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# Voltage Profile Improvement using Distributed Generation in 33-bus and 69-bus RDS by Flower Pollination Algorithm and Sensitivity Factor

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**Abstract—***In distribution systems minimization of active power loss is very essential to raise the overall efficiency of power system. This article presents a method of reducing the loss by placing distribution generation. In this paper a two stage methods have been proposed for optimal allocation of distribution generation in a radial distribution system. In first stage loss sensitivity factor is used to calculate the location and secondly the flower pollination algorithm is to find the optimal size of distribution generation .The proposed method is tested on 33-bus and 69-bus system and results are obtained by simulation.*

**Keywords***: Flower pollination algorithm, Loss sensitivity factor, Radial distribution system, Distributed generation.*

## 1. INTRODUCTION

Nature has provided a huge source of renewable energy like wind, sun, water and many more. In few decades' population has grown very fast thus need and demand of conventional sources energy has also grown sharply and because of this high need the conventional sources is decaying day by day. So, use of DG from renewable energy to produce electricity can be a good option. As the population is increasing, the need of electricity is also increasing thus increasing the load demand, and making the distribution system more complicated and complex.

System losses are also increasing due to rapid increase in load demand and hence voltage profile is decreasing badly. The main power plants on which a huge population depends is thermal, nuclear and hydro. But due to large dependencies on these plants, the fossil fuels and the sources of energy like coal, petroleum etc. is diminishing. The other renewable sources like wind and solar is becoming an alternative source for those non-renewable sources. Day to day they are becoming more economical and technical. They are having ratings of few MWs. These small power plants can be connected to the primary distribution network and can be placed very close to consumers, so it is known as distributed generation, dispersed generation or decentralized generation. Development of various optimization techniques has helped the researchers to work on this topic of placement of distributed generation. The problem associated with distribution network planning is to determine the capacity and location of DG. Various research works has already been done in the field of DG placement. Such as genetic algorithm, tabu search, analytical based methods [1], heuristic algorithms [2] and metaheuristic algorithms developed based on the swarm intelligence in nature like PSO, AFSA [3] and SFLA [4]. Willis [5] developed ''2/3 rule''which is related to optimal capacitor location, for finding an ideal bus for DG location. Due to these assumptions its applicability is limited to radial distribution systems and for that reason it is only suitable for one DG planning. Wang and Nehrir employed an analytical method to find the optimal DG location in distribution systems with different load topologies while the main objective of that was to minimization of real power losses. In the research, the DG units were assumed to have unit power factor, and the overhead lines with neglected shunt capacitance are studied [6]. Popovic et al. [7] applied sensitive analysis that was based on the power flow equations for locating and sizing of DGs. In all of the buses two indices were used for suitable locating the DGs. Iyer et al. [8] employed the primal–dual IP method for finding optimal DG location by using both line loss reduction and voltage profile improvement indices. However, the method was based on initial location of DGs at all of the buses in order to determine DGs proper placements. For large scale systems this method may not be realistic. Rau and Yih-Heui [9] used the generalized reduced gradient method for DG sizing problem. They have used this method for minimizing the system losses. In this proposed method, only the power flow constrains taken, whereas the inequality constraints and the boundary conditions were studied. Teng et al. [10] employed a value-based approach for locating the DGs'. The GA method was used in maximizing DG's benefit cost ratio index which its boundary is determined with voltage drop and feeder transfer capacity. Falcao and Borges[11] utilized the metaheuristic method for solution of single and multiple DG sizing and locating problems. They used the GA method to maximize a DG benefit to total cost ratio index. Pluymers et al. [12] employed the GA method for optimum solution of DG's related problems. They used a photo voltaic model for DG modeling. The objective function that was taken into consideration was ratio index from maximizing benefit of DG to total cost. Moradi and Abedini [13] utilized the hybrid technique in solving multiple DG sizing and locating, to find optimal DG location through combined losses reduction, voltage profile improvement and increasing the voltage stability within the framework of system and security constraints in network systems. In this method they have used both GA and PSO, the GA for locating and particle swarm optimization (PSO) for sizing the DGs [14].

## 2. PROBLEM FORMULATION

Here the main objective is to minimize the total power loss and to improve voltage profile. To solve the DG placement and sizing problem the following objective function has been taken.

$$\text{Minimize}S_{LOSS} = \sum_{i=1}^{n}(P_{LOSS} + Q_{LOSS}) \quad (1)$$

Voltage magnitude at each bus must be maintained within its limit and can be expressed as

$$V_{min} \le |Vi| \le V_{max} \quad (2)$$

Where $|Vi|$ 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.

