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Optimal Sizing And Placement Of Distributed Generation In A Radial Distribution System Using Loss Sensitivity Factor And Firefly Algorithm.

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ABSTRACT

Active power loss minimization plays a very vital role in increasing the efficiency of power system. Numerous methods are there for minimization of active power loss in radial distribution. The methodology which has been proposed in this article presents a method of reducing the loss by placing distributed generation. In this paper a two stage method have been proposed for optimal allocation of distributed generation in a radial distribution system. In first stage loss sensitivity factor is used to calculate the location and secondly the firefly algorithm to find the optimal size of DG and for reducing power loss. The proposed method is tested on 33-bus and 69-bus system and results are given below.

Keywords: Firefly algorithm, Loss sensitivity factor, Radial distribution system, Distributed generation.

1. INTRODUCTION

Population is huge and the sources of non-renewable energy are limited. And everyday use of coal, petroleum, natural gas etc. is creating scarcity of this energy sources. 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 due to that voltage profile is decreasing. 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 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. And 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.

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

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

$V_{min} \leq |Vi| \leq V_{max}$ (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.

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

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

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

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:

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

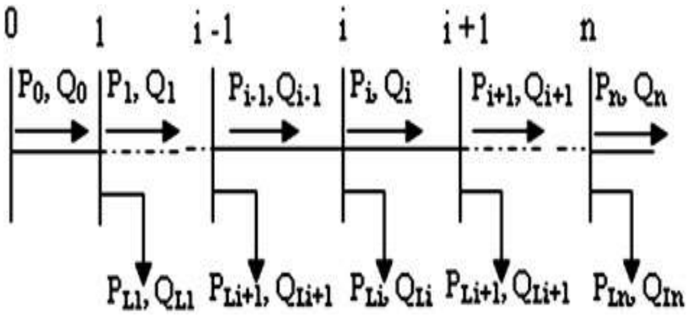


Fig1. Single line diagram of main feeder.

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

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

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:

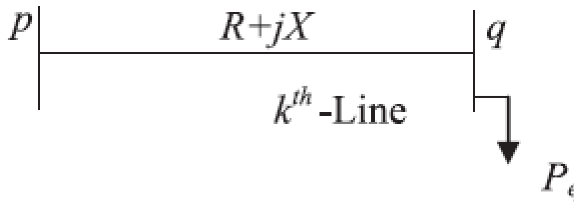
(I) $V_{min} \leq |Vi| \leq V_{max}$ 0.95P.U ≤ |Vi| ≤ 1.00P.U (9)

(ii) $P_{DG\,min} \leq P_{DGi} \leq P_{DG\,max}$ i.e 0.1 MW ≤ $|P_{DGi}|$ ≤ 3.7 MW. (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 DG 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 +j X 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:

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

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

2.3. Candidate node selection using loss sensitivity factors

The Loss Sensitivity Factors ($\frac{\partial Plineloss}{\partial Qeff}$) 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

($\frac{\partial Plineloss}{\partial Qeff}$).The descending order of ($\frac{\partial Plineloss}{\partial Qeff}$) elements of ''bpos[i]' vector will decide the sequence

Firefly Algorithm

in which the buses are to be considered for compensation. This sequence is purely governed by the ($\frac{\partial Plineloss}{\partial Qeff}$) and hence the proposed 'Loss Sensitive Coefficient' factors become very powerful and useful in DG 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. FIREFLY ALGORITHM

The Firefly algorithm (FA) is a recently developed heuristic optimization algorithm by Yang [15] and the flashing behavior of fireflies has inspired it. According to Yang [15], the three idealized rules of FA optimization are as follows.

(a) All fireflies are unisex, so that one firefly is attracted to other fireflies regardless of their sex.

(b) Attractiveness is proportional to brightness, so for any two flashing fireflies, the less bright firefly will move towards the brighter firefly. Both attractiveness and brightness decrease as the distance between fireflies increases. If there is no firefly brighter than a particular firefly, that firefly will move randomly.

