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Distributed Generation Allocation in Radial Distribution Systems Using Various Particle Swarm Optimization Techniques

***Abstract**. Distributed generations (DGs) are continuously integrated into the distribution systems either by the utilities or the customers. Site and size of DGs have significant impacts on the system power losses . In this paper, the most recent and practical PSO algorithms are used to optimally allocate DGs in radial distribution systems, and the obtained results are discussed and compared to each other. The single objective is to minimize network power losses using the least possible injected power from DGs. To have a good benchmark for comparisons of different PSO Techniques, simulations carried out on IEEE 33-bus and 69-bus standard radial distribution systems.*

***Streszczenie.** Rozproszone układy generacji DGs mogą być dołączane do system energetycznego albo przez wytwórcę albo użytkownika. W artykule przedstawiono algorytm PSO umożliwiający optymalizację dołączenia system DGs do sieci radialnej. Głównym celem optymalizacji jest zmniejszenie strat mocy. (**Optymalizacja alokacji system generacji rozproszonej w sieci radialnej z wykorzystaniem algorytmu PSO**).*

Keywords: distributed generation, optimal allocation, particle swarm optimization, active power losses.
Słowa kluczowe: system generacji rozproszonej, sieci energetyczne, algorytm PSO.

Introduction

Distributed (*or* dispersed) generations (DGs) can be understood as the production of electricity by small generators sited in the distribution systems or near the loads they are attending [1]. In the past few years the electric power industries have increased interest in DGs due to the various factors such as recent advances in small and effective generation technologies, attentions to the environmental issues, postponing investment on new transmission and distribution systems, and the need for more flexible and reliable electric power systems. DGs can be divided into four levels including micro DG (1 W to 5 kW), small DG (5 kW to 5 MW), medium DG (5 MW to 50 MW), and large DG (50 MW to 300 MW) [2].

Many potential benefits of DG depend on its size and location. For this, there are several methods proposed in the literature. In [3], a mixed integer linear program was formulated to solve the DG placement optimization problem. The objective function was to determine the DG unit mix on a network section. In [4], a TS-based method was proposed to solve the problem. However, TS is a time-consuming algorithm in addition that it is trapped in local minima. In [5], an analytical expressions is suggested for finding optimal size and power factor of four types of DG units. DGs are sized to achieve the highest loss reduction. Authors in [6] proposed a novel optimization approach that employs an ABC algorithm to determine the optimum size of DGs, power factor, and location so as to minimize the total system active power loss. In [7], dynamic ant colony search algorithms are used to solve the optimization problem. In [8], an optimization algorithm is suggested, its objectives consist of minimization of costs, emission and losses of distributed system and optimization of voltage profile. This multiobjective optimization was solved by HBMO algorithm. In [9], a GA-based technique together with optimal power flow (OPF) calculations was used for DG placement to minimize the cost of active and reactive powers. Like TS, the GA is a time-consuming method, although it can reach global or near-global solutions.

PSO is a nature-inspired algorithm motivated by social behavior of organisms such as bird flocking and fish schooling [10]. PSO algorithm is very easy to be implemented and has few parameters to adjust. PSO and its various branches have been utilized in power system optimization [11]. In this paper, different advanced and evolved PSO Techniques are utilized for DG allocation. Rest of the paper is organized as follows: Section II presents problem formulation and objective function. PSO techniques for finding optimal sizes and locations of DGs are included and referred in Section III. Results and Discussion of optimum placement in two IEEE 33-bus and 69-bus radial distribution systems are addressed in Section IV. Finally, the major contributions and conclusions are summarized in Section V.

Problem Formulation

For DG placement problem, at first a power flow method should be used which its goal is to obtain complete voltage angle and magnitude for each bus in a power system. In this paper, power flow calculation is performed by backward-forward (bw-fw) method which is necessary to obtain the variation of power and voltage when DGs are installed in the system [11].

