Determination of Optimal Size and Site of Distributed Generators using Particle Swarm Optimization Technique

Debasish Choudhury
Testing and Commissioning Division
Assam Electricity Grid Corporation Limited
Guwahati-781001, Assam, India

Abstract— **The problem of installation of DG units at proper location and sizing is of great importance. The placement of distributed generation (DG) at non-suitable places can result increasing in system losses, implying an increase in costs and therefore having an effect opposite to the desired. This paper introduces an optimal placement method in order to sizing and sitting of distributed generation in IEEE 30 bus mesh test system to improve of voltage profile, stability, reduction of power losses etc. The algorithm for optimization is Particle Swarm Optimization (PSO). Proposed objective function is the active power losses of the system and to test the feasibility of the proposed method, five cases of power increasing from 1 to 5 DG's are considered.**

Keywords— ***Distributed Generation, Particle Swarm Optimization***

I. INTRODUCTION

With the on-going expansion and the growth of industries in developing countries, the demand for electric power is increasing globally. This in turn forces a certain level of intricacy on the power system and that intricacy compounds with time; to the point where the power system face the inability to progress with ease due to introductions of new transmission systems and construction of generating plants near load centre. As the system grows more complex and burdened with increasing load; various issues regarding cost, pollution, power quality and voltage stability takes centre stage. These problems can be solved/minimized by the introduction of Distributed Generation (DG). "Distributed Generation" (DG) can be defined as the system in which any type of electrical generating units (conventional or non-conventional sources of energy) of limited size which is connected directly to the distribution network systems. It means DG consist the small generating units installed in strategic points of allocations of the electric power system close to the load centers. Distributed generators can provide the consumer's local demand (isolated way) as well as an incremental capacity to electric power system, (integrated way). Some researchers presented some power flow algorithms to find the optimal size of DG at each load bus [1], [2]. Several algorithms have been proposed to place DG such as particle swarm optimization [3]–[5], ant colony [6], optimal power flow [7], analytical methods [8], [9], evolutionary algorithm [10]–[13], simulated annealing [14]–[16]. Meta heuristic algorithms are preferred when large number of combinations is required, such as PSO [17] to get better solutions and improve convergence. In this work, PSO is implemented to solve placement and size of DG with the objective of minimizing power losses of meshed networks.

II. PROBLEM FORMULATION

The problem of finding the best location of DG can be formulated as a minimization of power losses with constraints, as shown in (1)

Minimize

$$F = K_p \sum_{j=1}^{NL} (P_{Lossj}) + K_v \sqrt{\left\{ \sum_{i=1}^{NVB} \left\{ (V_{Li} - V_{LIM})^2 / N \right\} \right\}} \quad \text{---(1)}$$

where P_{Lossj} real power loss in the given line in MW.

NL number of lines in the system.

K_p, K_v penalty factors.

Equality Constraints:

(a) Active power balance in the network

$$P_i(V,\delta) - P_{gi} + P_{di} = 0, \quad for\ i = 1,2,\ldots,N$$

Real power equations are

$$P_i(V,\delta) = V_i \sum_{j=1}^{N} V_j (G_{ij} Cos(\delta_i - \delta_j) + B_{ij} Sin(\delta_i - \delta_j))$$

(b) Reactive power balance in the network

$$Q_i(V,\delta) - Q_{gi} + Q_{di} = 0, \quad for\ i = NG+1, NG+2, \ldots, N$$

Reactive power flow equations are

$$Q_i(V,\delta) = V_i \sum_{j=1}^{N} V_j (G_{ij} Sin(\delta_i - \delta_j) - B_{ij} Cos(\delta_i - \delta_j))$$

where NG number of generator buses,

N number of buses,

P_i active power injection into bus i,

Q_i reactive power injection into bus i,

P_{di} active load on bus i,

Q_{di} reactive load on bus i,

P_{gi} active power generation on bus i,

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 01, January-2017

Q_{gi} reactive power generation on bus i,

V_i magnitude of the voltage at i[th] bus,

δ_i voltage phase angle of bus i,

δ_j voltage phase angle of bus i

$Y_{ij} = G_{ij} + jB_{ij}$ elements of admittance matrix.

