+1 aredenoted by $R_{i,i+1}$and $X_{i,i+1}$respectively.The power loss of the line section connecting buses i and i+1 may be computed as

$$P_{Loss}(i, i+1) = R_{i,i+1}\frac{P_i^2 + Q_i^2}{|V_i|^2}$$

The total power loss of the feeder,$P_T^{LOSS}$ may then be determined by summing up the lossesof all line sections of the feeder, which is given as

$$P_T^{LOSS} = \sum_{i=0}^{n-1} P_{LOSS}(i, i+1)$$

Considering the practical capacitors, there exists a finite number of standard sizes which are integermultiples of the smallest size Q0c. Besides, the cost per Kvar varies from one size to another.In general, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to

$$Q_c^{max} = LQ_c$$

Therefore, for each installation location, there are L capacitor sizes {1$Q_C$, 2$Q_c$, 3$Q_c$, …, LQc} available. Given the annual installation cost for each compensated bus, the total cost due to capacitorplacement and power loss change is written as

$$COST = K_p \times P_T^{LOSS} + \sum_i^c (K_{cf} + K_i^c Q_i^c)$$

Where n is number of candidate locations for capacitor placement, Kp is the equivalent annual cost perunit of power loss in $/(Kw-year); $K_{cf}$is the fixed cost for the capacitor placement. Constant $K_i^c$is the annual capacitor installation cost, and, i = 1, 2, ..., n are the indices of the buses selected forcompensation. The bus reactive compensation power is limited to

$$Q_i^c \leq \sum_{i=1}^{n} Q_{Li}$$

Where1$Q_c$and L$Q_c$are the reactive power compensated at bus i and the reactive load power at bus i,respectively.

## 4. Power Flow Analysis Method

The methods proposed for solving distribution power flow analysis can be classified into three categories: Direct methods, Backward-Forward sweep methods. The Backward-Forward Sweep method is an iterative means to solving the load flow equations of radial distribution systems which has two steps. The Backward sweep, which updates currents using Kirchoff's Current Law (KCL), and the Forward sweep, which updates voltage using voltage drop calculations [5].

The Backward Sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus. These calculated currents are stored and used in the subsequent Forward Sweep calculations. The calculated source voltage is used for mismatch calculation as the termination criteria by comparing it to the specified source voltage. The Forward Sweep calculates node voltages as a function of the currents injected into each bus. The Forward Sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in previous the Backward Sweep [5]. Figure 2 is flowchart t Backward-Forward sweep methods.

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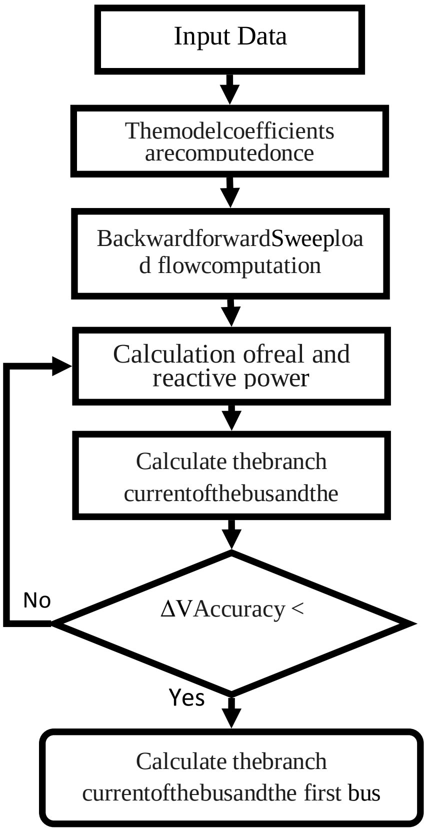


Figure 2: Single line diagram of main feeder

## 5. Firefly Algorithm

The firefly algorithm has three particular idealized rules which are based on some of the major flashing characteristics of real fireflies. These are the following [15]:

1) All fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex.

2) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a brighter or more attractive firefly than a particular one, it will then move randomly.

3) The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. For maximization problems, the light intensity is proportional to the value of the objective function.

### 5.1. Attractiveness

In the firefly algorithm, the form of attractiveness function of a firefly is the following monotonically decreasing function:

$$B_r = B_O * \exp(-\gamma_{ij}^m)$$

where, r is the distance between any two fireflies, β0 is the initial attractiveness at r equal 0, and γ is an absorption coefficient which controls the decrease of the light intensity.