(c) The brightness of a firefly is affected or determined by the landscape of the objective function. Based on these three rules, the basic steps of the FA can be summarized as the pseudo-code shown in Fig. 1 [15].There is two essential components to FA: the variation of light intensity and the formulation of attractiveness. The latter is assumed to be determined by the brightness of the firefly, which in turn is related to the objective function of the problem

1. Initializing all the parameters of FA.
2. Generate initial population of fireflies X_i=(i = 1,2…….n)
3. Assume that f(X) is the objective function of X(x1,x2….xn)
4. Light intensity L_i is defined by f(X_i)
5. while(g<max gen)
6. for i = 1:n where n is all fireflies
7. for j = 1:n where n is all fireflies
8. If(L_j>L_i)
9. move fireflies i towards j in all d dimensions.
10. end if
11. Attractiveness varies with the distance r via e^{-r^2}
12. Evaluate new solution and update new light intensity L_i.
13. end for
14. end for
15. Rank the fireflies and find the current best and update the global best if required
16. end while
17. Results and visualization.

Fig 1. Pseudo code for firefly algorithm.

With decrease in light intensity and attractiveness, the distance from the source increases, and the variation of light intensity and attractiveness should be a monotonically decreasing function. For example, the light intensity can be:

$$I\ (r_{ij}) = I_o\, e^{-yr_{ij}^2} \qquad (15)$$

where the light absorption coefficient y is a parameter of the FA and r_{ij}, is the distance between fireflies i and j at x_i and x_j, respectively, and hence can be defined as the Cartesian distance $r_{ij} = ||x_i - x_j||$. Because a firefly's attractiveness is proportional to the light intensity seen by other fireflies, it can be defined by:

$$\beta_{ij} = \beta_o e^{-\gamma r_{ij}^2} \quad (16)$$

in which β_o is the attractiveness at r = 0. Finally, the probability of a firefly i being attracted to another, more attractive (brighter) firefly j is determined

$$\Delta x_i = \beta_o e^{-\gamma r_{ij}^2}(x_j^t - x_i^t) + \alpha \epsilon_i , \; x_i^{t+1} = x_i^t + \Delta x_i \quad (17)$$

Where t is the generation number, € is a random vector (e.g., the standard Gaussian random vector in which the mean is 0 and the standard deviation is 1) and α is the randomization parameter. The first term on the right-hand side of Eq. (17) represents the attraction between the fireflies and the second term is the random movement. In other words, Eq. (17) shows that a firefly will be attracted to brighter or more attractive fireflies and also move randomly. Eq. (17) indicates that β, γ, α must be set by user and the distribution of ϵ_i to apply the FA, and also when γ is too small or large there are two limit cases as shown in Eq .(17)

(a) If γ approaches zero, the attractive and brightness are constants, and consequently, a firefly can be seen by all other fireflies. In this case, the FA reverts to the PSO.

(b)If γ approaches infinity, the attractiveness and brightness approach zero, and all fireflies are short-sighted or fly in a foggy environment, moving randomly. In this case, the FA reverts to the pure random search algorithm.

Hence, the FA generally corresponds to the situation falling between these two limit cases.

4. PROPOSED OPTIMAL DISTRIBUTED GENERATION PLACEMENT METHODOLOGY

Here in this proposed method the Firefly algorithm is applied as an optimization technique to determine the optimal size of the DG 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:

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 Firefly Algorithm.

Step1: Initialize all the parameters and constants of Firefly Algorithm. They are P_{DGmin}, P_{DGmax},(minimum and maximum limit of DG) noff, noP_{DG}, α_{min}, α_{max}, β_o, γ and itermax (maximum number of iterations).

