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# Improvement of Voltage Profile using Shunt Capacitor in Radial Distribution System by Flower Pollination Algorithm and Sensitivity Analysis

**Priyanka Das[1] and Manoj Kumar[2]**

*[1]Department of Electrical Engineering, JJTU, Rajasthan, India*
*[2]Department of Electrical Engineering KKCEM,Dhanbad, India*
*E-mail: [1]bcet.priyanka1989@gmail.com, [2]mk5272@gmail.com*

**Abstract—***Shunt capacitors are one of the reliable options for loss minimization and also for voltage profile improvement in a distribution system. Minimization of active power loss enhances the overall efficiency of power system. In a radial distribution system placing the shunt capacitor at the optimal location is very important and to find that optimal locations is another important task. This article presents a method of reducing the loss by placing shunt capacitors. In this paper a two stagemethod has been proposed for optimal allocation of capacitor in a radial distribution system.In first stage loss sensitivity factor is used to calculate the location and secondly the flower pollination algorithm is used for cost minimization including capacitor cost and cost due to power loss. The proposed method is tested on 33-bus and 69-bus system and results are given below.*

**Keywords***: Flower pollination algorithm, Loss sensitivity factor, Radial distribution system, Shunt capacitors.*

## 1. INTRODUCTION

Like food, water and shelter, electricity has also become part and parcel of life. No one can imagine living without electricity now a day. India is a country with huge population and electricity is needed to all. Because of this the load demand is also increasing and if the load will increase it will make the distribution system more complex and complicated,due to increase in loads it tends to increase the systems losses and due to that reason the voltage profile is decreasing. At heavily loaded conditions the reactive power flow causes significant losses and also causes reduction in voltage level.So to keep the voltage at required level and to minimize the system's loss it is the duty of an electrical engineer to perform his/her duty in such a way that these objective of loss minimization and voltage profile improvement can be fulfilled.So to increase the voltage profile and to reduce the power loss the use of shunt capacitor is the best option as it provides reactive compensation. The shunt capacitor should be optimally sized and placed that it should be able to reduce the power loss and can enhance the voltage profile of the system. Minimization of loss not only increases the life span of the distribution network but also the reliability of the system. Optimal allocation of capacitor deals with the appropriate location where the capacitor to be placed, type of the capacitor, size of the capacitor and the total number of the capacitor that should be placed so that the total cost should be minimized without violating the operational constraints. With the development in optimization many research work has been done on this topic. Numerous optimization techniques have been used by researchers to optimally allocate the capacitor in a radial distribution system. They are classified into four groups, analytical methods, numerical programming methods, heuristic methods and meta-heuristic methods. The early proposed approaches are the analytical numerical programming techniques like local variation methods[1]and mixed integer linear programming techniques [2,3] have been introduced for solving the problem of capacitor sizing and allocation. In recent years, the most popular meta- heuristic approaches have been introduced for the VAr planning problem study. The authors who used meta-heuristics methods we find, Huang et al. [4] They have solved the capacitors optimal placement using an immune multi-objective algorithm. They have modeled the objective functions by fuzzy logic (FL).The method provides us a set of feasible solutions. Bhattacharya and coauthors [5] have introduced a FL-based simulated annealing (SA) method to find the optimal sizes of capacitor. Using FL the suitable locations are identified and their sizes are obtained using SA by Prakash et al. [6] have also used a hybrid method where the capacitor suitable places are determined by means of loss sensitivity factors.The optimal sizes, considered as continuous variables, are determined using particle swarm optimization (PSO) algorithm. To determine the fixed and switched capacitor sizes, Das [7] has suggested a genetic algorithm (GA) based

FL approach to maximize the net savings and minimize node voltage deviations. The two objectives are first fuzzified and integrated into a fuzzy global objective function through appropriate weighting factors. The weighting factors are optimized by GA. On the other hand, Seifi et al. [8] in their FL–GA hybrid technique have used the fuzzy reasoning to find the best capacitor locations and GA, for finding the optimal weightingfactors of the voltage and the power losses exponential membership functions. The capacitor optimal size is that, among the available standard capacitors, giving the best objective function. Abdelaziz et al. [9] have proposed a method based on fuzzy expert systems to select the best candidate nodes for receiving capacitors in order to maximize the power loss reduction and total net savings. For the total power loss minimization they have determined the optimal locations and tapping ratio for voltage regulator.

