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Multi-objective Based on Pareto System for Integration of Distributed Generation in Power Distribution Networks Using Particle Swarm Optimization

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Abstract

The report of the Sustainable Development Goal (SDG) shows that in 2012, ambient air pollution from traffic, industry, power generation, waste burning and residential fuel combustion resulted in an estimated 3 million deaths. There is an opportunity to reduce greenhouse gas emission through the integration of non-conventional /renewable energy source such as Distributed Generation. In this paper an approach based on Pareto of optimal solutions in a search space that evolved in multi-objective optimization problems is proposed for optimal placement of Distributed Generation (DG) in radial distribution networks. The major objectives are the minimization of power loss and the voltage deviation to improve network voltage profile. The problem is formulated as multi-objective using particle swarm optimization (PSO) as a constraint nonlinear optimization problem with both locations and sizes of DG considered as continuous. The objective functions adopted 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. The proposed method is tested on the standard IEEE 34-bus and validated with 33-bus test systems distribution networks. The result of the simulation study indicates that PSO algorithm technique shows an edge over other types of search methods due to its effectiveness and computational efficiency. In addition, results show that the sizing and location of DG are system dependent and should be optimally selected before installing in the power distribution network.

Keywords: *Pareto, Distributed generation, Particle Swarm Optimization (PSO), Power loss, Voltage deviation.*

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Background to the Study

Climate scientists and policy makers in developed countries consider that an 80% reduction in greenhouse gas emissions by 2050 is necessary if average global temperature rises of more than 2°C are to be avoided (Jenkins, Ekanayake and Strbac, 2010). Recent Sustainable Development Goal (SDG) report from the United Nations identified global warming as one of the gaps to be filled towards achieving its 2030 agenda for Sustainable Development. In 2012, ambient air pollution from traffic, industry, power generation, waste burning and residential fuel combustion resulted in an estimated 3 million deaths (SDG, 2017).

The electrical power generation industry can be seen as offering easier and more immediate opportunity to reduce greenhouse gas emission than, for example, road or air transport thus, likely to bear a large share of any emission reductions. These problems have led to a new trend of generating power locally at the distribution voltage level by using non-conventional/renewable energy sources. This type of power generation is termed Distributed Generation (DG). The term 'Distributed Generation' has been devised to distinguish this concept of generation from centralized conventional generation(Chowdhury, Chowdhury and Crossley, 2009). There has been a dramatic increase in distributed generation integration in power networks driven by sustainability, concerns about energy independence and increasingly favourable economics. Thus, the increasingly important role of Distributed generation in energy systems across the world cannot be overemphasized. DG has technical, economical and environmental benefits. The environmental benefits of DG include low noise and low emission realized by renewable generators such as solar photovoltaic (PV), which have no marginal emissions or CHP systems whose use of waste heat can result in higher efficiencies than central generation units (Akorede,*M. F, 2010)*,.

The integration of DG into a distribution system requires in-depth analysis and planning tools. Thus, this paper focuses mainly on the optimal placement and sizing of DG in the distribution network. Electrical distribution network systems normally include distribution feeders that has been arranged or configured either in mesh or radial pattern and it is mainly fed by a utility substation, 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. In the light of this aforementioned problem, installations of DG within the distribution level will have an overall positive impact towards reducing the losses, voltage deviation as well as improving the network voltage profiles (AlHajri, M. 2009).

Problem Formulation

In this paper, 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 (Anantasate,*2008)*.

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

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

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.

Voltage Deviation
The voltage improvement index for a power system is defined as the deviation of voltage magnitudes at each from unity. Thus, for a given system, the voltage improvement index is defined as;

$$L_v = \sqrt{\sum_{i=1}^{n} \left(\frac{V_{iref} - V_i}{V_{iref}} \right)^2}$$

Where;

n is the number of buses,
V_{iref} is the reference voltage at bus i and
V_i is the actual voltage at bus i.

