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Optimal Planning of Distributed Generators in an Unbalanced Distribution Networks using Particle Swam Optimization Method

[1]S. M. Lawal, [2]M, Mohammed & [3]R. A. Abarshi
[1&3]Electrical and Electronic Engineering Department
Kaduna Polytechnic, Kaduna
[2]Department of Electrical Engineering Technology
Federal Polytechnic, Kaura-Namoda

Corresponding Author: S. M. Lawal

Abstract

This paper presents an algorithm for optimal planning of Distributed Generator (DG) connected to the unbalanced distribution networks. The proposed algorithm is able to deal with the practically constrained optimization problems by proposing formulas for tuning the algorithm parameters and updating equations. The proposed algorithm rigidly determines the optimal location and size of the distributed generation units in order to minimize the system power loss without violating the system practical constraints and nominal voltage. Moreover, the optimal DG location and minimum size for achieving a certain specified power loss are determined using the proposed method and compared to the results of a proposed heuristic technique such as Genetic Algorithm (GA). The distributed generation units in the proposed algorithms is modeled as voltage controlled node with the flexibility to be converted to constant power node in case of reactive power limit violation. The result shows that base case load flow to determine the Power loss and voltage deviation is found to be 221.27kilo watt (kW) and 1.4651V respectively at an objective function value of 1. The Optimal Placement and Sizing of a single DG in an electrical distribution network using Particle Swarm Optimization (PSO) revealed that the best location of the DG in the network is found to be bus number 12 with a size of 2494kW with a dropped in power loss to 114.73kW and voltage deviation of 1.3416V from 221.27kW and 1.4651V, while That of GA settled at bus number 31 as it best location with a maximum size of DG to be 2534kW. The power loss was reduced 117.72kW as against the initial value of 221.27kW with a reduction also in voltage deviation to 1.3816V from 1.4651V at an objective function of 0.7376. The proposed algorithms are implemented in MATLAB and tested on the IEEE 34-bus and validated with the IEEE 33-nodes feeder. The validated results were compared with published results obtained from other competing methods and show the effectiveness, accuracy and speed of the proposed method.

Keywords: *Algorithm, Distributed generation, MATLAB, Particle swarm optimization, Power loss*

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Background to the Study

The electrical power generation unit is expected to function as reliable as possible in both voltage and frequency stability of the network by avoiding all necessary disturbances which can jeopardize the electrical system performance(El-Hawary, 2008). The transmission aspect of power system network transfer the bulk energy generated through a long distance to the distribution network and used to interconnect neighbouring utilities which allow the economic dispatch of power within regions during normal conditions(Akorede, et al, 2010). The distribution system otherwise known as medium or low voltage systems transfer the energy to the consumer or load centres as the end user based on the nominal voltage of the energy generated. This type of generation is called the conventional or centralized system of electrical power generation, and the generation plant can be thermal power, hydro power station, nuclear power station etc. But due to general concern for the environment and also conservation of fossil fuels, alternative sources are now being considered so as to preserve and minimize the negative impact caused by these conventional power generating plants to the environment(De Souza & De Albuquerque, 2006). This alternative source of power generation option is known as Distributed Generation.

Distributed Generation (DG) has become one of the options in electrical power provision in order to curtail or reduce the problems posed by the conventional power systems. As DG is becoming increasingly popular with high level of acceptability, the problem of optimum placement of the DG in the distribution networks with the correct capacity are the main challenges for power utilities (Tautiva et al, 2009). To address these issues, this paper focuses mainly on the optimal placement and sizing of DG in the distribution networks, but distribution networks has been found to be exhibiting significant voltage drop due to their high R/X ratio that could cause substantial power losses along the feeders (Ghosh & Ghoshal, 2010). In the light of this aforementioned problem, installations of DG within the radial distribution networks level will have an overall positive impact towards reducing the power losses, voltage deviation as well as improving the network voltage profiles. A forward/backward sweep method was adopted for the load flow analysis due to its distinctive solution techniques on distribution networks that out way other conventional load flow methods in terms robustness and efficiency performance in distribution networks system(Kansal et al 2011).

A number of works have been reported in this area of optimal location and sizing in power system using different optimization techniques. A good number of publications have looked at optimizing the location and sizing of DG based on different criteria. Celli &Pilo, 2001,employed Genetic algorithm optimization technique for optimal DG allocation in medium voltage distribution networks. Power demands of the loads and their growth versus time, duration of the planning period were considered, some cost parameters such as inflation and interest rates, unit cost of kilo Watt hour (kWh) lost due to Joule effect (cost of losses), construction and maintenance costs of feeders of different cross-sections were all evaluated in objective function.