## 2. MATHEMATICAL PROBLEM FORMULATION

Here the main objective is to minimize the total cost due to real power loss and capacitor installation.To solve the capacitor placement and sizing problem the following objective function has been taken.

$$\text{minf}=\min(\text{COST}) \quad (1)$$

where COST isthe objective function which includes the cost of power loss and capacitor placement. The voltage magnitude at each bus must be maintained within its limit and can be expressed as

$$V_{min} \leq |V_i| \leq V_{max} \quad (2)$$

Where $|V_i|$ is the voltage magnitude at bus i and $V_{min}$ and $V_{max}$ are the minimum and maximum voltage limits respectively.For the calculation of power flows the following sets of simplified recursive equations which are derived from single line diagram are shown in fig 1.

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1} \cdot \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \quad (3)$$

$$Q_{i+1} = Q_i - Q_{i+1} - X_{i+1} \cdot \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \quad (4)$$

Where $P_i$ and $Q_i$ are the real and reactive power flowing out of bus i,$P_{Li}$and$Q_{Li}$are the real and reactive load powers at bus i. The resistance and reactance of the line section between bus i and i+1 are denoted by $R_{i,i+1}$ and $X_{i,i+1.}$

The power loss of the line section connecting the buses i and i+1 may be calculated as:

$$P_{LOSS}(i,i+1)=R_{i,i+1} \cdot \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \quad (6)$$

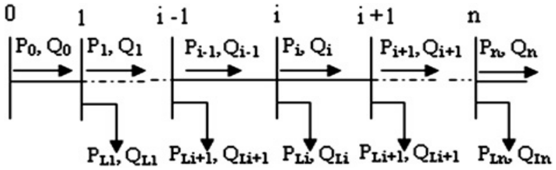



**Fig. 1: Singleline diagram ofmain feeder.**

The total power loss of the feeder $P_{T,LOSS}$can be computed by summing up the losses of all the line sections of the feeder, and given as

$$P_{T,LOSS}=\sum_{i=1}^{n} P_{LOSS}(i, i+1) \quad (7)$$

The total cost due to capacitor placement and power loss change is given by:

$$\text{COST}=K_p \cdot P_{T,LOSS}+\sum_{i=1}^{n}(K_{cf} + K_i^c Q_i^c) \quad (8)$$

Where n is the number of candidate locations for capacitor placement.$K_p$ is the equivalent annual cost per unit of power loss in Rs/( kW year ); $K_{cf}$ is the fixed cost for the capacitor placement. The constant $K_i^c$ is the annual capacitor installation cost, and, i = 1, 2, . . . , n are theindices of the buses selected for compensation.$K_p$= Rs10749.71/(kW year) and $K_{cf}$= Rs 63986.4 are taken.

### 2.1 Constraints

Each capacitor size minimizing the objective function, must verify the equality and inequality constraints. Two inequality constraints are considered here for capacitor placement that must be satisfied are as such:

$$\text{(a)} V_{min} \leq |V_i| \leq V_{max} \quad (9)$$

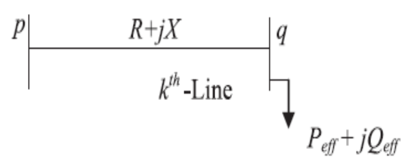
(b) Capacitors are available in discrete sizes. So, shunt capacitorsare to be deal with multiple integers of the smallest capacitorsize available and it may mathematically be expressed as:

$Q_{ci} \leq LQ_s$(10)where L is an integer from 1,2,3…nc. And nc is number of shunt capacitors, $Q_{ci}$ is the kVAR rating of capacitor installed at the $i^{th}$ bus and $Q_s$ smallest capacitor size available.

### 2.2 Sensitivity Analysis and Loss Sensitivity Factors

By using loss sensitivity factors the candidate nodes for the capacitor placement is determined. By estimation of these candidate nodes it helps in the reduction of search space for optimization problem.Considering a distribution linewith an impedance R+jX and a load $P_{eff}$ and $Q_{eff}$ connected between buses p and qis given by.

$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i,i+1} \cdot P_i + X_i$




Active power loss can be given by in (3) is rewritten for $k^{th}$ line between buses p and q as

$$P_{lineloss}[q]=\frac{(P_{eff}^2[q]+Q_{eff}^2[q])R[k]}{(V[q])^2} \quad (11)$$

Similarly the reactive power loss in the $k^{th}$ line is given by

$$Q_{lineloss}[q]=\frac{(P_{eff}^2[q]+Q_{eff}^2[q])X[k]}{(V[q])^2} \quad (12)$$

Where $P_{eff}[q]$ = Total effective active power supplied beyond the node 'q'.$Q_{eff}[q]$= Total effective reactive power supplied beyond the node 'q'.