The objective function for solving the DG optimal placement problem is computed using equations (1)-(2). Due to the fact that the two objectives are different, it would be impossible to incorporate all the constraints in the same mathematical function. (Celli and Pilo 2001) 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;

$$f(x) = W_1 \cdot \frac{P_{loss}}{\sum \Delta Loss_{base}} + W_2 \cdot \frac{L_v}{\sum \Delta V_{base}}$$

Where;

$\mathbf{P}_{loss}$ and $\mathbf{L}_v$ are total active power loss and voltage deviation index, respectively.
$\mathbf{W}_1$ and $\mathbf{W}_2$ are the corresponding coefficients the corresponding objective functions;
Cost factor, $\sum \Delta_{base}\ Loss$ is the total base case active power loss in the network and $\sum_{baseV}$ is the total base case voltage deviation.

Multi-Objective Functions (MOBF)

Once more than one objective functions are to be combined, therefore it will be called Multi-objective function (Anantasate,*2008)*.. In this case multi-objective is formulated in searching for a solution consisting of both the DG location and size that minimizes the voltage deviation and active power loss as described by the percentage in each objective function base on the individual weight so as to have the same magnitude range.

Therefore;

The weighting factors W1 + W2 =1; (0.5 and 0.5 respectively)

In this study, the corresponding coefficients for each objective are defined as 50%.

Since total the sum of W1 + W2 = 100% (w1+w2=1)

34-Bus Radial Distribution System

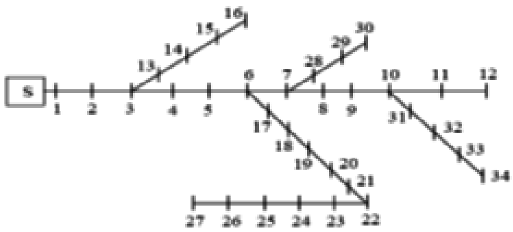

Fig 1. Single Line Diagram of IEEE 34 Bus Distribution System(El-Hawary, 2008).

VI. Particle Swarm Optimization (PSO)

Particle Swarm Optimization is a population based metaheuristic optimization technique that was first developed by Kennedy and Eberhart in 1995 inspired by the social behavior of bird flocking or fish schooling, on which individuals (particles) change their position (state) with time. Particle moves or fly around in a multidimensional direction in search of space, on which during the flight, each particle adjust or change its position according to its own experience(This value is called Pbest) and the neighboring particle(This value is called Gbest) experience, and finally made use of the best position encountered by itself and its neighbor[14] (see figure 2).

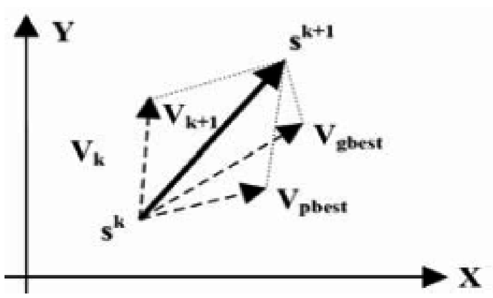

Figure 2. Concept of a searching point by particle swarm optimization

Where *sk* is current searching point, *sk* +1 is modified searching point, *vk* is current velocity, *vk* +1 is modified velocity of agent *i*, *pbest v* is velocity based on pbest, *gbest v* is velocity based on gbest, *n* is number of particles in a group, *m* is number of members in a particle, pbest*i* is pbest of agent *i*, gbest*i* is gbest of the group, ω*i* is weight function for velocity of agent *i*, *ci* is weight coefficients for each term.

PSO has same effectiveness as the genetic algorithm but with significantly better computational efficiency in term of less functional evaluations by implementing statistical analysis and formal hypothesis testing (Ghosh*, 2010)*.