De Souza &De Albuquerque, 2006, made use of Evolutionary Programming for optimal placement of DG in distribution networks so as to minimize the active power losses of the feeder and the total network supply cost. The method used is highly efficient for distributed generation economic analysis because the generators allocation and sizing proposed by the algorithm could significantly reduce the total load supply cost, and its applicability has been tested in a feeder with high losses index. Vallem &Mitra, 2005, made used of Simulated Annealing optimization technique for optimal sitting and Sizing of Distributed Generation for Micro-grid Architecture, which involved the planning issues such as optimally designing the interconnections, sizing and sitting the DG units to maximize reliability, reduce costs and improve security of the system, and also an estimated capacity and location of the DG has been achieved with level of reliability (Anantasate et al, 2008). In this paper, optimal placement and sizing of DG in radial distribution networks were determined to minimize power loss and voltage deviation as well as maximize voltage profile in the distribution networks by means of particle swarm optimization (PSO).

Methodology

Problem Formulation

The optimal placement and sizing of Distributed Generation (DG) problem is formulated as a constraint nonlinear optimization problem with both locations and sizes of DG being continuous. The objective functions adopted in this study are the total active power loss function and voltage deviation function. The multiple nature of the problem, made it necessary to form a multi-objective function in search of the solution that consist of both the DG location and size.

Constraints

Along with the objective function, there is another significant part of the optimization model that needs to be defined and that is the constraints. In real applications, there are always limits on the choices of control variables. The constraints considered in this research are of two types: equality and inequality.

Equality Constraints

The equality constraints are those associated with the nonlinear power flow equations. It is noted in many published papers that the power flow equations are the real and reactive power mismatch equations. The reason for this is that modified versions of conventional power flow programs such as Newton-Raphson method and Gauss- Siedel method are widely used. In this work, the power flow representation is based on bus current injections and thereby the equality constraints are the bus current mismatch equations. Mathematically speaking, the equality constraints can be always expressed in a vector form as follows:

$$H(x, u) = Q \quad (1)$$

Where: **x**: the vector of state (dependent) variables, and **u**: the vector of control (independent) variables.

Inequality Constraints

The inequality constraints are those associated with the bus voltages, total current flow, and DG(s) to be installed.

Bus Voltage and Current Limits

The bus voltage magnitudes are to be kept within acceptable operating limits throughout the optimization process.

Vmax>|*V*|>*Vmin*
Imin<| I| <I max
Where; *Vmin*: the lower bound of bus voltage limits, *Vmax*: the upper bound of bus voltage limits, and |V|: the rms value of the *i*th bus voltage
The same applicable to the current in the system, from minimum to maximum

Active Power Loss
The total active power loss in an electric power system is given by,

$$P_{loss} = \sum_{l=1}^{b} R_l I_l^2 = \sum_{i=1}^{n} \sum_{j=1, i\neq j}^{n} [V_i^2 + V_j^2 - 2V_iV_j \cos(\delta_i - \delta_j)] Y_{ij} \cos\varphi_{ij} \qquad (2)$$

Where; **b** is the number of lines, $\mathbf{R}_l$ is the resistance of line ***l***, $\mathbf{I}_l$ is the current through line ***l***, $\mathbf{V}_i$ and $_i$ are the voltage magnitude and angle at node ***i*** and $\mathbf{Y}_{ij}$ and $_{ij}$ are the magnitude and angle of the line admittance, respectively.

The objective function for solving the DG optimal planning problem is computed using equations (2). Due to the objectives, it would be impossible to incorporate all the constraints in the same mathematical function. An overall fitness function is considered such that each objective function is normalized in a comparative manner with the base case system without DG. This fitness function is given by;

$$f(x) = \frac{P_{loss}}{\sum \Delta Loss_{base}} \qquad (3)$$

Where; $\mathbf{P}_{loss}$: Total active power loss.

$\sum \Delta Loss_{base}$: The total base case active power loss in the network

Objective Functions (OBF)
Due to peculiar nature of the nonlinear optimization problem with an objective function that are to be combined and solve simultaneously; it is therefore an objective function. In this case objective is being formulated in searching for a solution consisting of both the DG location and size that minimizes active power loss as in the objective function base on the individual weight assigned to the objective function base on its magnitude. Therefore;

This fitness function is given by;

$$f(x) = \frac{P_{loss}}{\sum \Delta Loss_{base}} \qquad (4)$$

34-Bus Radial Distribution System

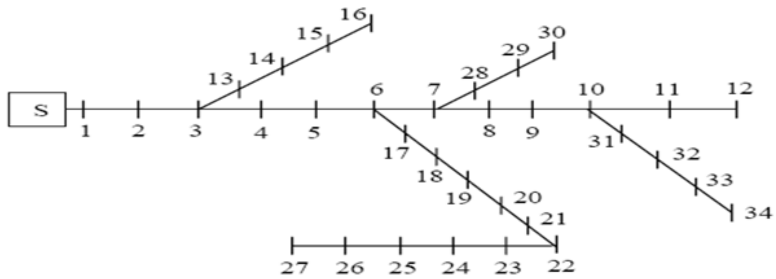


Fig 1.1 Single Line Diagram of IEEE 34 Bus Distribution System (Kannan et al, 2010).

