

OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION IN DISTRIBUTED NETWORK FOR ACTIVE POWER LOSS REDUCTION USING PARTICLE SWARM OPTIMIZATION TECHNIQUE

Ibrahim, S.B.

Department of Electrical Engineering, Bayero University Kano, Nigeria

E-mail: sabkibr@yahoo.com

ABSTRACT

This paper presents application of Particle Swarm Optimization (PSO) based method for optimal sizing and placement of single Type 1 Distributed Generation (DG) into 69-bus IEEE test network for active power minimization and voltage profile enhancement. The proposed method makes use of an analytical approach (exact loss formula) to compute the size of DG at each bus. The DG sizes identified are used in the PSO algorithm to determine the optimum size and location of the DG in the network. The results obtained from the proposed method indicate that the optimal size and location of a Type 1 DG on the network are 1807kW and bus 56 respectively. The proposed method records 63.1% reduction of the active power loss in the network, a reduction from 230.33kW (without DG) to 84.98kW with DG optimally sized and located. The result also showed that the average voltage profile of the network is improved by 2.8% from 0.9399pu to 0.9663pu when Type 1 DG of size 1807kW is installed at bus 56.

Keywords: Optimal, Placement, Sizing Active power, PSO, DG

1.0 INTRODUCTION

The conventional electric power generation systems utilize conventional energy resources, such as fossil fuels, hydro etc for electricity generation. The operation of such systems is based on centralized utility generators, delivering power through an extensive transmission and distribution networks to meet load demands. The justification for the conventional electric power generation is becoming weak by the day due to the depletion of the conventional resources, increased transmission and distribution cost/losses, environmental concerns and technological advancement.

Modern electric power systems are configured as decentralized systems with smaller generating units (Distributed Generators) connected directly to distribution networks near the load centres [1, 2]. Appropriate sizing and placement of distributed generation (DG) in distribution network would lead to improvement in the voltage profile and reduce power loss in the power system [3, 4].

In order to harness the above stated benefits from DG, it should be optimally sized and placed in the distribution network. Improper placement and sizing will worsen the voltage profile and increase power loss in the power system. Researchers have used many methods for the

optimal placement of DG. An analytical method such as 2/3 method has been used for the optimal placement. The underlying assumption for the method is that if the loads in the power system are balanced, then the size of the DG is 2/3 of the total incoming generation of the system and the DG should be placed at 2/3 location of the distribution feeder. However, the method is not suitable for non-uniform loads on the feeder [5].

Optimal DG placement and sizing for power loss reduction with optimal size and power factor have been presented in [6, 7]. The method in [6] has been tested on three test distribution systems with varying size and complexity and validated using exhaustive method. Results showed that the proposed method requires less computation, but can lead to optimal solution as verified by the exhaustive load flow method. Optimal size of different types of DG using analytical method for optimal placement and sizing is described in [8]. The results obtained on a 69-bus distribution test system demonstrated that the proposed approach is adequate to determine the location, size and power factor of DG unit for minimizing energy losses. An analytical method based on power stability index for power loss reduction has been presented in [9]. The method takes less computation time by 50–60% as compared to Golden Section Search (GSS) algorithm.

Linear programming method for optimal DG placement based on maximum amount of energy, considering financial and technical constraints was presented in [10, 11]. The methodology in [10] was implemented and tested on sections of the Irish distribution network and the results of the work demonstrated that the proper placement and sizing of Embedded Generation is crucial to the accommodation of increasing levels of Embedded Generation on distribution networks. Non-linear programming method to solve the optimal DG placement and sizing problem for wind and all DG types were discussed [12, 13]. The methodology in [12] is based on generating a probabilistic generation load model that combines all possible operating conditions of the wind-based DG units and load levels with their probabilities, hence accommodating this model in a deterministic planning problem. The proposed technique was applied to a typical rural distribution system and compared with the traditional planning technique (constant output power of DG units and constant peak load profile). The optimal sitting and sizing of DG considering multi-constraints with single or multi-objective using Genetic Algorithm (GA) was used in [14, 15]. The algorithm in [15] proposes a satisfying method to solve the constrained multiple objective problem. Updating the expected value of each objective function allows the dispatcher to obtain the compromised or satisfied solution efficiently. The DG and STATCOM for power loss minimization using PSO was presented in [16]. The author used direct load flow method, called BIBC matrix for load flow analysis, and compared results with sensitivity factor method. Binary PSO based multi-objective model for optimal placement and sizing of DG with uncertainty was presented in [17]. The new planning model was applied to a realistic distribution network and its flexibility was demonstrated through different case studies. The solution set provides the planner with an insight into the problem and enables him to choose the best solution according to planning preferences. A new hybrid method for optimal sitting and sizing of DG using discrete PSO and optimal power flow was presented in [18]. The