Objective Function-mathematically, the objective function is formulated as minimizing total active power losses (Equation 1):

$$(1)\quad \begin{cases} Minimize \quad O.F. \\ O.F. = \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij}(P_i P_j + Q_i Q_j) + B_{ij}(Q_i P_j - P_i Q_j) \end{cases}$$

where, $A_{ij} = \dfrac{R_{ij}cos(\delta_i - \delta_j)}{V_i V_j}$, $B_{ij} = \dfrac{R_{ij}sin(\delta_i - \delta_j)}{V_i V_j}$

P_i and Q_i are active and reactive power injected in *i*th bus.
R_{ij} is the resistance between *i*th and *j*th buses.
V_i and δ_i are the voltage magnitude and angle of *i*th bus.
V_j and δ_j are the voltage magnitude and angle of *j*th bus.

Constraints

Optimization problem is solved subject to several problem constraints which are given further.

Load balance constraint: For each bus, demand-supply balance should be satisfied (Equation 2).

$$(2)\quad P_{Slack} + \sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L$$

P_{Slack}, P_{DGi}, P_{Di} and P_L are active power of slack bus, DGs, demand and loss, respectively.

Voltage limits: For each bus, voltage should be limited to the upper and lower voltage bounds.

$$(3)\quad |V_i|^{\min} \le |V_i| \le |V_i|^{\max}$$

$|V_i|^{min}$=0.95 *p.u.* and $|V_i|^{max}$=1.05 *p.u.*

Active and reactive power limits of DG: To size DGs, there should be a range of available DG size.

(4)
$$P_{DGi}^{\min} \le P_{DGi} \le P_{DGi}^{\max}$$
$$Q_{DGi}^{\min} \le Q_{DGi} \le Q_{DGi}^{\max}$$

Active power loss limits: It is obvious that total active power loss should be decreased after DG installation.

(5)
$$\sum Loss_k(withDG) \le \sum Loss_k(withoutDG)$$

Particle Swarm Optimization

The reason behind selecting PSO as the optimization algorithm is that unlike Evolutionary Algorithms, in PSO there is neither competition between particles nor self-adaptation of the strategic parameters. PSO has the fast convergence ability which is a great attractive property for a large iterative and time consuming problem [13].

Standard PSO- in PSO, the optimization process begins with a randomly created population which is constituted by the so called particles. Each member of the population is moved in the search space according to three vectors called inertia (first term), memory (second term) and cooperation (third term). The first vector leads the particle in its previous direction. The second vector attracts the particle towards its previous best position. And, the third vector points the particle to the best solution ever found by the entire population. These movement "concepts" are summarized in the Equations 6-8:

(6)
$$v_i^{k+1} = \omega v_i^k + c_1 r_1 (X_{Pbest_i^k} - X_i^k) + + c_2 r_2 (X_{Gbest^k} - X_i^k)$$

(7)
$$x_i^{k+1} = x_i^k + v_i^{k+1}, i = 1,2..., n$$

(8)
$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \times iter$$

v_i^{k+1} is the *ith* particle velocity in iteration *k+1*, $\omega \ge 0$ is inertia weight factor, large ω has more global search ability while small ω results in a faster convergence; constants c_1 and c_2 determine the balance between the influence of the individual's knowledge (c_1) and swarm's knowledge (c_2); r_1 and r_2 are uniformly distributed random numbers in [0, 1]; X_{Pbesti}^k, X_i^k and X_{Gbest}^k are the best position for *i*th particle achieved based on its own experience, the *ith* particle position in iteration *k* and the swarm's best experience, respectively. *iter* is iteration number and *n* is the number of particles.

PSO techniques-so far several PSO techniques have been developed and implemented on various parts of engineering problems. Five improved PSOs are utilized in this paper for optimally sizing and sitting distributed generations [11]. The PSO techniques used in this paper are selected among vast majority of PSO including Adaptive Dissipative PSO (ADPSO), Escape Velocity PSO (EVPSO), PSO with passive congregation (PSOPC), PSO with area extension (AEPSO) and Dynamic Adaptation of PSO (DAPSO) [14-18]. Fig. 1 shows the computational flow chart of the PSO algorithms.

Results and discussion

PSO Techniques for optimal siting and sizing of DGs have been implemented in MATLAB software and tested in two IEEE 33-bus and 69-bus radial distribution systems.

