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Distributed generation placement in radial distribution networks using a bat-inspired algorithm

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Abstract
Distributed generation (DG) is an important issue for distribution networks due to the improvement in power losses, but the location and size of generators could be a difficult task for exact techniques. The metaheuristic techniques have become a better option to determine good solutions and in this paper the application of a bat-inspired algorithm (BA) to a problem of location and size of distributed generation in radial distribution systems is presented. A comparison between particle swarm optimization (PSO) and BA was made in the 33-node and 69-node test feeders, using as scenarios the change in active and reactive power, and the number of generators. PSO and BA found good results for small number and capacities of generators, but BA obtained better results for difficult problems and converged faster for all scenarios. The maximum active power injections to reduce power losses in the distribution networks were found for the five scenarios.

Keywords: bat-inspired algorithm; distributed generation; particle swarm optimization; distribution system.

Ubicación de generación distribuida en redes de distribución radiales usando un algoritmo inspirado en murciélagos

Resumen
La generación distribuida (DG) es un tema importante para las redes de distribución debido a la reducción de las pérdidas de energía, pero la ubicación y el tamaño de generadores puede ser una tarea difícil para las técnicas de solución exactas. Las técnicas metaheurísticas se han convertido en una mejor opción para determinar soluciones válidas y en este trabajo se presenta la aplicación de un algoritmo inspirado en murciélagos (BA) a un problema de ubicación y dimensionamiento de generación distribuida en sistemas de distribución radial. Una comparación entre la técnica de optimización por enjambre de partículas (PSO) y BA fue hecha en los sistemas de prueba de 33 nodos y 69 nodos, utilizando como escenarios el cambio en la potencia activa y reactiva, y el número de generadores. PSO y BA encontraron buenos resultados para un número pequeño y pocas capacidades de generación, pero BA obtuvo mejores resultados para problemas difíciles y converge más rápido para todos los escenarios. Las máximas inyecciones de potencia activa para reducir las pérdidas de energía en las redes de distribución fueron encontradas para los cinco escenarios.

Palabras clave: algoritmo inspirado en murciélagos; generación distribuida; optimización con cúmulo de partículas; sistemas de distribución.

1. Introduction

Power losses of distribution networks have always been an important issue due to the energy efficiency and the costs that the problem represents for electricity companies. This problem has usually been solved using feeder restructuring [1], DG placement [1-10], capacitor placement [1,11] and network reconfiguration [12, 13].

Location and size of distributed generation in distribution networks has difficulties due to the combination of the number and capacities of generators, and the selection of the best nodes. Several algorithms have been used to solve the problem such as particle swarm optimization [14-16], ant colony [17], optimal power flow [18], analytical methods [19,20], evolutionary algorithm [21-24], and simulated annealing [25-27], among others [14,28,29].

PSO have been widely used to solve this problem [30], but some convergence problems have been identified [31]. BA has been proposed as a good technique to optimize several functions [32], but more research is needed to determine the performance for power system problems.

In this paper, BA and PSO were used to obtain the solutions to a problem of location and size of generators. A comparison of the two algorithms was conducted changing capacities and the number of generators in two distribution networks.

2. Power losses

The total active power losses in distribution networks can be calculated as the sum of the active power losses of each branch, as shown in (1).

$$P_{Loss} = \sum_{b=1}^{nb} I_b^2 * R_b \tag{1}$$

where, P_{Loss} is the total active power losses, b is the branch number, nb is the number of branches, I_b is the series current that circulates through the branch b, and R_b is the resistance of the branch b.

The total reactive power losses can be calculated as the sum of the reactive power losses of each branch, as shown in (2).

$$Q_{Loss} = \sum_{b=1}^{nb} I_b^2 * X_b \tag{2}$$

where, Q_{Loss} is the total reactive power losses, b is the branch number, nb is the number of branches, I_b is the series current that circulates through the branch b, and X_b is the reactance of branch b.

As the demand increases, the current increases and the power losses are higher, due to the long distance from the generators to supply the demand. Centralized generation does not allow a reduction of power losses, to improve voltage levels at critical nodes or to reduce network congestion. Therefore, distributed generation is a better option to supply power to the load.

3. Distributed generation model

Location and size of DG were modeled in this research as a vector representing the active power, the reactive power, and the node at each iteration k, as shown in (3).

$$DG_d^k = x[P_{DGd}^k, Q_{DGd}^k, i_{DGd}^k] \tag{3}$$

where, d is the DG number (d=1, 2…ndg), and ndg is the maximum number of DG. DG_d^k is the generator d located at node i with an active and a reactive power at the iteration k. P_{DGd}^k and Q_{DGd}^k are the active and reactive power of the generator d, located at node i at the iteration k. i_{DGd}^k is the node of the DG at the iteration k.