proposed algorithm reached a better solution than Genetic Algorithm considering similar number of evaluations.

In this paper an analytical method (Exact Loss formula) is employed for the sizing of Type 1 DG (DG that is capable of injecting active power only like photovoltaic system) for active power loss reduction using MATLAB R2013a and a Particle Swarm Optimization (PSO) algorithm is also applied to find the optimal size and location of the DG in 69-bus IEEE network. The problem is formulated as a single objective function of minimizing the system active power losses considering the constraints on active power generation, DG position and voltage limits. This optimization problem is solved using Particle Swarm Optimization (PSO) algorithm. At each step, DG is placed at a bus and the power flow analysis is carried out using Backward-Forward Sweep power flow method to evaluate the variation in power losses of the system considering the constraints. This work uses Power System Analysis Tool (PSAT) for evaluating the voltage profile and active total power loss of the 69-bus IEEE test network. The proposed method is validated using the base case system (system without DG).

2.0 MATERIALS AND METHODS

The materials used in the work include a computer with specifications: 2.00GHz Intel(R) Core(TM) 2Duo central processing unit (CPU), 4GB installed memory (RAM) and 32-bit windows operating system (OS). Simulations were performed under the platform of MATLAB R2013a, using PSAT Toolbox for analysis.

2.1 Methodology

The various methods used for optimal placement of DG differ based on the problem statement, desired objective functions, constraints and the individual characteristics of the chosen method. A broad classification of the methods used for optimal location and sizing of DG are: Analytical, Heuristic and hybrid techniques.

2.1.1 Analytical Method for DG Sizing

A common strategy for location and sizing of DG is mostly to minimize the total active power loss of the power system subject to voltage limits, line flows limit and total harmonic distortion limits etc. These limits are important so that integration of DG into a system does not contribute negatively to the power quality of the system [19]. The total active power loss in power systems popularly known as ‘Exact loss formula’ is expressed in equation (1) [6].

$$P_L = \sum_{i=1}^N \sum_{j=1}^N \left[\alpha_{ij} \left(P_i P_j + Q_i Q_j \right) + \beta_{ij} \left(Q_i P_j - P_i Q_j \right) \right] \dots\dots\dots (1)$$

Where

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j} \cos(\delta_i - \delta_j) \dots\dots\dots (2)$$

$$\beta_{ij} = \frac{r_{ij}}{V_i V_j} \sin(\delta_i - \delta_j) \dots\dots\dots (3)$$

$$z_{ij} = r_{ij} + x_{ij} \dots\dots\dots (4)$$

$V_i \angle \delta_i$ is the complex voltage at the *i*th bus; P_i and P_j are the active power injections at the *i*th and *j*th buses respectively; Q_i and Q_j are the reactive power injections at the *i*th and *j*th buses respectively and *N* is the number of buses.

The active and reactive power injected at bus ‘*i*’, where a DG is located is given by equations (5) and (6) respectively.

$$P_i = P_{DG_i} - P_{Di} \dots\dots\dots (5)$$

$$Q_i = Q_{DG_i} - Q_{Di} = aP_{DG_i} - Q_{Di} \dots\dots\dots (6)$$

Where ‘*a*’ is a constant depending on the type of DG.