Algorithm for Optimal Placement of DG Based on PSO Technique

Step 1:Randomly generates an initial population (array) of particles with random positions and velocities on dimensions in the solution space. Set the iteration counter $k = 0$.

Step 2: For each particle if the bus voltage and line loading are within the limits, calculate the total power loss.

Step 3: For each particle, compare its objective value with the individual best. If the objective value is lower than *Pbest,* set this value as the current *Pbest,* and record the corresponding particle position.

Step 4: Choose the particle associated with the minimum individual best P best of all particles, and set the value of this *P best* as the current overall best *G best*.

Step 5: Maximum fitness and average fitness values are calculated. Error is calculated using the following equation;
Error = (maximum fitness – average fitness). If this error is less than a specified tolerance then go to step 9.

Step 6: Update the velocity and position of particle using equations provided.

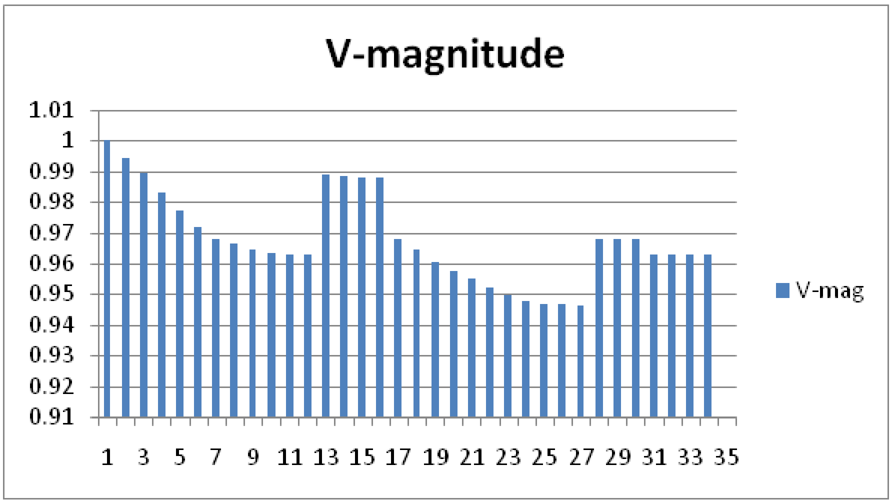
Step 7: New fitness values are calculated for the new positions of all the particles. If the new fitness value for any particle is better than previous P best value then P best value for that particle is set to present fitness value. Similarly G best value is identified from the latest P best values.

Step 8: The iteration count is incremented and if iteration count is not reached maximum then go to step 2.

Step 9: G best particle gives the optimal DG Placement in *n* candidate locations and the results are printed.

Simulation Results and Discussion

The study was conducted on 34-bus Radial Distribution network system as shown in Fig 1.1, where the developed algorithms were tested on an IEEE-34-bus radial distribution system. The test system (34-Bus-Radial Distribution networks System) is an unbalanced radial distribution system used as a standard test system and validated with 33-bus test systems as presented in Table 1.1 and 1.2. The power loss minimization is close to each other even though voltage has been considered in this work unlike in the referred paper. In order to check the efficiency and working performance of the PSO algorithm, another algorithm was developed using Genetic Algorithm (GA) for comparison. The results were carried out based on single and double DG placement in radial networks.