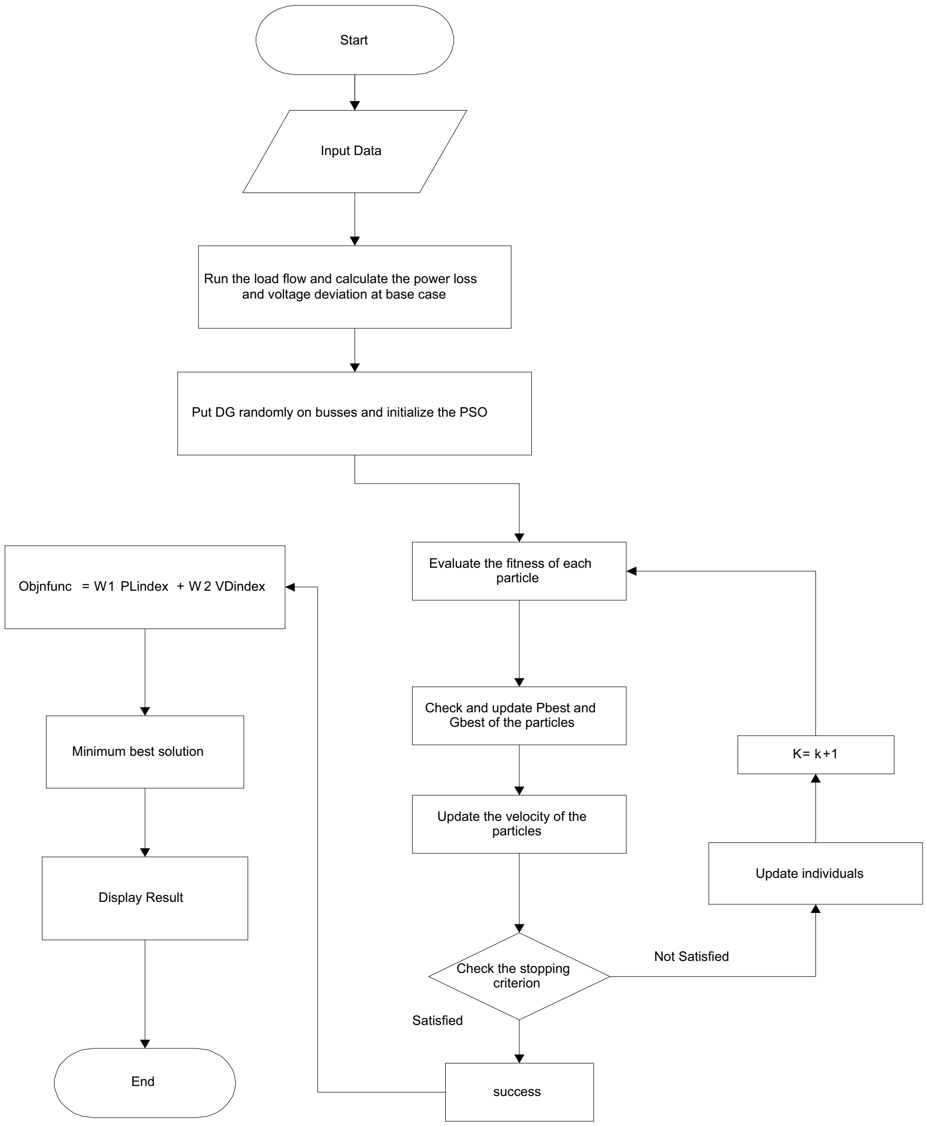

Fig 3. Flow Chart of the Solution Procedure Using PSO

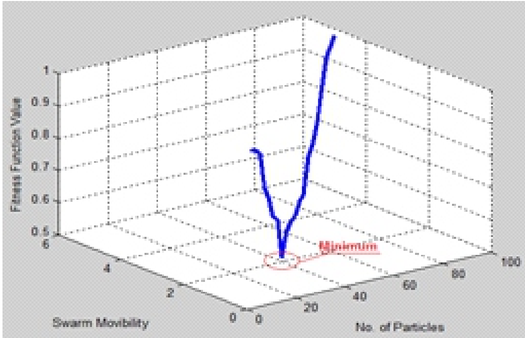

Fig 4. V. Pareto curve:

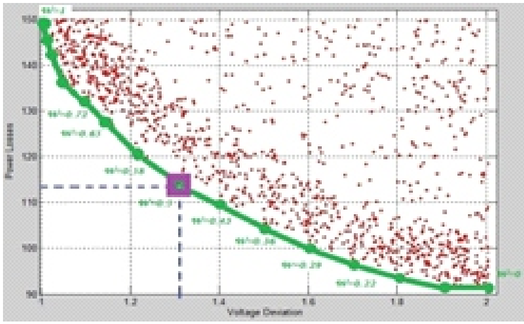

Fig 5. Pareto curve; Non-optimum realization (●), Pareto curve points (●)

This is for 15 different ω-values, the balanced optimum occurred on ω=0.5. The ω=0.5 is the 8th point among 15 Pareto curve points. The 8th point is exactly in the middle of 15 points and leads to balanced optimum (trade-off point). So ω=0.5 was chosen as coefficient factor of our fitness function.