Based on equations (1), (5) and (6), the active power loss can be rewritten as:

$$P_L = \sum_{i=1}^N \sum_{j=1}^N \left[\alpha_{ij} \left((P_{DG_i} - P_{Di}) P_j + (aP_{DG_i} - Q_{Di}) Q_j \right) + \beta_{ij} \left((aP_{DG_i} - Q_{DG_i}) P_j - (P_{DG_i} - P_{Di}) Q_j \right) \right] \dots\dots\dots (7)$$

The total active power loss of the system is minimum if the partial derivative of equation (7) with respect to the active power injection from DG at bus ‘*i*’ becomes zero. Thus, the optimal size of DG at each bus ‘*i*’ for minimizing loss can be written as:

$$P_{DG_i} = \frac{\alpha_{ii} (P_{Di} + aQ_{Di}) + \beta_{ii} (aP_{Di} - aQ_{Di}) - x_i - aY_i}{a^2 \alpha_{ii} + \alpha_{ii}} \dots\dots\dots (8)$$

For type 1 DG, power factor is at unity, i.e., $PF_{DG} = 1$ and $a = 0$. For this type of DG the size of DG at each bus ‘*i*’ for minimizing loss can be written as:

$$P_{DG_i} = P_{Di} - \frac{1}{\alpha_{ii}} \left[\beta_{ii} Q_{Di} + \sum_{j=1, j \neq i}^N (\alpha_{ij} P_j + \beta_{ij} Q_j) \right] \dots\dots\dots (9)$$

The total active power loss is the losses due to the voltage drop along the branches of the power system network, which is expressed as:

$$P_{loss} = \sum_{i=1}^{br} P_{loss(i)} = \sum_{i=1}^{br} |I_B|^2 R \quad i = 1, 2, 3, \dots, br \dots\dots\dots (10)$$

Where I_B is the branch current and R is the resistance of the branch.

The sizes of the DG at various buses together with the total active power loss can be computed using equation (9) and (10) respectively. The flow chart for the analytical sizing of the DG is shown in Fig. 1.

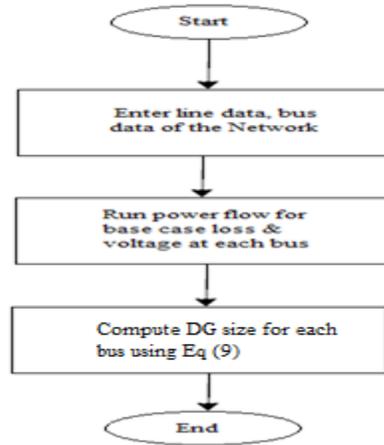


Fig. 1: Flowchart of Analytical Method for DG Sizing

2.1.2 Objective Function and Constraints

The main objective of the work is to determine the optimal location and sizing of the DG in the distribution network (69-bus IEEE test network) that will minimize active power loss as well as satisfies the voltage, DG position and power constraints of the network. The following objective function is used, subject to constraints given in equations (12), (13) and (14).

$$F = \min P_{loss} = \sum_{i=1}^{br} P_{loss}(i) = \sum_{i=1}^{br} |I_B|^2 R \dots\dots\dots (11)$$

The network active power flow, DG position and bus voltage levels limits must be satisfied. Thus,

$$P_{DG_i} = P_{loss} + \sum P_{Di} \dots\dots\dots (12)$$

$$2 \leq DG_{position} \leq 69 \dots\dots\dots (13)$$

The voltage at every bus in the network should be within $\pm 5\%$ of the permissible limit [20].

$$V_i^{\min} \leq V_i \leq V_i^{\max} \dots\dots\dots (14)$$

2.1.3 Optimal Location of DG using PSO

Particle Swarm Optimization (PSO) is a population based optimization method inspired by social behaviour of bird flocking or fish schooling. In a PSO system, particles fly around in a multi-dimensional search space, and each particle adjusts its position according to its own experience (called Pbest), and according to the experience of a neighbouring particle (called Gbest). During each iteration of the PSO algorithm, the velocity and position of each particle is updated by equations (15) and (16) respectively till the stopping criterion (max number of iteration) is met.

$$v_{id}^{k+1} = \omega v_{id}^k + c_1 rand() (Pbest_{id} - x_{id}^k) + c_2 rand() (gbest_{id} - x_{id}^k) \dots\dots\dots (15)$$

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \text{ for } i = 1, 2, 3, \dots, n \text{ and } d = 1, 2, 3, \dots, m \dots \dots \dots (16)$$

where x^k is the current searching point, x^{k+1} is the modified searching point, v^k is the current velocity, v^{k+1} is the modified velocity of a particle, n is the number of particles in a group, m is the number of members in a particle, d is the dimensional space, k is the k th iteration, ω is the inertia weight factor, c_1 and c_2 are the acceleration constants, $rand()$ is a random value in the range 0 -1.