Optimal Placement and Sizing of a Single DG in 34-bus RDS

A single DG source is to be installed in the 34-bus RDS, and the PSO is used in investigating the optimal DG size and bus location simultaneously. The PSO maximum number of iterations, swarm particles and acceleration constant parameters are tuned for optimal result as presented in the program. The obtained PSO results for this case are tabulated in Table 1.1

Table 1.1 DG Placement Results using different Optimization Methods

	Base Case	**GA**	**PSO**
The best Location of DG (No. of Bus)	--	31	12
The best Size of DG(kW)	--	2534 on (31)	2494 on (12)
Power Loss (kW)	221.27	117.72	114.73
Voltage Deviation	1.4651	1.3816	1.3416
Objective Function Value	1	0.7376	0.7171

The PSO method obtained both the single DG optimal bus location and rating simultaneously. It returned a different bus location for the DG to be installed in both cases than that of the GA method. The PSO proposed bus No. 12 for the single DG, while the bus location obtained by the GA method is No. 31. The mean values of the real power losses for cases is comparable to that of the GA method for both cases, The simulation time of the PSO method to reach both location and sizing results simultaneously outperforms that of its counterpart (GA). The convergence characteristic of the proposed PSO in the single DG case is shown in Figure 1.4 for a maximum PSO number of iterations of 200. And also this shows that even if the number of the iterations is increased, the PSO algorithm has already settled to its final value.

The base case load flow to determine the Power loss and voltage deviation is found to be 221.27KW and 1.4651 respectively at an objective function value of 1. The Optimal Placement and Sizing of a single DG in an electrical distribution network using PSO revealed that the best location of the DG in the network is found to be bus number 12 with a size of 2494KW with a dropped in power loss to 114.73KW and voltage deviation of 1.3416 from 221.27KW and 1.4651v as can be seen in Table 1.1, while That of GA settled at bus number 31 as it best location with a maximum size of DG to be 2534KW. The power loss was reduced 117.72KW as against the initial value of 221.27KW with a reduction also in voltage deviation to 1.3816 from 1.4651 at an objective function of 0.7376. The PSO convergence characteristic is shown in Fig 1.4 while that of GA is presented in Fig 1.5

Comparing the two output results, it is clear that the proposed PSO algorithm is more efficient and faster in terms of convergence (at 144) as against it counterpart GA which converged at 184, and also when it minimizes the power loss and voltage deviation much lower than that of GA, therefore the proposed PSO algorithm has shown an aged performance over GA as shown in table 1.1

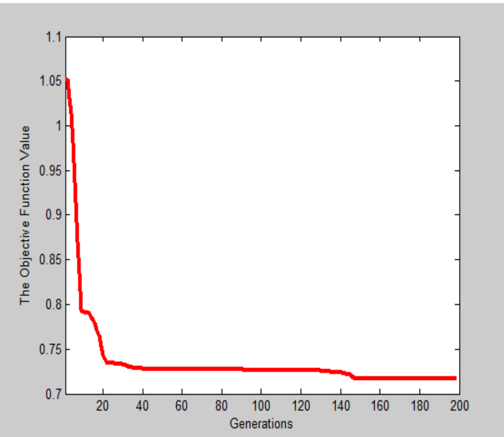


Fig 1.4 PSO (Converged in Iteration No. 144)

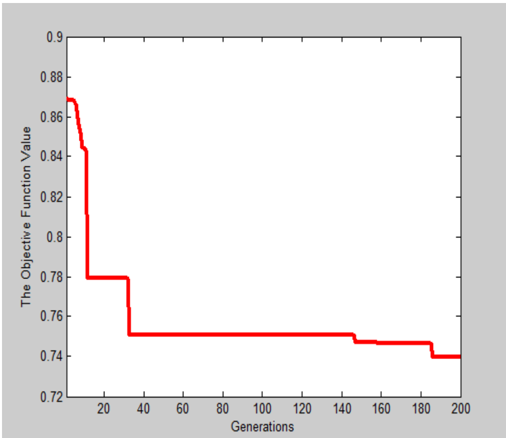


Fig 1.5 GA (Converged in Iteration No. 182)

Voltage deviation has been minimized greatly that helps the distribution networks to regain it nominal voltage within the network because the smaller the voltage deviation the better for the distribution network as the nominal voltage maintain it status, as can be seen in Fig 1.6, the voltage profile improved within the networks while Fig 1.7 shows how voltage deviation has controlled and minimized as it moves towards 1p.u.