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

Where $|Vi|$ 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.

$$P_{i+1}=P_i-P_{Li+1}-R_{i,i+1}.\frac{(P_i^2+Q_i^2)}{|V_i|^2} \quad (4)$$

$$Q_{i+1} = Q_i - Q_{i+1} - X_{i+1}.\frac{(P_i^2+Q_i^2)}{|V_i|^2} \quad (5)$$

$$|V_{i+1}^2| = |V_i^2| - 2(R_{i,i+1}.P_i + X_{i,i+1}.Q_i) + (R_{i,i+1}^2 + Q_{i,i+1}^2).\frac{(P_i^2+Q_i^2)}{|V_i|^2} \quad (6)$$

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:

$$P_{LOSS}(i,i+1) = R_{i,i+1}.\frac{(P_i^2+Q_i^2)}{|V_i|^2} \quad (7)$$

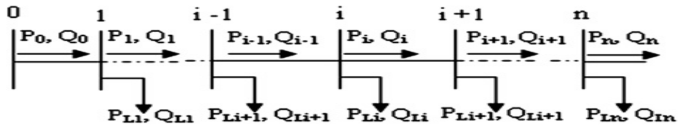



**Fig. 1: Single line diagram of main feeder.**

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

$$P_{T,LOSS}=\sum_{i=1}^{n} P_{LOSS}(i, i+1) \quad (8)$$

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

## 2.1 Constraints

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

(i) $V_{min} \le |V_i| \le V_{max}$

i.e $0.95P.U \le |V_i| \le 1.00P.U$ (9)

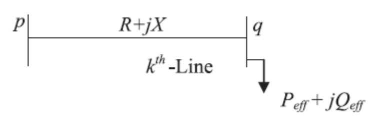
(ii) $P_{DG\ min} \le P_{DGi} \le P_{DG\ max}$ i.e

$0.1MW \le |P_{DGi}| \le 3.7MW$. (10)

$P_{DG}$ is the minimum and maximum real power generation from DG Capacity in MW.

### 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 line with an impedance R+jX and a load $P_{eff}$ and $Q_{eff}$ connected between buses p and q is given by.




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 or Placement. 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 DG 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) such bus needs no compensation and that bus will not be listed in the 'rank bus' vector. The 'rank bus' vector offers the information about the possible potential or candidate buses for DG placement.

## 3. FLOWER POLLINATION ALGORITHM

The above characteristics of pollination process, i.e flower constancy and pollinator behavior can be idealized as the following rules:

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 performs L´evy flights when they travel.
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 of the 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 multi objective optimization problems. All the idealized characteristics and the discussions that have been done we can design an algorithm which based on the pollination of flowers, called as flower pollination algorithm (FPA). The two basic steps of this algorithm are;

1) Global pollination

2) 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 a L'evy distribution

$$L \sim \frac{\lambda \Gamma(\lambda) \sin\left(\frac{\Pi\lambda}{2}\right)}{\Pi} 1/s^{1+\lambda} \; (s » s\,0 > 0). \quad (16)$$

Here Γ(λ) is the standard gamma function, and this distribution is valid for large steps s > 0.Here the value of λ = 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 DG PLACEMENT METHODOLOGY

Here in this proposed method the Flower pollination algorithm 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 DG placement method has been described in two stages are as follows:

### 4.1 Determination of candidate location

**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**: Run the load flow program and find the total power loss Ploss1 of the original system (before DG placement)

**Step2**: Generate randomly "n" number of flowers, where each flower is represented asX[i]={DG1,DG2,….,DGj}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 $S_{LOSS}$ using equation (1)

**Step4**: By placing all the 'n' number of DGs at the respective optimal DG locations, and run the load flow program to find total power losses Ploss2 after placement.

**Step5**: Define switching probability p€ [0, 1]

**Step6**: Set the Iteration count, iter=1.

**Step7**: Choose random number between [0,1].

**Step8**: Draw a step vector L from L'evys distribution and update flower solution by equation (15) and (16).

**Step9**: Randomly choose j and k solutions from existing solutions and update solution by $X_i^{t+1}=X_i^t + €(X_j^t - X_k^t)$.

**Step10**: Run the load flow with updated $X_{Values}$. If power loss is less than previous iteration, update flower (DG values) , if not keep old values as solutions.

**Step11**: Find current best solution g*

**Step12**: if iter<max_iter goto step 6 other wise stop.

## 5. RESULT

Loss sensitivity factor is used to calculate the candidate location for the DG placement and FPA is used to find the optimal DG size. In this work, Number of iterations 100, $DG_{min}$= 1000kW, $DG_{max}$=3700kW.