The following weighting function is used:

$$\omega_i = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \cdot iter \dots \dots \dots (17)$$

where ω_{\min} and ω_{\max} are the minimum and maximum weights respectively, $iter$ and $iter_{\max}$ are the current and maximum iteration.

The parameters of the PSO algorithm used in this work are: $c1 = 2$, $c2 = 2$, $w_{\max} = 0.9$, $w_{\min} = 0.4$, $r1 = r2 = \text{random number between 0 and 1}$, $iter_{\max} = 20$

$\text{number of particles} = \text{maximum number of buses} = 69$. The parameters chosen have proven to give good results in past research works [21].

2.1.4 PSO Algorithm

The PSO based method for determining the optimal size and location of a single DG is depicted by the flowchart in Fig. 2.

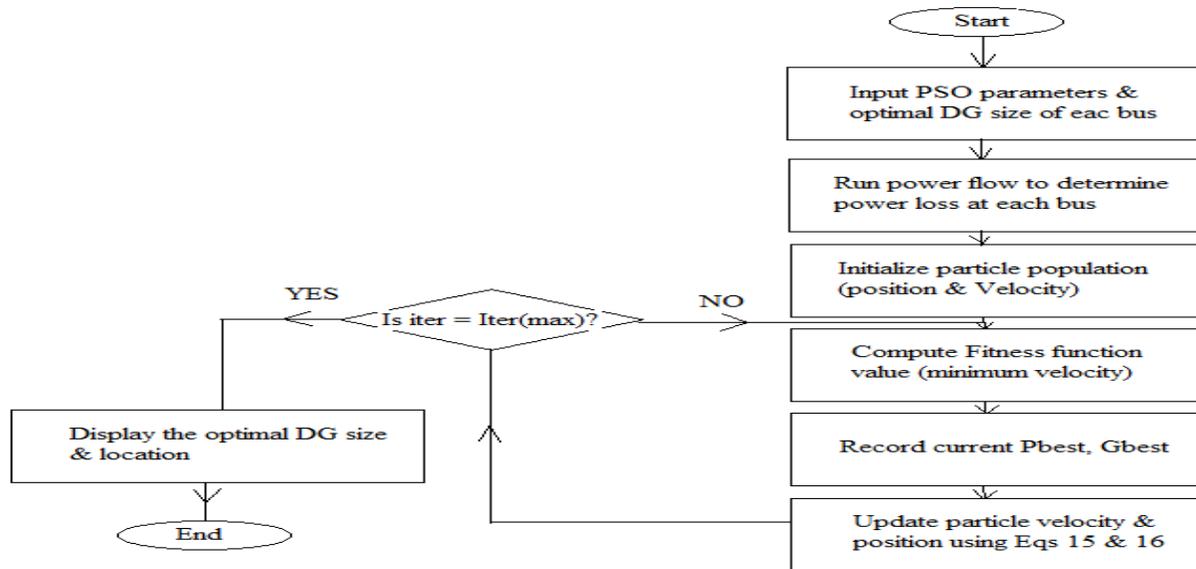


Fig. 2: Flowchart for Optimal DG Sizing and Placement

3.0 RESULTS AND DISCUSSIONS

Simulations were carried out for Type 1 DG which injects real power only like photovoltaic cell or fuel cell. Fig. 3 shows the single line diagram of the 69-bus IEEE test network, it has 69 buses, 68 sections, 7 laterals and one feeder which is taken as a generator bus. The total demand of the network is 3.793MW and 2.714MVar. The substation voltage is 12.66kV and the base power is 10MVA. The original (base case) total real and reactive power losses of the network is 230.04kW and 104.38kVar respectively.