IEEE 33-bus radial distribution system

The first system is a radial distribution system with the total load of 3.72 MW, 2.3 MVar, 33 bus and 32 branches, the active power losses in the system is 210.98 kW while the reactive power losses is at 143 kVar [19]. The best results for each technique are obtained with population size of 30, after 30 runs and for power factor of 0.85 lag. The results for optimal siting and sizing problem of distributed generations are described in Table 1-3 for single, two and three DGs, respectively.

Case-I-*single DG placement:* for this case, it was assumed that maximum DG size is less/equal to 1250 kW. Obtained results using five PSO techniques are given in Table 1.

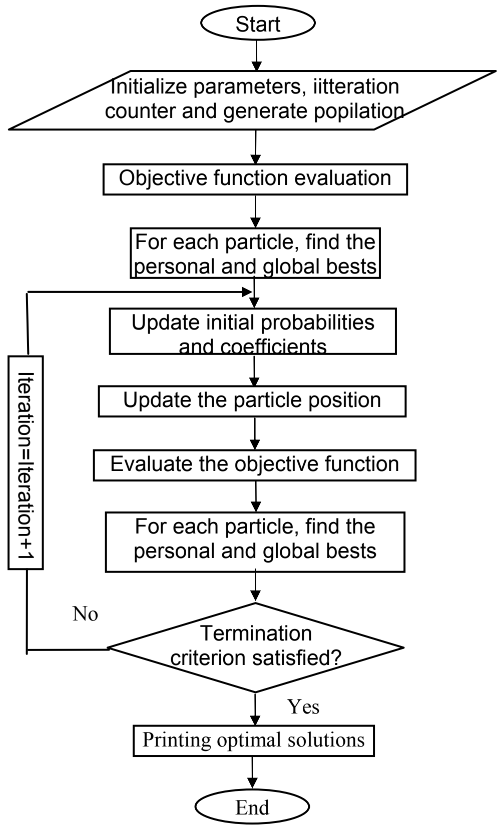

Fig. 1. Flowchart of PSO algorithms in problem solving

Table 1. Optimal size and location of single DG unit in IEEE 33-bus radial distribution system in Case-I

Technique	DG Installation		Power Loss		Bus Voltages	
	total size (kW)	*@ bus*	*value (kW)*	*decline (%)*	*min. (p.u.)*	*mean (p.u.)*
Without DG	-	-	210.98	-	0.9038	0.9453
EVPSO	763	(11)	140.19	33.55	0.9284	0.9604
PSOPC	1000	(15)	136.75	35.18	0.9318	0.9679
AEPSO	1200	(14)	131.43	37.70	0.9347	0.9715
ADPSO	1210	(13)	129.53	38.60	0.9348	0.9712
DAPSO	1212	(8)	127.17	39.70	0.9349	0.9635

As it can be seen from the results in Table 1, the minimum active power loss is achieved by DAPSO such that the active power loss reduction is at 39.70% in comparison to the case without any DG installation. However, this solution does not lead to the best voltage profile (because the main purpose is to minimize active power loss). AEPSO, ADPSO and DAPSO are marginally similar for min. and mean voltage values. AEPSO has the best results for voltage profile, since it propose a DG near the lowest bus voltage (bus 18) for which the voltage drop is remarkable. Fig. 2 and Fig. 3 are depicted to show the aforementioned results for bus voltage in Table 1. It is clear that DAPSO could increase bus voltages considerably while satisfy power loss reduction better than the other techniques.