### 5.1 Results of 33-bus system

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

**Table 1**

| | |
|---|---|
| BUS NO; | 6 |
| DG SIZE in ( kW) | 3275 |
| TOTAL REAL POWER LOSS in (kW) before compensation. | 201.8588 |
| TOTAL REAL POWER LOSS in (kW) after compensation. | 109.0938 |
| VOLTAGE IN P.U at bus number 6 before compensation. | 0.9499 |
| VOLTAGE IN P.U at bus number 6 after compensation | 0.9976 |
| LOSS REDUCTION | 92.765 |
| LOSS REDUCTION % | 45.9553% |

### 5.2 Results of 69-bus system

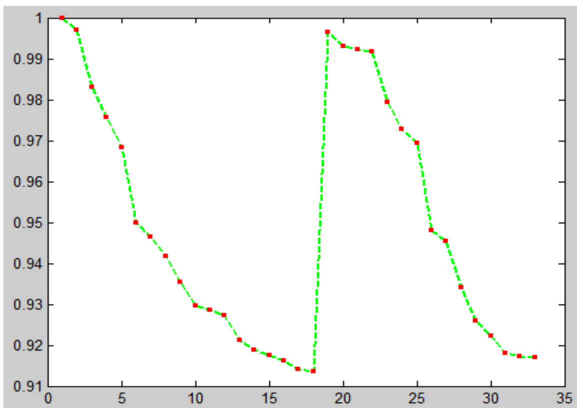
FPA is applied on 69-bus system and the desired results are found. Optimal DG location is identified based on the Loss sensitivity factor values. For this 69-bus system, one optimal location is identified. DG sizes in that optimal location, total real power losses before and after compensation, voltage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

**Table 2**

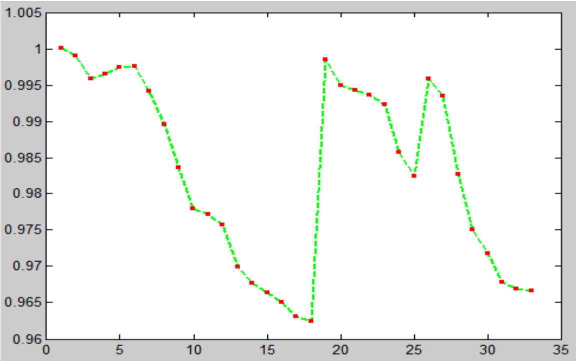
| **BUS NO;** | **61** |
|---|---|
| DG in ( kW) | 1802 |
| TOTAL REAL POWER LOSS in(kW) before compensation | 224.5407 |
| TOTAL REAL POWER LOSS in (kW) after compensation | 81.7569 |
| VOLTAGE IN P.U at bus number 61 before compensation | 0.9133 |
| VOLTAGE IN P.U at bus number 61 after compensation | 0.9833 |
| LOSS REDUCTION | 142.7838 |
| LOSS REDUCTION % | 63.5892% |

### 5.3 Graphical Representation of Voltage profile before DG placement and after placement

#### 5.3.1 For 33–bus system. Voltage profile before DG placement.



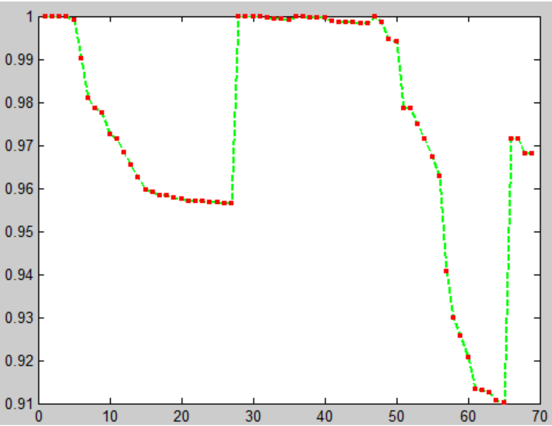

#### 5.3.2 For 33–bus system. Voltage profile after DG placement.



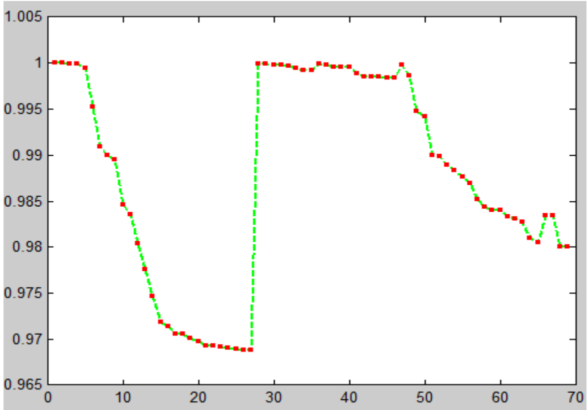

## 6. CONCLUSION

Here the work is providing a two- stage method i.e Loss Sensitivity Factor and FPA algorithm which is successfully applied for DG placement. By the installation of DG at the optimal position there is a significant decrease in power loss and increase in voltage profile. So the combination of both Loss sensitivity factor and FPA yields good results.

**5.3.3 For 69–bus system. Voltage profile before DG placement.**




**5.3.4 For 69–bus system. Voltage profile after DG placement.**

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