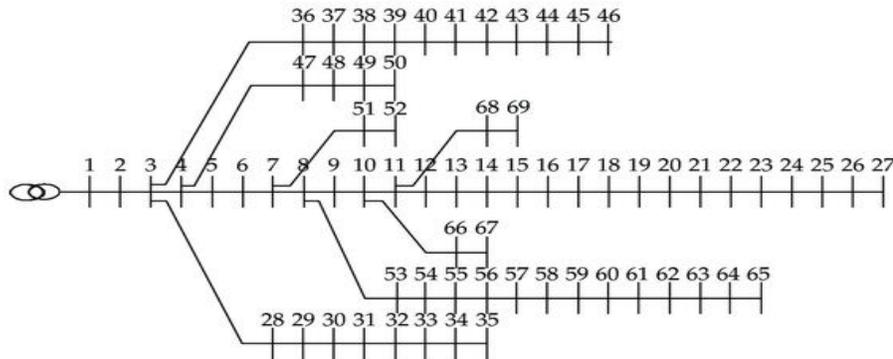


Fig. 3: Single Line Diagram of IEEE 69-Bus Test Network

DG size is computed at each bus for the test network that will give the lowest total loss using equation (9) and depicted in Fig. 4.

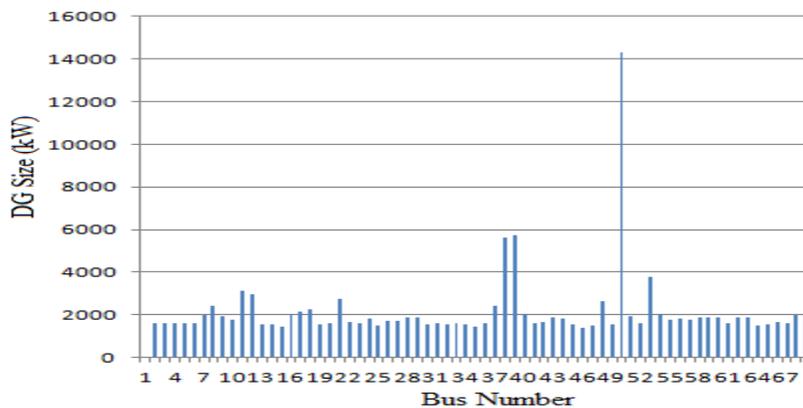


Fig. 4: Suitable DG Sizes of the 69-bus IEEE Test Network

The DG sizes so obtained together with PSO settings stated above are fed to the PSO algorithm depicted in Fig.2. The convergence characteristic of the best solution of the PSO is shown in Fig. 5.

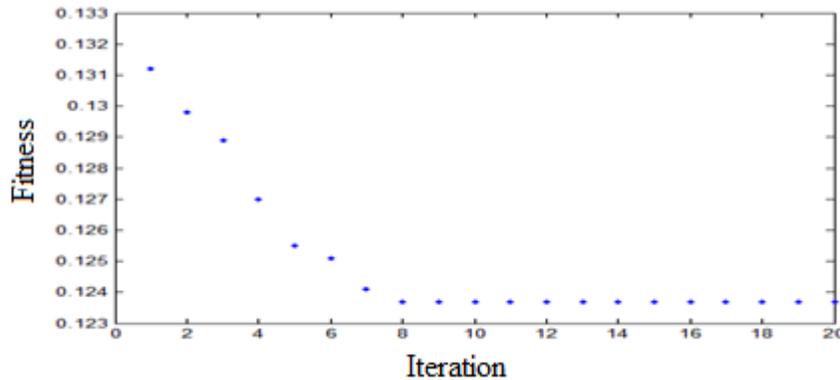


Fig. 5: Convergence Characteristics of PSO at 20 iterations

The result obtained from the PSO technique indicates that the optimal size of the DG is 1807kW for minimized active power loss and the optimal location of the DG is bus 56. Fig. 6 shows the active power loss in the network with installed DG size of 1807kW at bus 56.