Inequality Constraints:

(a) Limits on real power generations:

$$P_{gi^{\min}} \le P_{gi} \le P_{gi^{\max}} \quad for\ i = 1, 2, ..., NG$$

(b) Limits on reactive power generations:

$$Q_{gi^{\min}} \le Q_{gi} \le Q_{gi^{\max}} \quad for\ i = 1, 2, ..., NG$$

(c) Limits on voltage generation:

$$V_{i^{\min}} \le V_i \le V_{i^{\max}} \quad for\ i = 1, 2, ..., N$$

(d) Line flow limits:

$$P_{ij} < TL_{ij}$$

Where TL thermal limit of the line

i sending end bus number

j receiving end bus number

III. PARTICLE SWARM OPTIMIZATION

A. Overview

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling.

PSO is initialized by a population of random solutions and potential solution is assigned a randomized velocity. The potential solutions, called particles, are then 'flown' through the problem space. Each particle keeps track of its coordinates in the problem space, which are associated with the best solution or fitness achieved so far. The fitness value is stored and it is called as **pbest**. Another value that is tracked by the global version of the particle swarm optimizer is the overall best value, and its location, obtain so far by any particle in population and this value is called **gbest**. Thus at each time step, the particle changes its velocity and moves toward its pbest and gbest; this is global version of PSO.

B. Mathematical Form

Consider the global optimum of an n-dimensional function defined by

$$f(x_1, x_2, x_3, \ldots\ldots, x_n) = f(X)$$

where x_i is the search variable, which represents the set of free variables of the given function. The aim is to find a value x^* such that the function $f(x^*)$ is either a maximum or a minimum in the search space.

The Particle Swarm Optimization (PSO) algorithm is a multi-agent parallel search technique which maintains a swarm of particles and each particle represents a potential solution in the swarm. All particles fly through a multidimensional search space where each particle is adjusting its position according to its own experience and that of neighbors.

Suppose X_i^t denote the position vector of particle i in the multidimensional search space (i.e. $X \in R^n$, where n is the dimension of X) at time step t, then the position of each particle is updated in the search space by $X_i^{t+1} = X_i^t + V_i^{t+1}$.

Therefore, in a PSO method, all particles are initiated randomly and evaluated to compute fitness together with finding the personal best (best value of each particle) and global best (best value of particle in the entire swarm). After that a loop starts to find an optimum solution. In the loop, first the particles' velocity is updated by the personal and global bests, and then each particle's position is updated by the current velocity. The loop is ended with a stopping criterion predetermined in advance. In this method the position of each particle is influenced by the best-fit particle in the entire swarm. It uses a star social network topology where the social information obtained from all particles in the entire swarm. In this method each individual particle, $i \in [1,\ldots, n]$ where n >1, has a current position in search space X_i, a current velocity, V_i, and a personal best position in search space, pb_i. The personal best position, pb_i, corresponds to the position in search space where particle i had the smallest/ largest value as determined by the objective function, considering a minimization/maximization problem. In addition, the position yielding the best value amongst all the personal best pb_i is called the global best position which is denoted by gb. The following equations define how the personal and global best values are updated, respectively.

Considering minimization problems, then the personal best position pb_i at the next time step, t+1, where, $t \in [0,\ldots, n]$ is calculated as

$$pb_i^{t+1} = pb_i^t \ \text{ if } f(X_i^{t+1}) > pb_i^{t+1}$$
$$= pb_i^t \ \text{ if } f(X_i^{t+1}) \le pb_i^{t+1}$$

Where f: $R^n \rightarrow R$ is the fitness function. The global best position gb at time step t is calculated as

$$gb = \min\{ pb_i^t \}, \text{ where } i \in [1, \ldots\ldots, n] \text{ and } n > 1$$

Therefore it is important to note that the personal best pb is the best position that the individual particle i has visited since the first time step. On the other hand, the global best position gb is the best position discovered by any of the particles in the entire swarm. The velocity of particle i is updated according to the following expression:

$$V_i^{t+1} = \underbrace{V_i^t}_{\text{Inertia}} + \underbrace{c_1 U_1^t (pb_i^t - X_i^t)}_{\text{Personal Influence}} + \underbrace{c_2 U_2^t (gb^t - X_i^t)}_{\text{Social Influence}} \quad \text{------------(2)}$$

And position is updated according to following expression:

$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad \text{--------------(3)}$$

Where,

c_1 is called cognitive parameter

c_2 is called social parameter, both are called acceleration coefficients.