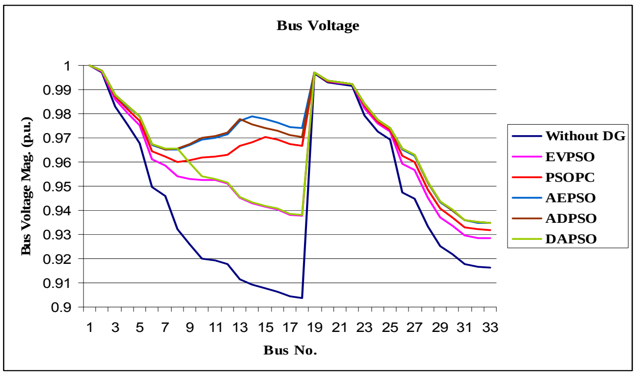

Fig .2. IEEE 33-bus radial distribution system bus voltage in *Case-I*

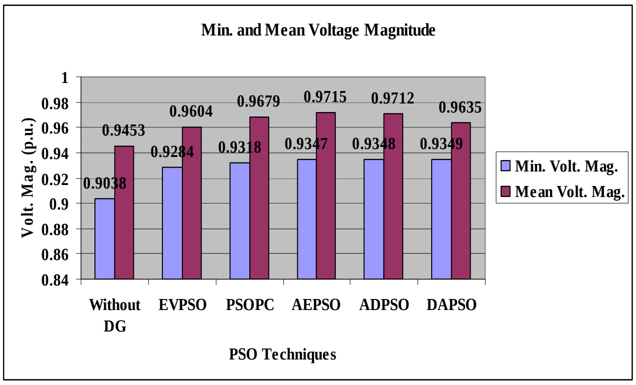

Fig .3. Min. and mean voltage values for different PSO techniques in *Case-I*

***Case-II**-two DGs placement (simultaneously):* for Case-II, it was assumed that maximum DG size is less/equal to 2000 kW. Obtained results using five PSO techniques are included in Table 2.

Table 2. Optimal size and location of two DG units in IEEE 33-bus radial distribution system (simultaneous placement) in Case-II

Technique	DG Installation		Power Loss		Bus Voltages	
	total size (kW)	*@ bus*	*value (kW)*	*decline (%)*	*min. (p.u.)*	*mean (p.u.)*
Without DG	-	-	210.98	-	0.9038	0.9453
PSOPC	1638	(8)(12)	111.45	47.17	0.9418	0.9738
EVPSO	1109	(14)(31)	108.05	48.78	0.9457	0.9661
AEPSO	1200	(14)(29)	106.38	49.57	0.9447	0.9671
ADPSO	1172	(15)(30)	106.24	49.64	0.9467	0.9667
DAPSO	1965	(13)(32)	95.93	54.53	0.9651	0.9819

Table 2 indicates that the minimum active power loss is achieved again using DAPSO for which the maximum active power loss reduction is at 54.53% in comparison to the case without any DG installation. It is obvious that the more the DG size and number, the more is the benefits. Unlike the previous Case-I, in this case, DAPSO not only could reach the maximum active power loss reduction which is the main goal of paper, but also suggests the best bus voltages among all PSO techniques. However, it should be noted that these benefits are achieved using much more DG sizes comparing to the other PSO techniques (i.e., 1965 kW). Fig. 4 and Fig. 5 illustrate bus voltages and the comparison of min. and mean voltage values, respectively.

***Case-III**-three DGs placement (simultaneously):* it is again assumed that maximum DG size is less/equal to 2000 kW. Obtained results using five PSO techniques are included in Table 3.