Both the loss sensitivity factor can be given as:

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = 2 * \frac{Q_{eff}[q] * R[k]}{V[q]^2} \quad (13)$$

$$\frac{\partial Q_{lineloss}}{\partial Q_{eff}} = 2 * \frac{Q_{eff}[q] * X[k]}{V[q]^2} \quad (14)$$

**2.3 Candidate node selection using loss sensitivity factors**

The Loss Sensitivity Factors ($\frac{\partial P_{lineloss}}{\partial Q_{eff}}$) are calculated from the base case load flows and the values are arranged in descending order for all the lines of the given system. A vector bus position 'bpos[i]' is used to store the respective 'end' buses of the lines arranged in descending order of the values ($\frac{\partial P_{lineloss}}{\partial Q_{eff}}$).The descending order of ($\frac{\partial P_{lineloss}}{\partial Q_{eff}}$) elements of ''bpos[i]' vector will decide the sequence in which the buses are to be considered for compensation. This sequence is purely governed by the ($\frac{\partial P_{lineloss}}{\partial Q_{eff}}$) and hence the proposed 'Loss Sensitive Coefficient' factors become very powerful and useful in capacitor allocation orPlacement.At these buses of 'bpos[i]' vector, normalized voltage magnitudes are calculated by considering the base case voltage magnitudes given by (norm[i]= V[i]/0.95). Now for the buses whose norm[i] value is less than 1.01 are considered as the candidate buses requiring the Capacitor Placement. These candidate buses are stored in 'rank bus' vector. It is worth note that the 'Loss Sensitivity factors' decide the sequence in which buses are to be considered for compensation placement and the 'norm[i]' decides whether the buses needs Q-Compensation or not. If the voltage at a bus in the sequence list is healthy (i.e. norm[i]>1.01) suchbus needs no compensation and that bus will not be listed in the'rank bus' vector. The 'rank bus' vector offers the information about the candidate bus.

## 3. FLOWER POLLINATION ALGORITHM

The various characteristics of pollination process, flower constancy and pollinator behavior can be idealized by the following rules:

1. The global pollination process that has been considered here is Biotic and cross-pollination with pollen-carrying pollinators performsL´evy flights when they travels.
2. For the process of local pollination, A-biotic and self-pollination has been considered.
3. The constancy of the flower can be treated as the probability of reproduction and is proportional to the similarity of two flowers that are involved.
4. Switch probability p € [0, 1] controls the both local pollination process and global pollination process.

Because ofthe physical proximity and the factors like wind, local pollination can have a significant fraction p in the overall pollination activities. In the real scenario, each plant can have multiple flowers, and billions of pollen gametes have been released every time by each flower patch. For simplification, we may consider that each plant only has one flower, and each flower only produce one pollen gamete. Thus, we have no need to distinguish a pollen gamete, a flower, a plant or solution to a problem. The meaning of this simplification is that solution $X_i$ is equivalent to a flower and/or a pollen gamete. In future there is a scope to apply the above algorithm to multiple pollen gametes for each flower and multiple flowers for multiobjective optimization problems. All the idealized characteristicsand the discussions that have been done we can design an algorithm which based on thepollination of flowers, called as flower pollination algorithm (FPA). The two basic steps of this algorithm are;

(i) Global pollination

(ii) Local pollination.

In the process of global pollination, the pollinators such as insects carries the pollens,and pollens can travel over a long distance because insects can often fly long distance and can move to longer range. This ensures the pollination and reproduction of the fittest, and we represent the fittest as $g_*$.

The first rule and flower constancy can be given as

$$X_i^{t+1} = X_i^t + L(X_i^t - g_*) \quad (15)$$

where$X_i^t$ is the pollen i or solution vector $X_i$ at iteration t, and $g_*$ is the current best solution found among all solutions at the current generation/iteration. The parameter L is the strength of the pollination, which essentially is a step size. The movement of insects may be over a long distance with various distance steps, a L´evy flight can be used to mimic this characteristic efficiently [10, 11]. That is, we draw L > 0 from aL'evy distribution

$$L = \frac{\lambda \Gamma(\lambda) \sin\left(\frac{\Pi\lambda}{2}\right)}{\Pi} 1/s^{1+\lambda} \ (s \gg s0 > 0). \quad (16)$$

Here $\Gamma(\lambda)$ is the standard gamma function, and this distribution is valid for large steps s > 0.Here the value of $\lambda$ = 1.5. The (Rule 2) of local pollination and flower constancy can be given as

$$X_i^{t+1} = X_i^t + €(X_j^t - X_k^t) \quad (17)$$

where$X_j^t$ and $X_k^t$are pollens from the different flowers of the same plant species. This essentially mimics the flower constancy in a limited neighborhood. Mathematically, if $X_j^t$ and $X_k^t$ comes from the same species or selected from the same population, this become local random walk if we draw € from a uniform distribution in [0,1].