U_1^t and U_2^t are two random numbers varies between 0 to 1.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 01, January-2017

In the next iteration, updated velocities and positions are used as the present velocities and positions. Now these particle positions are used for the calculation of new value. In that condition, position of particle corresponds to optimum value is called new "gbest" and position of particle corresponds to optimum value that was evaluated by itself, is called new "pbest". And these above processes are repeated until stopping criteria (limitation of maximum iteration) is satisfied.

C. PSO Algorithm

1. Start.
2. Create a population of agents (called Particle) uniformly distributed over search space (x).
3. Evaluate each particle's position according to the objective function.
4. If a particle's current position is better than its previous best position, update it.
5. Determine the best particle (according to the particles previous best positions).
6. Update particles velocities according to

$$V_i^{t+1} = V_i^t + c_1 U_1^t (pb_i^t - X_i^t) + c_2 U_2^t (gb^t - X_i^t)$$

7. Move particles to their new positions according to

$$X_i^{t+1} = X_i^t + V_i^{t+1}$$

8. Go to step 2 until stopping criteria is satisfied.
9. Stop.

D. Basic Terms Used in PSO

- Initialization: PSO algorithm starts by producing a random set of points over the solution space. The function will be evaluated over these points. This is the first generation.
- Particle: Each search point is known as a particle. The position of the particle is determined by the independent variables. The position of every particle represents a possible solution of the optimization problem.
- Population Size: The number of search points (particles) is known as population size. Suppose we choose population size to be 200. So, each generation will have 200 particles.
- Fitness Function and Fitness Value: The function that we are trying to optimize is called the fitness function. The value of the fitness function corresponding to the position of a particle is known as the fitness value of that particle.
- Movement: The particles are imagined to be moving over the solution space trying to find the maximum (or minimum) value. In PSO, the new set of search points (particles) at each generation is visualized as position change of the particles. The position is changed according to the equations:

$$X_i^{t+1} = X_i^t + V_i^{t+1}$$

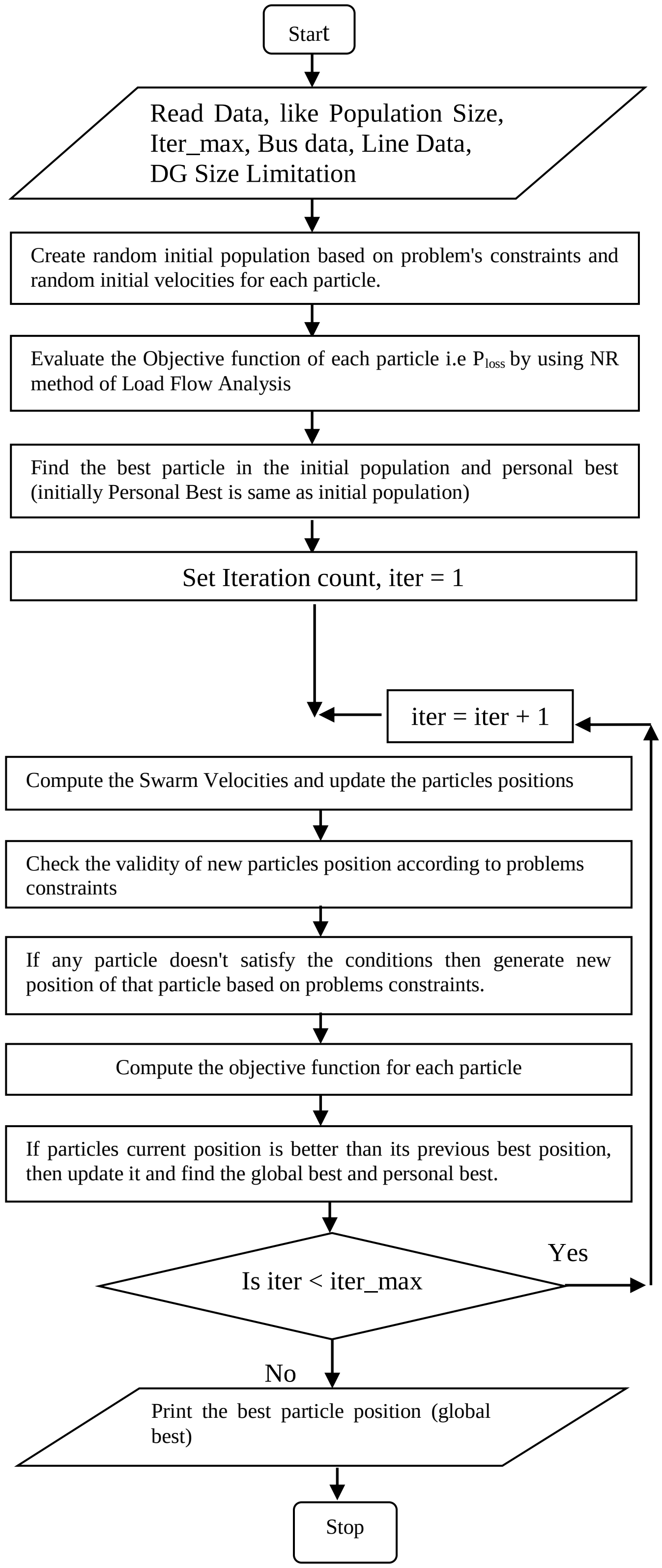
- Personal Best (pbest) and Global Best (gbest): As each particle moves (over successive generations), it remembers the position where it found the best fitness value so far. That position is known as *personal best.* The best fitness position that is found by population (over the generations) is known as *global best*.
- Particle Memory: Each particle remembers its own personal best. Each particle also knows the global best that is found by the entire swarm.
- Particle Motion: The movements of the particles are influence by the factors: pbset, gbest and previous position of the particle. The particles are pulled by the pbset and gbest positions.

IV. ALGORITHM FOR SOLUTION OF OPTIMAL SITTING AND SIZING OF DGS BY PSO

1. Read the various data, which includes bus data, line data, population size, dimension of the problems, maximum number of iterations, DG size limitations, cognitive parameter(c_1) , social parameter (c_2) etc.
2. Create random population of DG size and random population of location of DG considering the limit of DG size and its locations respectively. Initialize the random velocities (V) of all particles.
3. Calculate the Objective Function (OF) i.e. Loss by using N-R method of load flow analysis, of all particles considering the DG size and its location which is generated in previous step.
4. Find the optimum Loss which is called global minima or local minima (in the initial condition, both local and global minima are same). Find the particle position corresponding to optimum Loss, i.e. global best (gb), and also find the personal best *(pb)*. In the initial condition, personal best position *(pb)* is same as initial population.
5. Set iteration counter, iter = 1.
6. Update the particles' velocities according to the equation (2). After calculating the new velocities, update the particles' positions according to the equation (3).
7. Check the validity of particles according to the particles' particular conditions i.e. validate the particles' new positions according to the limitations of DG size and its valid locations. If new position of any particle is not valid, then randomly regenerate that particle according to their conditions.
8. Calculate the Objective Function (OF) i.e. Loss of the system by using N-R method of load flow analysis, corresponding to new particles.
9. After evaluating the objective function for all new position of each particle, if the new solution is better than the local solution, replace the local best. And if the new solution of each particle is the global best, replace with the new particle.
10. Increment the iteration counter by 1, i.e. iter=iter+1.
11. If convergence condition is not satisfied (i.e. if iter <= iter_max) then go to step 7, otherwise continue to next step.
12. Display the global best and their respected positions. Global best is the optimum Loss and their position indicates the optimum value of DG size and its optimum location. Plot the graph between optimum Loss and iteration number.
13. Stop.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 01, January-2017

V. FLOWCHART FOR SOLUTION OF SIZING & ALLOCATION PROBLEM BY PSO TECHNIQUE



VI. RESULTS AND ANALYSIS

The IEEE 30-bus system used to evaluate location and size of DG and reduce power losses in a meshed transmission and distribution network.