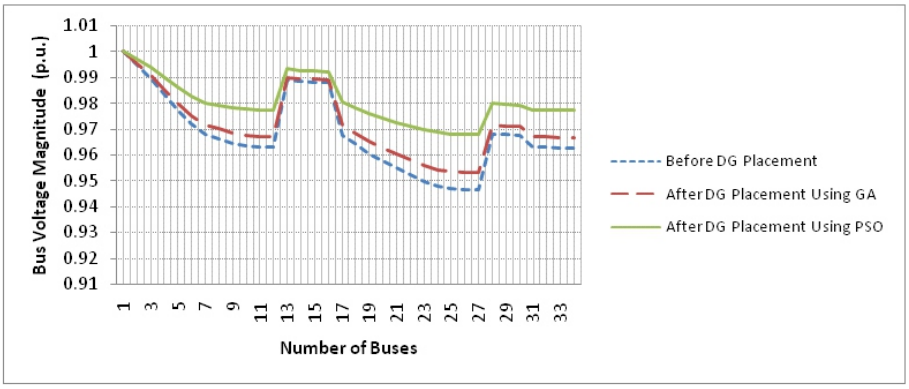


Fig 1.6 Voltage Profile and its improvement

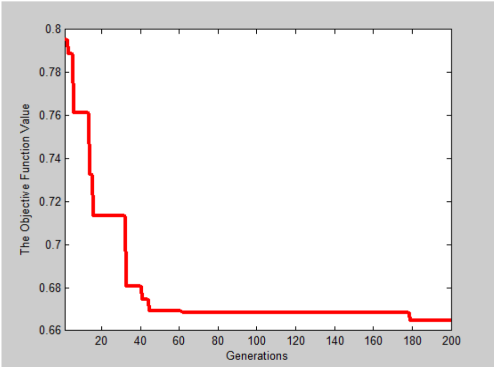
Optimal placement and sizing of double DGs in 34-bus RDS

The proposed PSO algorithm was utilized to optimally size and place two DG units in the 34-bus RDS. Table 1.2 presents the double DG case simulations results of the PSO and GA respectively. The PSO consistently chooses buses 22 and 27 for the two optimally sized DG units to be installed after several runs of the simulation. The PSO meta-heuristic technique obtained the optimal DG locations and sizes simultaneously. The corresponding PSO results are compared to that of the GA method, as shown in Table 1.2. The PSO active power losses results are close to each other, i.e. GA losses are higher by 0.3%.

Table 1.2 DG Placement Results using Different Optimization Methods

	Base Case	**GA**	**PSO**
The best Location of DGs (No. of Buses)	--	17 & 28	22 & 27
The best Sizes of DGs(kW)	--	2465 on (17) & 497 on (28)	1108 on (22) & 841 on (27)
Total Size of DG (kW)	--	2962	1949
Power Loss (kW)	221.27	89.11	86.99
Voltage Deviation	1.4651	1.358	1.3529
Objective Function Value	1	0.6648	0.6583

Distribution System network real power losses were reduced by approximately 5% when compared to the losses of the GA method, as shown in Table 1.2. For both double DG cases, the Distribution System bus voltages range not only within limits but their deviation from the nominal voltage value is minimal and is similar to that of the GA method.



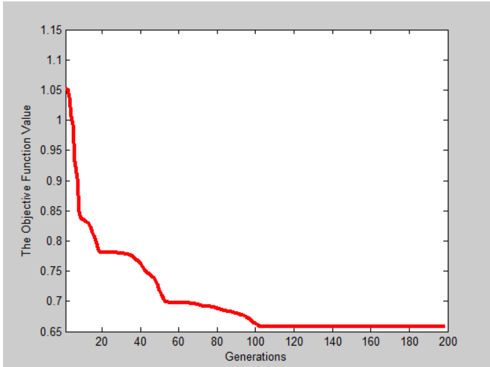


Fig 1.8 GA (Converged in Iteration No. 179) **Fig 1.9 PSO (Converged in Iteration No. 102)**

Conclusion and Recommendations

Optimal need of correct placement and sizing compelled the proposed work due to new trend of integrating DG within electrical distribution power system networks has gained popularity worldwide due to its overall positive impact despite the little short comings associated with the system. DG helps in load peak shaving and in enhancing system reliability when it is utilized as a back-up power source when a voluntary interruption has been scheduled. The DG can defer costly upgrades that might take place in the transmission and distribution network infrastructure and decrease real power losses. Having a minimal environmental impact and improving the Distribution networks voltage profiles are additional merits of such addition to the network.

In this paper, the optimal DG placement and sizing problems within distribution networks were investigated by utilizing heuristic method. This proposed power flow algorithm used was incorporated within the conventional method as well as in the PSO meta-heuristic method to satisfy the nonlinear equality constraints. The DG sizing problem is formulated as a constrained nonlinear programming optimization problem with the Distribution networks active power loss and voltage deviation as the objective functions to be minimized. The PSO search method was utilized to find the optimal DG placement and sizing in the tested 34-bus distribution networks, these results were subsequently compared to those obtained by the GA heuristic method. The PSO was utilized to optimally locate and size single and double DGs. The DG integration problem was formulated as a constrained mixed-integer nonlinear optimization problem and was solved via the developed PSO method. The output solution of the developed PSO optimization method is expected to deliver both the DG location bus as a positive integer number and its corresponding rating as real value in a single run. That is, both optimal DG placement and sizing are obtained simultaneously.

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