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OPTIMAL ALLOCATION OF DISTRIBUTED GENERATION IN A RADIAL DISTRIBUTION SYSTEM USING LOSS SENSITIVITY FACTOR AND HARMONY SEARCH ALGORITHM.

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Abstract—*The overall efficiency of power system can be raised by minimization of active power loss in radial distribution system. The article here proposing 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 harmony search algorithm is used for minimization of active power loss. The proposed method is tested on 33-bus and 69-bus system and results are given below.*

Keywords: *Harmony search algorithm, Loss sensitivity factor, Radial distribution system, Distributed generation*.

1. INTRODUCTION

With increasing population, 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 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 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.

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

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

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

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:

$$P_{LOSS}(i, i+1) = R_{i,i+1} \cdot \frac{(\square_{\square}^{2} + \square_{\square}^{2})}{|\square_{\square}|^{2}}$$
(6)

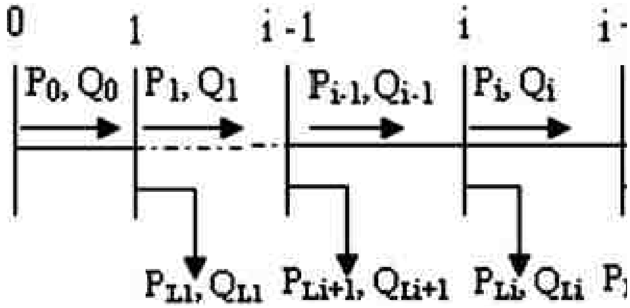


Fig1. Single line diagram of main feeder.

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

$$P_{T,\ LOSS} = \sum_{\square=1}^{\square} \square\square\square\square\square(\square, \square + 1)$$
(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:

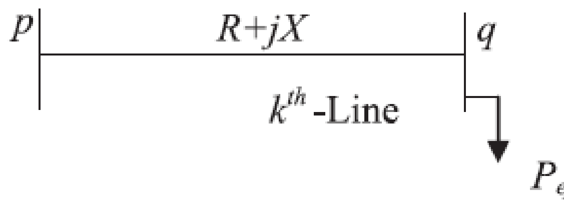
(I) $V_{min} \leq |Vi| \leq V_{max}$ i.e 0.95 P.U $\leq |Vi| \leq$ 1.00 P.U (8)

(ii) $P_{DG\ min} \leq P_{DGi} \leq P_{DG\ max}$ i.e 0.1 MW $\leq |P_{DGi}| \leq$ 3.7 MW. (9)

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

$$P_{lineloss}[q] = \frac{(\square_{\square\square\square}^{2}[\square] + \square_{\square\square\square}^{2}[\square])\square[\square]}{(\square[\square])^{2}}$$
(10) Similarly the reactive power loss in the k^{th} line is given by

$$Q_{Lineloss}[q] = \frac{(\square_{\square\square\square}^{2}[\square] + \square_{\square\square\square}^{2}[\square])\square[\square]}{(\square[\square])^{2}}$$
(11)

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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:

$$\frac{\partial P_{lineloss}}{\partial P_{eff}} = 2 * \frac{P_{eff}[q] * R[k]}{V[q]^2} \quad (12)$$

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

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 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. HARMONY SEARCH ALGORITHM

Harmony Search is a relatively new population-based meta-heuristic algorithm. In the field of engineering optimization it has shown excellent results. It deals with the behavior of an orchestra where main objective of the musician is to compose the most harmonious melody, as measured by aesthetic quality. While comparing the process of improvisation by musicians with the optimization process, we can realize that each musician corresponds to a decision variable; the pitch of each instrument determines the aesthetic quality, just as the objective function value is determined by the set of values assigned to each decision variable. After improvisation, the musical harmony corresponds to the solution vector at a particular iteration. Iteration to iteration it, enhances the fitness of the solution vector. The Optimization procedure of an HS algorithm steps are as follows:

Step 1: Initialize the optimization problem and algorithm parameters.
Step 2: Initialize the harmony memory (HM).
Step 3: Improvise a new harmony from the HM.
Step 4: Update the HM.