Assumptions for the placement of DG:

1. The total DG capacity is limited to 10% (app.) of the total load demand.
2. DG location is considered at the PQ buses only.
3. Maximum numbers of DGs are limited to 5.

Five cases were defined in this work from 1 to 5 distributed generators. The first DG is kept at all load buses in turn, and the location for which losses are the lowest is considered as the optimal location for that DG. Placing this DG at the load bus, the procedure (mentioned above) is repeated for placing the second DG at all load buses in turn and deciding the optimal location for the second DG. This procedure is repeated for all DGs. In this work, Five DGs, each of maximum Capacity of 5 MW are considered.

Table No.1

LOCATION AND SIZE OF DG USING PSO IN THE IEEE 30-BUS SYSTEM:

Case	P_{DG} (MW) $(0 \le P_{DG} \le 5)$	P_{total} (MW)	Bus No. (Location)	(MW)
0	0.00 (without DG)	After Optimal Power Flow (Objective Function: Cost Minimization)		9.046
1	One DG (4.969)	4.969	30	8.362
2	Two DGs (4.768, 4.907)	9.675	19,30	7.905
3	Three DGs (4.933, 4.895, 4.548)	14.376	19,24,30	7.469
4	Four DGs (4.951, 4.711, 4.117, 4.381)	18.159	19,21,24,30	7.176
5	Five DGs (4.155, 4.133, 4.396, 4.355, 4.840)	21.879	7,18,24,26,30	6.837