Step2: Run the load flow program and find the total power loss Ploss1 of the original system (before DG placement)

Step3: Generate noff * noP_{DG} number of fireflies randomly between the limits P_{DGmin} and P_{DGmax}. noff is the number of fireflies and noP_{DG} is the number of DG. Each row represents one possible solution to the optimal DG sizing problem. For example noP_{DG} =1 for one DG noP_{DG} =2 for two DG and noP_{DG} =3 for three DG. Similarly noff=10 for ten fireflies, noff=20 for twenty fireflies and noff=50 for fifty fireflies.

Step4: By placing all the noP_{DG} number of DG of each firefly at the respective optimal DG locations, and run the load flow program to find total power losses Ploss2 after placement.

Step5: Obtain the best fitness function GbestFF by comparing all the fitness function and also obtain the best firefly values GbestFV corresponding to the best fitness function GbestFF.

Step6: Determine alpha (α) value of the current iteration α(iter) using the equation: α (iter) =αmax -((αmax - αmin) (current iteration number)/itermax)

Step7: Determine r_{ij} values of each firefly using the following equation: r_{ij}= GbestFF –FF r_{ij} is obtained by finding the difference between the best fitness function GbestFF (GbestFF is the best fitness function i.e., jth firefly) and fitness function FF of the ith firefly.

Step8: New X_i values are calculated for all the fireflies using the following equation:

$X_i(new)=X_i(old)+\beta_o*exp(-\gamma r_{ij}^2)*(X_j-X_i)+\alpha(iter)*(rand - \frac{1}{2})$

where, β_o is the initial attractiveness γ, is the absorption co-efficient, rij is the difference between the best fitness function GbestFF and fitness function FF of the ith firefly.

α (iter) is the randomization parameter varies between 20 to 0.0001 and is the random number between 0 and 1. P_{DG} $X_i$new is the new.

Step9: Increase the iteration count. Go to step 5, if iteration count is not reached maximum.

Step10: GbestFV gives the optimal DG in 'n' optimal locations and the results are printed.

5. RESULTS

Loss sensitivity factor is used to calculate the candidate location for the DG placement and Firefly algorithm is used to find the optimal DG size. In this work, α=0.25, β=0.2, γ=1 Number of iterations 500, number of fireflies=20 , P_{DGmin} = 100kW, P_{DGmax} =3700kW.

5.1. Results of 33-bus system

The proposed algorithm is applied to 33-bus system [13]. Optimal distributed generation 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 and reactive power losses before and after compensation, voltage profile before and after compensation are shown below.

Table 1.

BUS NO;	6
DG SIZE in (kW)	1836
TOTAL REAL POWER LOSS in (kW) before compensation.	201.8588
TOTAL REAL POWER LOSS in (kW) after compensation.	153.3724
TOTAL REACTIVE POWER LOSS in (kVAr) before compensation	134.2546
TOTAL REACTIVE POWER LOSS in (kVAr) after compensation.	104.3373
VOLTAGE IN P.U at bus number 6 before compensation.	0.9499
VOLTAGE IN P.U at bus number 6 after compensation	0.9679
REAL POWER LOSS REDUCTION	48.4864
REAL POWER LOSS REDUCTION %	24.0199%

5.2. Results of 69-bus system

The proposed algorithm is applied to 69-bus system [14]. 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 and reactive power losses before and after compensation, voltage profile before and after compensation are shown below.

Table 2.

BUS NO;	61
DG SIZE in (kW)	1310
TOTAL REAL POWER LOSS in(kW) before compensation.	224.5407
TOTAL REAL POWER LOSS in (kW) after compensation	150.4358
TOTAL REACTIVE POWER LOSS in(kVAr) before compensation.	101.9661
TOTAL REACTIVE POWER LOSS in(kVAr) after compensation	69.7374
VOLTAGE IN P.U at bus number 61 before compensation	0.9133
VOLTAGE IN P.U at bus number 61 after compensation	0.9356
REAL POWER LOSS REDUCTION	74.1049
REAL POWER LOSS REDUCTION %	36.7691%

6. CONCLUSION

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

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