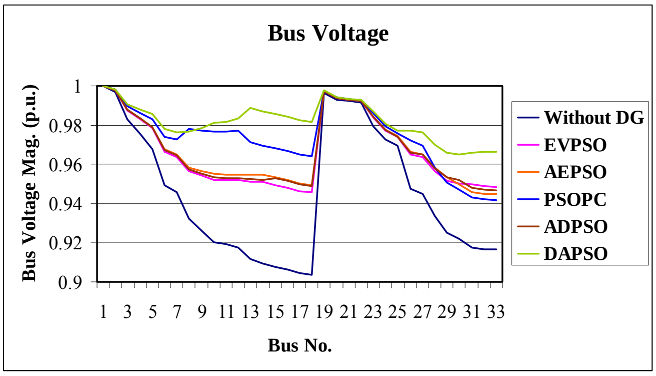

Fig .4. IEEE 33-bus distribution system voltage profile in *Case-II*

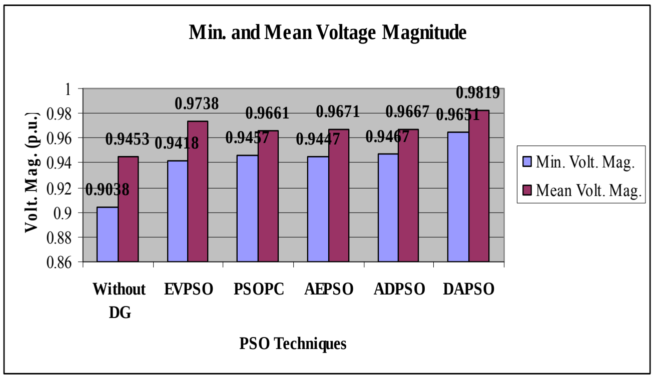

Fig .5. Min. and mean voltage values for different PSO techniques in *Case-II*

Table 3. Optimal size and location of three DG units IEEE 33-bus radial distribution system (simultaneous placement) in Case-III

Technique	DG Installation		Power Loss		Bus Voltages	
	total size (kW)	*@ bus*	*value (kW)*	*decline (%)*	*min. (p.u.)*	*mean (p.u.)*
Without DG	-	-	210.98	-	0.9038	0.9453
AEPSO	1187	(11)(16)(32)	103.58	50.90	0.9499	0.9676
PSOPC	1917	(6)(12)(16)	100.34	52.44	0.9418	0.9697
EVPSO	1588	(16)(18)(32	95.63	54.67	0.9611	0.9754
ADPSO	1729	(16)(26)(30)	94.02	55.43	0.9528	0.9758
DAPSO	2000	(10)(18)(31)	92.55	56.13	0.9654	0.9829

Studying results in Table 3 reveals that DAPSO and ADPSO could gain better results than the other techniques in active power loss reduction, by reducing active power loss to 56.13% and 55.43%, respectively. In addition, DAPSO could improve bus voltages better than the other techniques in Case-III. Also, considering Case-I and Case-II along with Case-III indicate that DAPSO and ADPSO could reach better solutions overally, however this was achieved using much more DG size in all cases.Tthe other techniques have not shown steady behavior in three cases and their ranking in Tables are changed by the change of DG size and numbers. It is worth to notice here again that so far many methods even the PSO itslef or its branches have been utilized in DG placement problems and could even get optimum solutions than this paper [18], whereas, in this paper we employed some limitations such as in DG size (less than 2000 kW), DG number (three or less), selecting recently developed and more dynamic PSO branches and etc. It should be mentioned that the size and number of DGs are very important in power loss reduction, and in particular, for voltage profile improvement. Thus, to show this fact, voltage profile is depicted in Fig. 6 only for DAPSO and ADPSO as two best techniques in three cases.

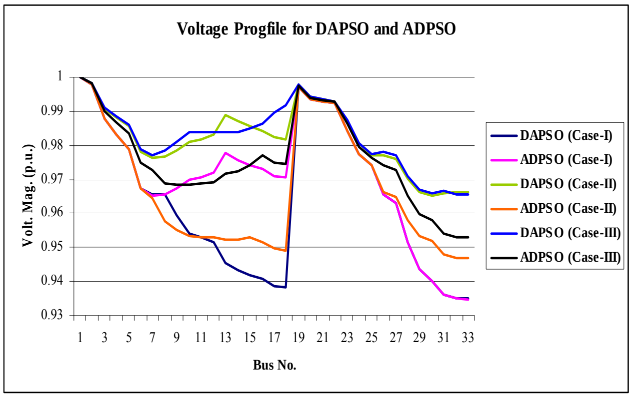

Fig .6. IEEE 33-bus radial distribution system bus voltage for DAPSO and ADPSO in *Case-I*, *Case-II* and *Case-III*

From Fig. 6., it is clear that, DAPSO has better results than ADPSO and the best is for DAPSO Case-III (blue curve). It is interesting that DAPSO in Case-II (light green curve-Fig.4) has better voltage profile than ADPSO in all cases. This fact is more obvious and attractive by considering bus-18 voltage which is the lowest voltage before DG installation and experience more improvement after installing DG units than the other buses. This phenomenon is due to the fact that DAPSO could escape from local minima and seek vast search space dynamically.