## 4. PROPOSED OPTIMAL CAPACITOR PLACEMENT METHODOLOGY

Here in this proposed method the FPA is applied as an optimization technique to determine the optimal size of the capacitor at the buses. Power flow is used for the computation of power loss. The procedures for implementation of the proposed optimal capacitor placement method has been described in two stages are as follows:

**Determination ofcandidatelocation**

Step1: Input all the parameters like line data and load data.

Step2: Run the load flow as explained above by using set of simplified recursive equation.

Step3: Calculate the loss sensitivity factor.

Step4: Select the buses whose norm[i] value is less than 1.01 as candidate location.

**Optimization using flower pollination Algorithm**

Step1:Runthe load flow program and find the total power loss Ploss1 of the original system (before capacitor placement)

Step2:Randomly generate “n” number of flowers,where each flower is represented as$X[i]=\{Q_{c1},Q_{c2},\ldots,Q_{cj}\}$Where ’j’ represents number of candidate buses or potential buses and find best solution g* in the initial population by running load

Flow for each X[i].

Step3: Compute the capacitor cost.

Step4: Compute the total cost (fitness function) using equation (8)

Step5: By placing all the ‘n’ number of capacitors at the respective optimal capacitor locations, and run the load flow program to find total power losses Ploss2 after placement.

Step6: Define switching probability p€ [0, 1]

Step7: Start the Iteration.

Step8: Choose random number between [0,1].

Step9: Draw a step vector L from L’evys distribution and update flower solution by equation (15)and (16).

Step10: Randomly choose j and k solutions from existing solutions and update solution by $X_i^{t+1}=X_i^t+ €(X_j^t- X_k^t)$.

Step11: Run the load flow with updated $X_{values}$.If power loss is less than previous iteration, update flower ($Q_c$ values) , if not keep old values as solutions.

Step12: Find current best objective function so far.

Step13: Increment iteration count and if the iteration count is not reached go to step 8.

Step14: Repeat the procedure till end of iterations and get the value of the best objective function.

## 5. RESULT

Loss sensitivity factor is used to calculate the candidate location for the capacitor placement and FPA is used to find the optimal capacitor size. Inthis work,Number of iterations = 100, number of flowers= 20, $Q_{cmin}$=150kVAR,$Q_{cmax}$=2200kVAR

### 5.1. Results of 33-bus system

FPA is applied on 33-bus system and the desired results are found.Optimal capacitor locations are identifiedbased on the Loss sensitivity factor values. For this 33-bus system, one optimal location is identified. Capacitor size in that optimal location, total real power losses before and aftercompensation,voltage profile before and after compensation and total annual cost before and after compensation are shown below.

**Table 1**

| BUS NO; | 6 |
|---|---|
| CAPACITOR SIZE in ( kVAR) | 1905 |
| TOTAL REAL POWER LOSS in(kW) before compensation. | 201.8588 |
| TOTAL REAL POWER LOSS in (kW) after compensation. | 153.4788 |
| VOLTAGE IN P.U at bus number 6 before compensation. | 0.9499 |
| VOLTAGE IN P.U at bus number 6 after compensation | 0.9686 |
| TOTAL ANNUAL COST before compensation | Rs2596159.879 |
| TOTAL ANNUAL COST after compensation | Rs1736633.767 |
| LOSS REDUCTION | 48.38 |
| LOSS REDUCTION % | 23.9672% |

### 5.2. Results of 69-bus system

FPA is applied on 69-bus system and the desired results are found. Optimal capacitor location is identified based on the Loss sensitivity factor values. For this 69-bus system, one optimal location is identified. Capacitor sizes in that optimal location, total real power losses before and after compensation,voltage profile before and after compensation, total annual cost before and after compensation is shown below.

**Table 2**

| BUS NO; | 61 |
|---|---|
| CAPACITOR SIZE in ( kVAR) | 1831 |
| TOTAL REAL POWER LOSS in(kW) before compensation | 224.5407 |
| TOTAL REAL POWER LOSS in (kW) after compensation | 157.9910 |
| VOLTAGE IN P.U at bus number 6 before compensation | 0.9133 |
| VOLTAGE IN P.U at bus number 6 after compensation | 0.9364 |
| TOTAL ANNUAL COST before compensation | Rs2413748.09 |

| | |
|---|---|
| TOTAL ANNUAL COST after compensation | Rs1786596.268 |
| LOSS REDUCTION | 66.5497 |
| LOSS REDUCTION % | 29.6381% |

## 6. CONCLUSION

Here in this paper a two- stage method has been used to solve the capacitor placement problem. Here Loss Sensitivity Factor and FPA which is successfully applied for capacitor placement. By the installation of shunt capacitor at the optimal position there is a significant decrease in power loss, decrease in total annual cost and increase in voltage profile.So the combination of both Loss sensitivity factor and FPA provides good results.

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