### 5.2. Distance

The distance between any two fireflies i and j, at positions xi and xj respectively, can be defined as a Cartesian or Euclidean distance as follows:

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d} (x_{i.k} - x_{j,k})^2}$$

Where xi,k is the kth component of the spatial coordinate xi of the ith firefly and d is the number of dimensions, for d = 2, we have:

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

However, the calculation of distance r can also be defined using other distance metrics, based on the nature of the problem, such as Manhattan distance or Mahalanobis distance.

### 5.3. Movement

The movement of a firefly i which is attracted by a more attractive (brighter) firefly j is given by the following equation:

$$X_i = X_i + \beta \; * \exp(-\gamma_{ij}^2) * (x_i - x_j) + a * \left(rand - \frac{1}{2}\right)$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies, and the third term is used for the random movement of a firefly in case there are not any brighter ones. The coefficient $\alpha$ is a randomization parameter determined by the problem of interest, while rand is a random number generator uniformly distributed in the space [0, 1]. As we will see in this implementation of the algorithm, we will use 0 β =1.0, $\alpha \in [0, 1]$ and the attractiveness or absorption coefficient γ=1.0, which guarantees a quick convergence of the algorithm to the optimal solution [16].

## 6. Application of the Firefly Algorithm

The results of FA are compared with those obtained by the Genetic algorithm [10]. The process of incorporating the firefly algorithm for solving the optimal capacitorplacement and sizing problem is shown in Figure 3the FA properties in this simulation are set as follow [17]:

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Number of fireflies: 20

Maximum iteration: 30

Number of capacitor: 1- 5

Capacitor size: 0.01 MVAR<Q< 2.5 MVAR

Alpha (scaling parameter): 0.25

Minimum value of beta: 0.2

Gamma (absorption coefficient): 1

The following three cases to study the impact of capacitor installation on the system performance are considered:

Case 1: Calculate the distribution network losses and minimum voltage without capacitor.

Case 2: Calculate the distribution network losses and minimum voltage with the 1capacitor included once its optimal location and size is determined.

Case 3: Calculate the distribution network losses and minimum voltage with the 5 capacitor included once its optimal location and size is determined.

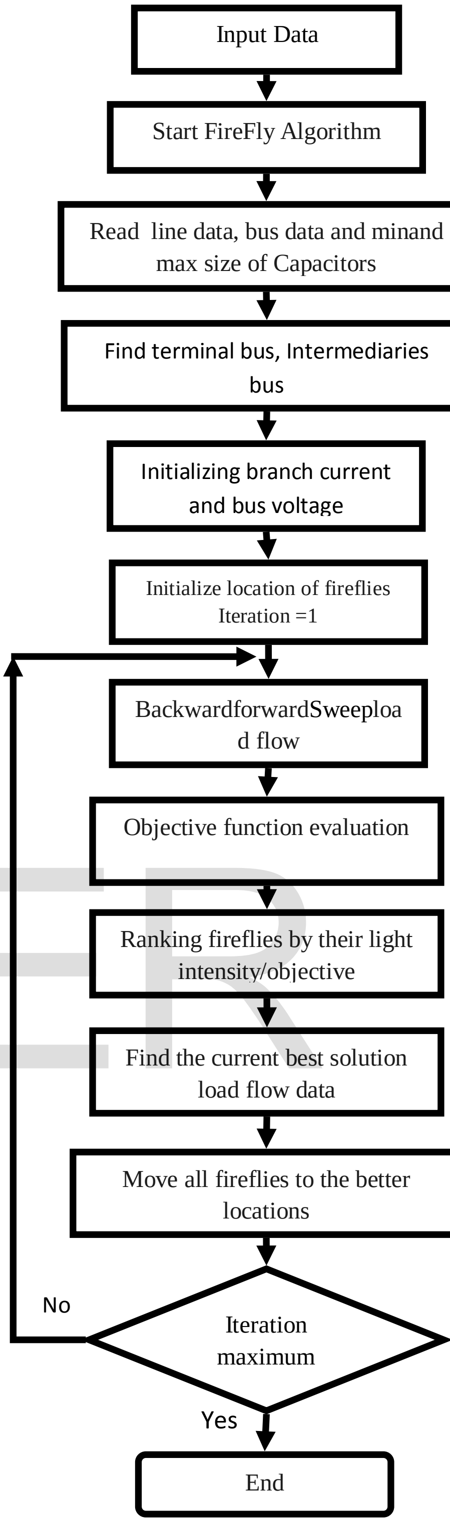


Figure 3: Flow of Optimal Allocation of DG using Firefly Algorithm

## 7. Test Results

To study the proposed method, actual power network of Kosar feeder of Kerman Province, Iran is simulated in Cymedist. Figure4 illustrates the single-line diagram of this network.The base values of the system are taken as 20kV and 20MVA. The system consists of 20 distribution transformers with various ratings. The details of the distribution transformers are given in table 1. The details of the distribution conductors are given in table 2. The total connected load on the system is 2550 KVA and the peak demand for the year is 2120 KVA at a PF of 0.8 lag. The connected loads on the transformers are listed in table3.