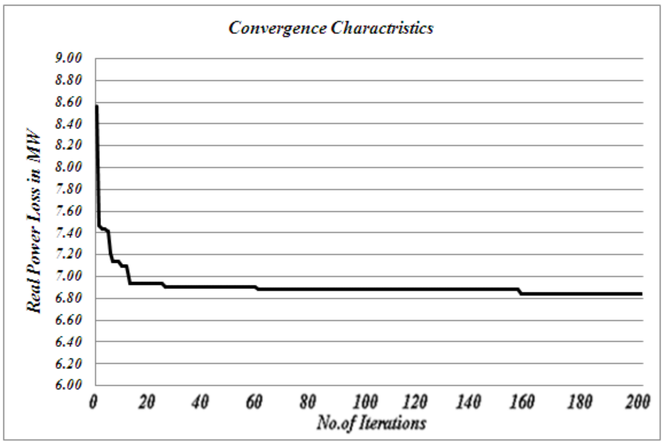


Fig 1: PSO convergences for Case 5 with 5 DGs

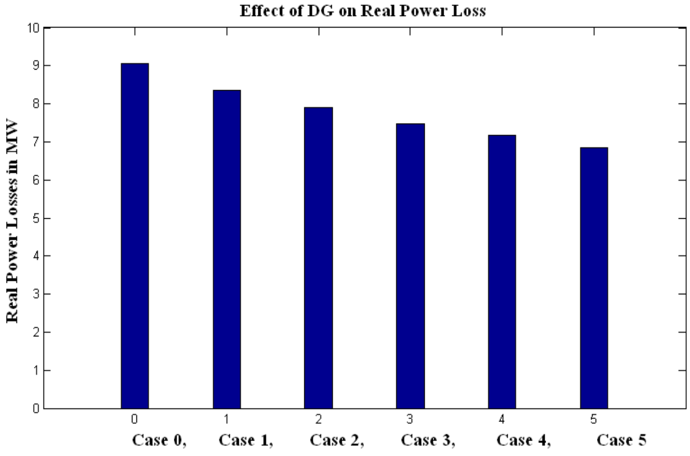


Fig 2: Power loss reduction using PSO

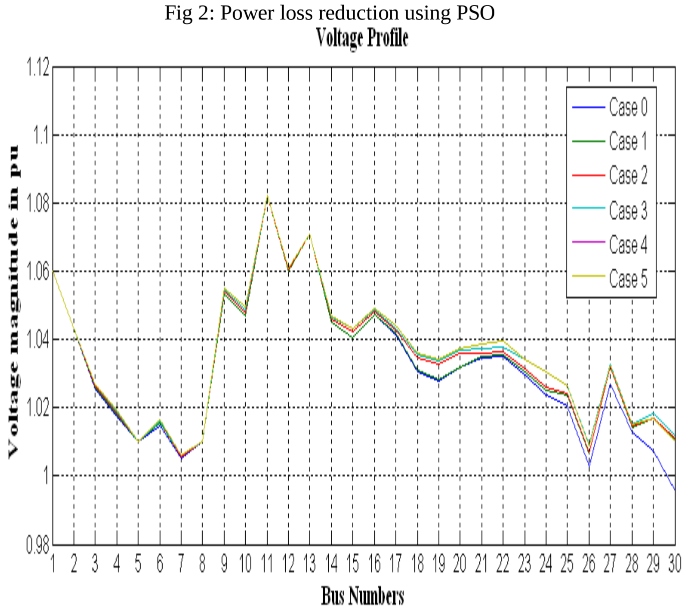


Fig3: Voltage before and after location of DG

The parameters used for PSO in all cases were a Population size of 70, and maximum number of iteration of 200. For testing, Five DG's each of Capacity 5 MW are considered i.e the maximum Capacity is 25 MW (about 10% of the Total System Load of 283.40 MW).

Firstly, one DG of 5 MW is considered for optimal placement and Optimal Location is found as Bus No. 30 (Table No. 1) and accordingly the Active Power Loss reduces to 8.362 MW from 9.046 MW and the Voltage at Bus No. 30 increases to 1.0107 p.u from 0.9958 p.u after and before placement of DG of Capacity 5 MW respectively. In addition to these, it is observed that Voltage magnitude of other Load Buses also improves. Five DG's each of 5 MW is considered and Optimum Locations are found as Bus No. 7, 18, 24, 26, and 30 (Table No. 1) and the active power loss of the system reaches a minimum value of 6.837 MW. The convergence characteristics can be studied from figure 1. The result converges in about 150 iterations. As shown in figure, the objective function reached a global minimum and stayed there till the end of iterations. The improvement in voltage magnitudes in all PQ Buses are also observed. It is shown that the optimal placement of DG units in the system caused a reduction in both power losses and MVA intake from the grid. From the above results, it is observed that Bus No. 30 is the best Location for Placement of a single DG.

Also figure 2 shows the power losses reduction according to the number of generators located in the system. The reduction in real power loss was in the range of 7.6% up to 24%.

The effect of inserting DG units in the system on the voltage profile shown in figure 3. It is seen that the voltage of all PQ buses has been improved after placing DG's respectively at proper locations. The Blue colour characteristic indicating the voltage profile of buses obtained after Optimal Power Flow (Cost Optimization as Objective Function) without penetration of DGs. The Green, Red, Light Green, Pink and Grey colour characteristics indicating the voltage profile of buses obtained after placement of one, two, three, four and five DG's respectively. From the figure it is observed that after placement of DG's, the voltage magnitude of Bus No. 30 improves specially.

VII. CONCLUSION

We have seen how PSO solves the DG placement issue by achieving reduced active power loss while maintaining voltage profile. Results obtained based on various cases presented in the paper correlates the same. The proposed method deals with optimal selection of nodes for the placement of DG using PSO and is tested with IEEE 30-Bus system. From the results the reduction of active power loss and the improvement of voltage profile can be observed. In conclusion, this paper highlights two important observations:
1. The power losses of distribution system can be effectively reduced by proper placement of DG.
2. On top of reduced power loss, voltage profile can also be maintained.

This method is also relatively versatile for handling various qualitative constraints. Being a stochastic search method, main disadvantage of this proposal is large computing time required to obtain optimal solution. However, benefits achieved via this method far outweighs this disadvantage.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 01, January-2017

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