Step 5: Repeat Steps 3 and 4 until the termination criterion is satisfied.

For explanation of Harmony Search in more detail, we have to first idealize the Improvisation process by a skilled musician. For improvising, he or she has three possible choices: (1) play any famous piece of music (a series of Pitches in harmony) exactly from his or her memory; (2) play something similar to a known piece (thus adjusting the pitch slightly); or (3) compose new or random notes. Zong Woo Geem et al. And formalized these three options into quantitative optimization process in 2001, and the three corresponding components become: usage Memory is important, and is similar to the choice of the best-fit individuals in genetic algorithms (GA). And this will ensure that the best harmonies will be carried over to the New Harmony memory. For the memory usage more effectively, it is typically assigned as a parameter r_{accept} [0, 1], called harmony memory accepting or considering rate. If this rate is too low, only few best harmonies are selected and it may converge too slowly. If this rate is extremely high (near 1), almost all the harmonies are used in the harmony memory, then other harmonies are not explored well, leading to potentially wrong solutions. Therefore, typically, we use r_{accept}=0.7 ~ 0.95. The second component is the pitch adjustment determined by a pitch bandwidth b_{range} and a pitch adjusting rate r_{pa}. Though in music, pitch adjustment means to change the frequencies, it corresponds to generate a slightly different solution in the Harmony Search algorithm [10]. In theory, the pitch can be adjusted linearly or nonlinearly, but in practice, linear adjustment is used. So we have $x_{new} = x_{old} + b_{range} * €$ where x_{old} is the existing pitch or solution from the harmony memory, and x_{new} is the new pitch after the pitch adjusting action. This essentially produces a new solution around the existing quality solution by varying the pitch slightly by a small random amount [11, 12]. Here € is a random number generator in the range of [-1, 1]. Pitch adjustment is similar to the mutation operator in genetic algorithms. We can assign a pitch-adjusting rate (r_{pa}) to control the degree of the adjustment. A low pitch adjusting rate with a narrow bandwidth can slow down the convergence of HS because the limitation in the exploration of only a small subspace of the whole search space. On the other hand, a very high pitch-adjusting rate with a wide bandwidth may cause the solution to scatter around some potential optima as in a random search. Thus, we usually use r_{pa}=0.1 ~0.5 in most applications

Harmony Search

begin

Objective function f(x), $x=(x_1, x_2, \ldots, x_d)^T$

Generate initial harmonics (real number arrays)

Define pitch adjusting rate (r_{pa}), pitch limits and bandwidth

Define harmony memory accepting rate (r_{accept})

while (t<Max number of iterations)

Generate harmonics by accepting best harmonics

Adjust pitch to get new harmonics (solutions)

if (rand>r_{accept}), choose an existing harmonic randomly

else if (rand>r_{pa}),
adjust the pitch randomly within limits
else
generate new harmonics via randomization
end if
Accept the new harmonics (solutions) if better
end while
Find the current best solutions
end

Fig 2: Pseudo code of the Harmony Search algorithm

The third component is the randomization, which is to increase the diversity of the solutions. Although adjusting pitch has a similar role, but it is limited to certain local pitch adjustment and thus corresponds to a local search. The use of randomization can drive the system further to explore various diverse solutions so as to find the global optimality. The three components in harmony search can be summarized as the pseudo code shown in Fig. 2. In this pseudo code, we can see that the probability of randomization is

$P_{random} = 1 - r_{accept}$ (14)

the actual probability of adjusting pitches is

$P_{pitch} = r_{Accept} * r_{pa}$ (15)

4. PROPOSED DISTRIBUTION GENERATION PLACEMENT METHODOLOGY

Here in this proposed method the HS 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 HARMONY SEARCH Algorithm.