P_{DGd}^k changes between the minimum active power P_{DGd}^{Min} and the maximum active power P_{DGd}^{Max} of the generator d. Q_{DGd}^k changes between the minimum reactive power Q_{DGd}^{Min} and the maximum reactive power Q_{DGd}^{Max} of the generator d. i_{DGd}^k changes position among all possible PQ nodes, searching for the best location during the iterations.

The new active power injection can be calculated as the sum of the real power and the change of active power at each iteration, as shown in (4).

$$P_{DGd}^k = \left(P_{DGd}^{k-1} + \Delta P_{DGd}^k\right) \tag{4}$$

where, P_{DGd}^k is the new active power at the iteration k, P_{DGd}^{k-1} is the last value of active power at the iteration k-1, and ΔP_{DGd}^k is the changes in active power at the iteration k.

The new reactive power generation can be modeled as the sum of the last reactive power calculated and the new power change at the current iteration k, as shown in (5).

$$Q_{DGd}^k = \left(Q_{DGd}^{k-1} + \Delta Q_{DGd}^k\right) \tag{5}$$

where, Q_{DGd}^k is the new reactive power at the iteration k, Q_{DGd}^{k-1} is the last value of the reactive power at the iteration k-1, and ΔQ_{DGd} is the new change in reactive power at the iteration k.

The active and reactive power supplied by the generators located at each node i, were limited by the minimum and maximum values as shown in (6) and (7).

$$P_{DGd}^{Min} \leq P_{DGd} \leq P_{DGd}^{Max} \tag{6}$$

$$Q_{DGd}^{Min} \leq Q_{DGd} \leq Q_{Gd}^{Max} \tag{7}$$

where, P_{DGd}^{Max} and Q_{Gd}^{Max} are the maximum active and reactive power of the generator d, respectively. P_{DGd}^{Min} and Q_{Gd}^{Min} are the minimum active and reactive power of the generator d, respectively.

In this research, all generators were considered to supply the active power up to the maximum value with a power factor of 0.98. During the search of an active power, the reactive power was adjusted to maintain the operation of each generator at the same power factor.

4. Location and size of distributed generation

This optimization problem was formulated as the minimization of the active power losses, with respect to the change in power of all new DG at nodes i, as shown in (8).

$$OF = Min\left(\sum_{b=1}^{nb} P_{Loss,b}(DG_d)\right) \quad (8)$$

d=1,2…ndg

where, OF is the objective function, b is the branch number and nb is the number of branches. $P_{Loss,b}$ is the active power losses of each branch b. DG_d is the vector of generators located at different nodes in the distribution network, as defined in (3). d is the generator number and nd the total number of generators.

This objective function is subject to the following constraints:

$\sum_{i=1}^{n} P_{Gi} - P_L - P_{Loss} = 0$	Active power balance
$\sum_{i=1}^{n} Q_{Gi} - Q_L - Q_{Loss} = 0$	Reactive power balance
$P_{Gi}^{Min} \leq P_{Gi} \leq P_{Gi}^{Max}$	Active power limits
$Q_{Gi}^{Min} \leq Q_{Gi} \leq Q_{Gi}^{Max}$	Reactive power limits
$V_i^{Min} \leq V_i \leq V_i^{Max}$	Voltage at node i
$I_{ij} \leq I_{ij}^{Max}$	Line current from i to j
$I_{ji} \leq I_{ji}^{Max}$	Line current from j to i

where, i is the node and n is the number of nodes. P_{Gi} and Q_{Gi} are the active and reactive power generation at node i, respectively. P_L and Q_L are the active and reactive power of all loads, respectively. P_{Loss} and Q_{Loss} are the active and reactive power losses, respectively. P_{Gi}^{Min} and P_{Gi}^{Max} are the minimum and maximum active power of the generator located at node i, respectively. Q_{Gi}^{Min} and Q_{Gi}^{Max} are the minimum and maximum reactive power generation, respectively. V_i is the voltage at node i, I_{ij} is the current supplied from node i to node j, and I_{ji} is the current supplied from node j to node i. V_i^{Min} and V_i^{Max} are the minimum and maximum voltage at node i, respectively. I_{ij}^{Max} and I_{ji}^{Max} are the maximum line currents from buses i to j and j to i, respectively.

5. Optimization techniques

5.1. Particle swarm optimization

PSO is a metaheuristic based on the behavior of birds or fishes. This iterative method moves all particles to the best local and the best global solutions.