The convergence characteristic of the proposed PSO in the single DG case is shown in Figure 6 for a maximum PSO number of iterations of 200. This shows that even when the number of the iterations is increased, the PSO algorithm is already settled to its final value.

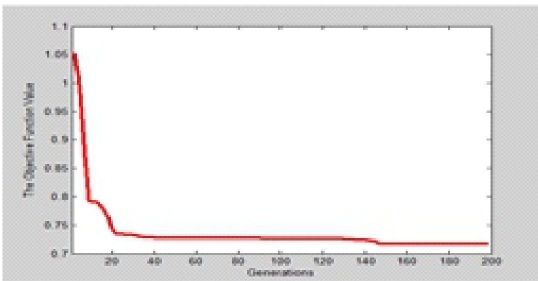

Fig 6. Convergence Characteristics of PSO (Converged in Iteration No. 144)

The base case load flow to determine the Power loss and voltage deviation is found to be 221.2657kW and 1.4651p.u 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 the size of 2494kW with a drop in power loss to 114.73kW and voltage deviation of 1.3416 p.u from 221.2657kW and 1.4651p.u as can be seen in Table 4.2. In comparison, using the GA solution showed bus number 31 as its best location with a maximum size of DG to be 2534kW. The power loss was reduced 117.72kW as against the initial value of 221.2657kW with a reduction also in voltage deviation to 1.3816p.u from 1.4651p.u at an objective function of 0.7376. The GA convergence characteristic is shown in Fig 7

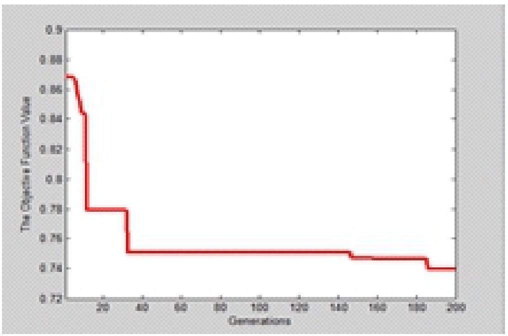

Fig 7 Convergence Characteristics of GA (Converged in Iteration No. 182)

On comparing the two output result, it is clear that the proposed PSO algorithm is more efficient in terms of faster in convergence (144) as against the GA which converged at 182. PSO also minimizes the power loss and voltage deviation much lower than that of GA; therefore the proposed PSO algorithm has shown better performances over GA as shown in Table 1

Table 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

For further clarification, a line graph have been presented in Fig 8 to how the system voltage profile has been improved using both the two optimization methods which shows the superiority of PSO over GA in terms of the voltage profile improvement in the networks as can be seen clearly from the graph.

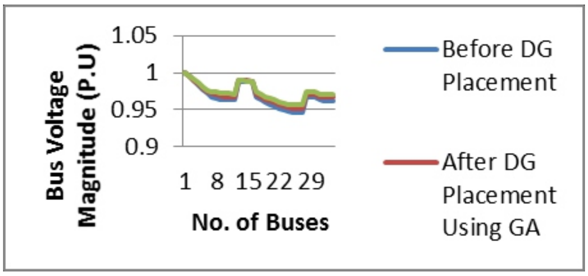

Fig 8. Voltage Profile and its improvement of Single DG Placement

Optimal Placement and Sizing of Double DG(s) in 34-bus RDN

The proposed PSO algorithm was utilized to optimally size and place two DG units in the 34-bus RDN. Table 2 presents the double DG case simulations results of the PSO. Table shows that the PSO consistently chooses buses 22 and 27 for the two optimally sized DG units to be installed after several runs of the simulation (Lalitha*2010)*.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 2. The PSO active power losses results are close to each other, whereby GA losses are higher by 0.3% (Satish*, 2011)*.

On the other hand, the proposed PSO method assigned a different bus location for the first DG unit in the first case, as shown in Table 2. Distribution System network real power losses were reduced by approximately 5% when compared to the losses of the GA method, as shown in Table 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 (Hassan*, 2004)*. Also Fig 7 shows the convergence characteristic of GA, where it converged at 179 of the generation while that of PSO (Fig 10) converged at 102 of the generation on double DG placement optimization.