Step1: Initialize all the parameters of the Harmony search algorithm. Like P_{DGmin} and P_{DGmax}, (minimum and maximum limits for DG sizes), hms, HMCR, PAR_{min} , $PAR_{max.}$
Step2: Initialize the harmony memory i.e. create [hms x n] number of initial solutions randomly within the limits ,where hms is the harmony memory size and n is the number of DG.
Step3: Place all the n DG of the harmony vector i.e each row of the Harmony vector at the respective optimal DG location and perform the load flow and find the total real power loss after placement.
Step4: Compute the total power loss.
Step5: Repeat the same procedure for all the rows of the harmony vector to find fitness functions.
Step6: Obtain the best fitness function by comparing all the fitness functions.
Step7: Start the improvisation (Iteration count is set to one)
Step8: Improvisation of the New Harmony is generating a New Harmony, A New Harmony

vector is generated based on the following steps:

(i)**Random selection:** It is used to select one value randomly for a certain element of the new vector from the possible range ($P_{DG\ min}$ and $P_{DG\ max}$ of values). (16)

(ii) **Memory consideration**: It is used to choose the value for a certain element of the new vector from the specified HM range.

$x'_i = x'_i \in \{x'_1, x'_2, x^{HMS}{}_i\}$ with probability HMCR

$x'_i = x'_i \in X_i$ with probability (1-HMCR)
(17)

Step 9: Pitch adjustment It is used to adjust the values of the New Harmony vector obtained in step 7. (Between PAR_{min} and PAR_{max}).

$x'_i = x'_i \pm$ rand (0,1)* bw (18)

(bw - band width varies between a higher value and a lower value from first iteration to last iteration)

Step 10: Find the fitness values corresponding to the New Harmony generated and pitch adjusted in steps (17) and (18).

Step 11: Apply Greedy Search between old harmony and New Harmony by comparing fitness functions.

Step 12: Update harmony memory, by replacing the worst harmony with the new best Harmony. Obtain the best fitness function by comparing all the fitness functions.

Step 13: The improvisation (iteration) count is incremented and if iteration count is not reached
the maximum then go to step 8.

Step 14: The solution vector corresponding to the best fitness function gives the optimal DG sizes in n optimal locations.

5. RESULTS

Loss sensitivity factor is used to calculate the candidate location for the DG placement and HSA is used to find the optimal DG size. In this work, hms = 60, HMCR=90%, Number of iterations 500, PAR_{min} = 0.4 and PAR_{max} = 0.9.

5.1. Results of 33-bus system

The proposed algorithm is applied to 33-bus system [14]. 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 are shown below in Table1.

BUS NO;	6
DG SIZE in (kW).	1197.1
TOTAL REAL POWER LOSS in (kW) before compensation.	201.8588
TOTAL REAL POWER LOSS in (kW) after compensation.	129.6879
TOTAL REACTIVE POWER LOSS in (kVAr) before compensation.	134.2563
TOTAL REACTIVE POWER LOSS in (kVAr) after compensation.	89.5279
VOLTAGE IN P.U at bus number 6 before compensation.	0.9499
VOLTAGE IN P.U at bus number 6 after compensation.	0.9678

REAL POWER LOSS REDUCTION	72.1709
REAL POWER LOSS REDUCTION %	35.7532%

5.2. Results of 69-bus system

The proposed algorithm is applied to 69-bus system [15]. 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 in Table-2.

BUS NO;	61
DG SIZE in (kW).	1121.3
TOTAL REAL POWER LOSS in (kW) before compensation.	224.5407
TOTAL REAL POWER LOSS in (kW) after compensation.	103.0007
TOTAL REACTIVE POWER LOSS in (kVAr) before compensation.	101.9661
TOTAL REACTIVE POWER LOSS in (kVAr) after compensation.	49.7942
VOLTAGE IN P.U at bus number 61 before compensation.	0.9133
VOLTAGE IN P.U at bus number 61 after compensation.	0.9580
REAL POWER LOSS REDUCTION	121.54
REAL POWER LOSS REDUCTION %	54.1282%

6. CONCLUSION

Here in this paper a two- stage method L.S.F and HS algorithm has been 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 HS algorithm yields good results.

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