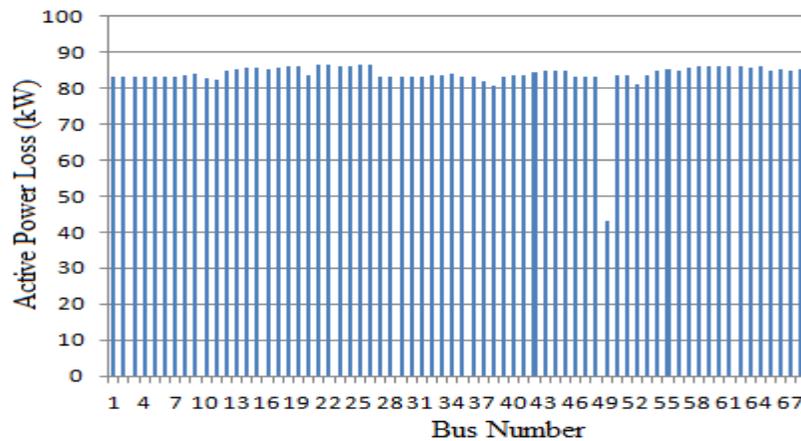


Fig. 6: Active Power Loss with DG Installed in the Network

The Power flow analysis on the network showed 63.1% reduction of the active power loss in the network, a reduction from 230.33kW (without DG) to 84.98kW with DG of 1807kW installed at bus 56.

The effect on voltage profile of the network with and without DG installed is shown in Fig. 7

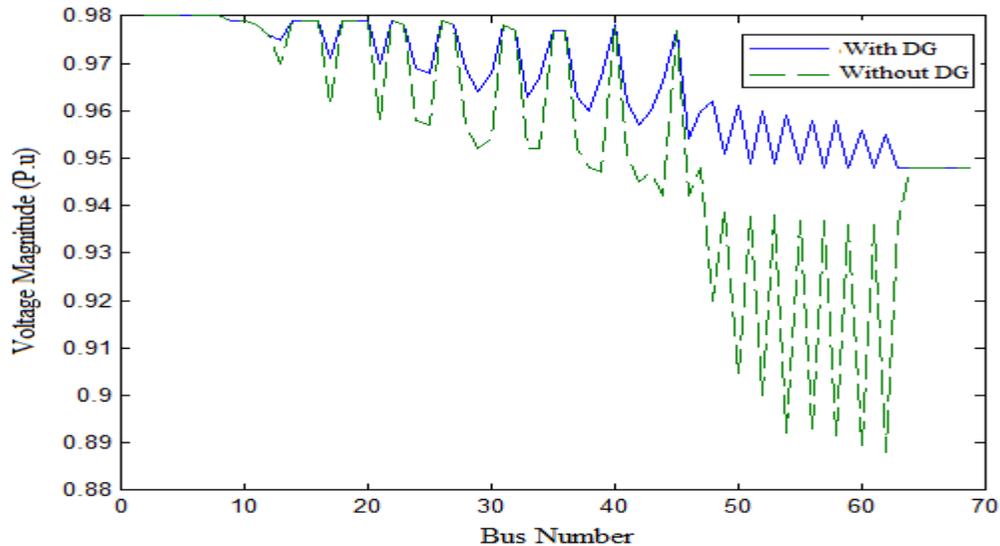


Fig. 7: Comparison of Voltage Profile with and without DG installed in the Network

It indicates that the voltage profile obtained with DG installed in the network give better average voltage level of 0.9663pu when compared with 0.9399pu obtained from the network without DG. Without DG installed in the network, bus 64 has the lowest voltage level of 0.888pu and has improved to 0.948pu with the optimal installation of DG of 1807kW at bus 56.

4.0 CONCLUSION

The paper presented a PSO based method for optimal sizing and location of Type 1 DG in the radial distribution system of 69-bus IEEE test network. An analytical method based on the exact loss formula was used to determine the likely size of DG at each bus of the network that will minimize active power loss in the network. PSO algorithm was applied and used to determine the optimal size and location of a single DG in the network with the objective of minimizing the total active power loss as well as improve the voltage profile of the network. The results shown in Figs. 6 and 7 obtained from the proposed method were validated using the performance metrics of active power loss and voltage profile improvement, by comparing them with the base case scenario (network without DG installed). The results showed that the average voltage profile of the network improved by 2.8% from 0.9399pu to 0.9663pu when Type 1 DG of size 1807kW is installed at bus 56. Similarly, the proposed method records 63.1% reduction of the active power loss in the network, a reduction from 230.33kW (without DG) to 84.98kW with DG.

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