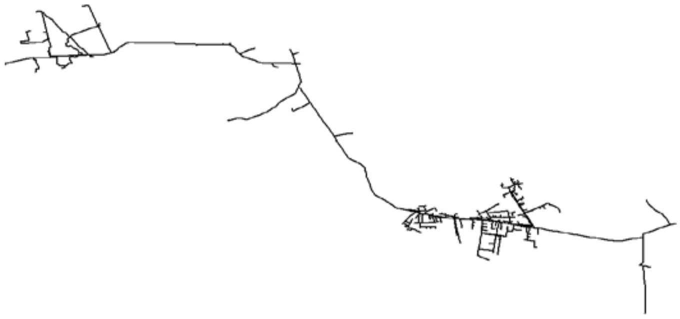

Figure 4: Single-line diagram of actual power network of Kosar feeder of Kerman Province

Table 1: Details of transformers in the system

| Rating [KVA] | 50 | 100 | 250 |
|---|---|---|---|
| Number | 5 | 9 | 6 |
| No load losses [watts] | 150 | 250 | 480 |
| Impedance [%] | 4.5 | 4.5 | 4.5 |

Table 2: Details of conductors in the system

| Type | R [Ω/km] | X [Ω/km] | Cmax [A] | A [mm2] |
|---|---|---|---|---|
| Hyena | 0.1576 | 0.2277 | 550 | 126 |
| Dog | 0.2712 | 0.2464 | 440 | 120 |
| Mink | 0.4545 | 0.2664 | 315 | 70 |

Table 3: Details of the connected loads

| Transformer no | Load [Kva] |
|---|---|
| 1 | 35 |
| 2 | 245 |
| 3 | 85 |
| 4 | 165 |
| 5 | 50 |
| 6 | 85 |
| 7 | 180 |
| 8 | 35 |
| 9 | 35 |
| 10 | 90 |
| 11 | 85 |
| 12 | 75 |
| 13 | 200 |
| 14 | 73 |
| 15 | 35 |
| 16 | 85 |
| 17 | 98 |
| 18 | 230 |
| 19 | 220 |
| 20 | 85 |

Initially, a load flow was run for the case study in both fundamental frequency and harmonics frequencies without installation of capacitor. Table 4 depicts the locations and capacity of capacitor banks using Firefly Algorithm. As it is clear, all the obtained values confines with all the considered constraints. The obtained penetration lever is 0.27, which is less than the assumed allowable value.

Table 4: Optimal place and capacity of capacitor banks

| Location [#bus] | Capacity [Mvar] |
|---|---|
| 19 | 1000 |
| 18 | 800 |
| 16 | 1000 |

The detailed pu voltages profileof allthe nodes of the system before and after capacitor placement are shown in the Figure 5.These results reveal that the inclusions of capacitor reduce the line losses as expected. It can be shown from the graphs that, LRI decreases marginally, since the core losses of the transformers and the LV side losses remain constant being independent of the presence of v. It can also be seen that with the increase in the reactive power of capacitor, LRI, decrease.



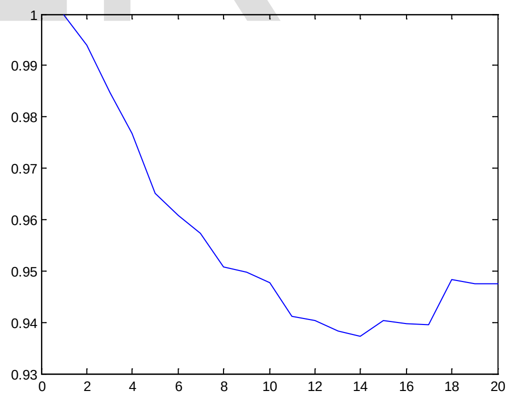


Figure5: Voltage profile of 20 bus system before and after capacitor placement

## 8. Conclusion

In the present paper, a new population based Firefly Algorithmhas been proposed tosolve capacitor placement problemand quantifying the total line loss reduction in distribution system. Simulations are carried onactual power network of Kerman Province, Iran.The simulation results show that the inclusion of capacitor, marginally reduce the losses in a distribution system. This is because; the line losses form only a minor part of the distribution system losses and the capacitor can reduce only the line losses. The other losses viz. the transformer losses and the LV side distribution losses remain unaltered. Hence this fact should be considered before installing a capacitor into a system. The results obtained by the proposed method outperform the other methods in terms of quality of the solution and computation efficiency.

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