The PSO optimization always converged faster than GA due to the advantages of PSO over the GA, which includes; fewer number of parameters to be manipulated during evaluation and better computational efficiency during execution while GA has to undergo selection, crossover and mutation rules before converging (Satish*, 2011)*.

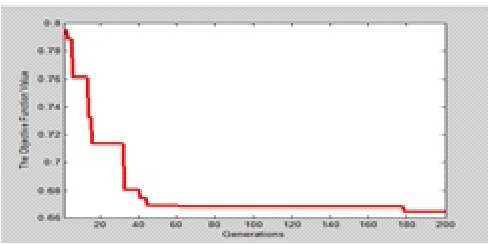

Fig 9. Convergence Characteristics of GA (Converged in Iteration No. 179)

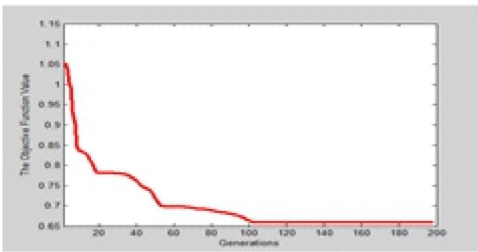

Fig 10. Convergence Characteristics of PSO (Converged in Iteration No. 102)

Table 2: Double 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

From Table 2, it can be seen that the PSO algorithm proposed a smaller size of DG, in which the cost will cheaper as compared to that proposed by GA. This shows that the second case of PSO yielded the cheapest cost of DG in case of future expansion planning and installation (Hung, *2011)*.

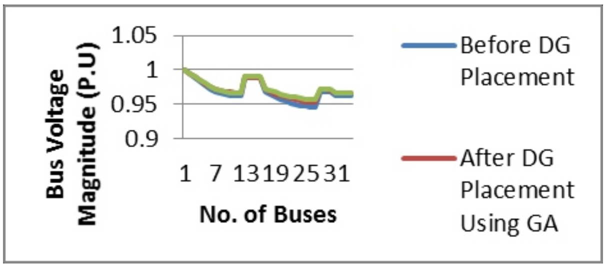

Fig 11. Voltage Profile and Its improvement of Double DG Placement

Table 3: Comparison of the DG sizes proposed by GA and PSO

Number of DG	Proposed by GA	Bus number (s)	Proposed by PSO	Bus number (s)
Single DG	2534kW	31	2494kW	12
Double DG	2465kW 497kW	17 28	1108kW 841kW	22 27

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 11, the voltage profile improved within the networks while Fig 12 shows how voltage deviation has been controlled and minimized as it moves towards 1p.u. (Vallem, and Mitra, 2005)

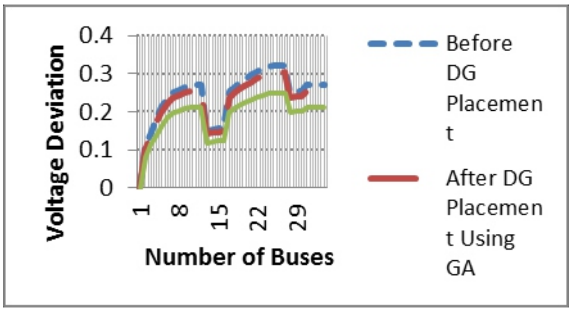

Fig 12. Total Voltage Deviations

Conclusion

This paper presents Sustainable Development Goal (SDG) number seven on affordable and clean energy targeted by the United Nations to identified and reduced global warming as one of the gaps to be filled towards achieving its 2030 agenda for Sustainable Development based ona new application of PSO in optimal placement of single and double DGs in radial distribution networks using Pareto method. The proposed PSO with the adopted FBSM method was used simultaneously to solve the optimal DG placement and sizing problem for active power loss and voltage deviation minimization with an improved networks voltage profiles(Le, 2006). This can be encountered once an optimal DG placement strategy is implemented. This can improve stability and reliability aspects of power distribution systems. PSO performance and robustness in its search for an optimal or near optimal solution is highly dependent on tuning its parameters and the nature of the problem at hand. The 34-bus RDS, as well as the 33-bus RDS had been used to validate the proposed method. Results of the PSO method were compared to those obtained by the GA. The comparison results demonstrate the effectiveness and robustness of the developed PSO algorithm. Moreover, the results obtained by the proposed PSO method were either comparable to that of the GA method or better.

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