IEEE 69-bus Radial Distribution System

The second test system is the IEEE 69-bus radial distribution system that has the total load of 3.80MW and 2.69 MVar. Data for this system are available in [20]. Results are furnished in Table 4 which is evaluated just for placement of three DG units. In this part of paper, DG size and location are again found based on active power loss reduction, however, good improvement is also observed in voltage profile such that in all cases mean voltage of buses never decrease under 0.98 p.u. For better understanding bus voltage profile and min., mean and max. voltage magnitudes are depicted in Fig. 7 and 8, respectively.

Results show the best behavior of DAPSO even for the large radial distribution system, DAPSO has a more better result, and could achive better results both for power loss reduaction and bus voltage improvement.

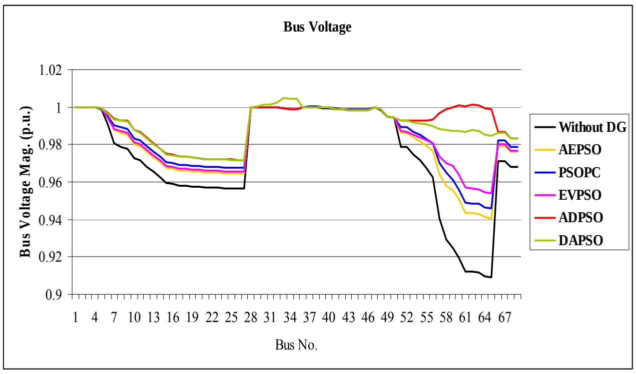

Fig .7. IEEE 69-bus radial distribution system bus voltage for PSO techniques

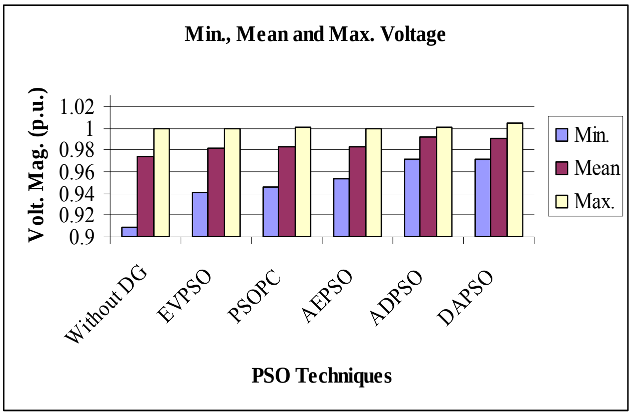

Fig. 8. min., mean and max. voltage by PSO techniques

Table 4. Optimal size and location of three DG units in IEEE 69-bus radial distribution system (simultaneous placement)

Technique	DG Installation			Power Loss		Bus Voltage				
						min.			*max.*	
	size kW)	*@ bus*	*Totals size (kW)*	*value (kW)*	*decline (%)*	*@ bus*	*(p.u.)*	*mean (p.u.)*	*@ bus*	*(p.u.)*
Without DG	-	-	-	224.89	-	(65)	0.9092	0.9734	(1) (2)	1
AEPSO	842	6	2344	125.86	44.03	(65)	0.9405	0.9812	(1) (2)	1
	901	59								
	601	63								
PSOPC	1090	37	2885	116.09	48.37	(65)	0.9458	0.9833	(37)	1.0002
	710	51								
	1085	58								
EVPSO	535	47	2638	106.88	52.47	(65)	0.9538	0.9833	(1) (2)	1
	1406	59								
	697	65								
ADPSO	945	2	3419	94.70	57.89	(26)(27)	0.9718	0.9914	(62)	1.0013
	521	60								
	1953	62								
DAPSO	500	9	2950	83.68	62.79	(27)	0.9716	0.9899	(33)	1.0050
	521	33								
	1929	62								

Conclusion

In this paper various PSO techniques were employed for optimal siting and sizing of the DGs. The major advantage of these methods is to be less time consuming. Given the fact that the methods may be implemented on an online basis, this issue is of major concern. The methods were implemented on IEEE 33 and 69 bus systems to minimize the active power losses. Results were compared to each other and it was verified that due to its dynamic behavior, DAPSO had the better results.

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