The algorithm presented in this paper was based on [30] with the following steps:

1. Generate the initial population.
2. Generate the initial velocities of each particle, using (9).
3. Evaluate the objective function for each particle x_p and find the fitness $F(x_p)$.
4. Select the particle with the best location according to the best fitness F_{best}.
5. While (t < Maximum iteration)
   a. Generate new positions adjusting the velocities of each particle according to (10) and (11).
   b. Evaluate the objective function for the new particles and find the new fitness F_{new}.
   c. if (F_{new} (x_p^k)< $F(x_p^k)$)
      - Update the new solution

      End if
      - if (Fnew (x_p^k)<Fbest))
      - Update the best solution

      End if

End while.

Initial velocities are generated between the minimum and maximum values, as shown in (9).

$$v_p \sim U(-v_p^{Max}, v_p^{Max}) \quad (9)$$

Where v_p is the velocity of the particle and v_p^{Max} is the maximum velocity of each particle p.

The velocity of each particle is updated at each iteration k, as shown in (10).

$$v_p^k = w * v_p^{k-1} + a * rnd_1 * \left(xpbest_p^k - x_p^{k-1}\right) + b * rnd_2 * (xgbest_p^k - x_p^{k-1}) \quad (10)$$

where, v_p^k is the velocity updated at the iteration k. w, a and b are the parameters of PSO, respectively. p is the number of the particle (p=1,2,3….np) and np is the number of particles. v_p^{k-1} is the previous velocity at the iteration k-1. rnd_1 and rnd_2 are random numbers generated at each iteration to multiply the action over the direction of each particle to the local best or the global best, respectively. $xpbest_p^k$ is the position of each particle p at the iteration k, x_p^{k-1} is the previous position of the particle p at the iteration k-1, and $xgbest_p^k$ is the position of the best particle.

The new position of the particle x_p^k, is updated after adding the new velocity v_p^k to the previous position x_p^{k-1}, as shown in (11).

$$x_p^k = x_p^{k-1} + v_p^k \quad (11)$$

A vector containing the position of the DG, $x_p^k(DG_d)$, was considered to locate the generation at PQ buses. This vector contains all DG installed in the distribution network, with the active and reactive power and the nodes (12)

$$x_p^k\left(DG_d^k\right) = x_p^{k-1}\left(DG_d^{k-1}\right) + v_p^k\left(DG_d^k\right) \quad (12)$$

where, $x_p^k\left(DG_d^k\right)$ is the position of the particle containing the power and the nodes of all DG. $v_p^k\left(DG_d^k\right)$ is the vector of velocities for each generator at the iteration k. $x_p^{k-1}\left(DG_d^{k-1}\right)$ is the vector of positions of all DG at the previous iteration k-1.

5.2. Bat-inspired algorithm

BA is a metaheuristic based on the behavior of the bats during the search for their prey. This algorithm was presented by [32] and the steps used in this paper were defined as follows:

1. Generate the initial population.
2. Initialize the velocities of bats
3. Define the pulse rate r_p, the frequency f_p and the loudness A_p.
4. Evaluate the objective function for each bat x_p and find the fitness F(x_p).
5. Rank the bats and select the best
6. While (t < Maximum iteration)
    a. Generate new positions adjusting the velocities with the frequency according to (13).
    b. If rand>r_p
    c. Generate solution close to the best
    - End if
    d. Generate new bats by flying randomly
    e. Evaluate the objective function for the new bats and find the new fitness F_{new}.
    f. if (F_{new} (x_p^k)< $F(x_p^k)$) and rand< A_p)
    g. Update the new solution
    - End if
    h. Increase r_p and reduce A_p
    i. Rank the bats and select the best

End while

The frequency f_p, used to update each bat during iterations, is calculated using (13) [32].

$$f_p = f_p^{Min} + \left(f_p^{Max} - f_p^{Min}\right) * \beta_p \tag{13}$$

where, p is the number of the bat, f_p is the frequency of the bat p, f_p^{Max} is the maximum frequency, f_p^{Min} is the minimum frequency and β_p is a random number to generate different frequencies.

The velocity of each bat was updated using the previous velocity *k-1*, and the difference between previous position x_p and the best $xgbest_p^k$, multiplied by the frequency f_p, as shown in (14).

$$v_p^k = v_p^{k-1} + \left(x_p^k - xgbest_p^k\right) * f_p \tag{14}$$

The new position of each bat is calculated using (11), with x_p^k as the new position of the bat, the new velocity v_p^k and the previous position x_p^{k-1}. The vector of position of DG for this technique was modeled using (12).

6. Test systems and simulations

6.1. Test system cases

Most of the loads are supplied using radial distribution networks and this test focused on determining the location and size of distributed generation. Therefore, the 33-node and the 69-node test feeders were selected to test the algorithms. General information about the test feeders can be found in Table 1.

Table 1.
Information of the radial distribution networks.

Specifications	33-node	69-node
Buses	33	69
Lines	32	68
Feeder	1	1
Transformers	0	0
Loads	32	49

Source: The Authors.

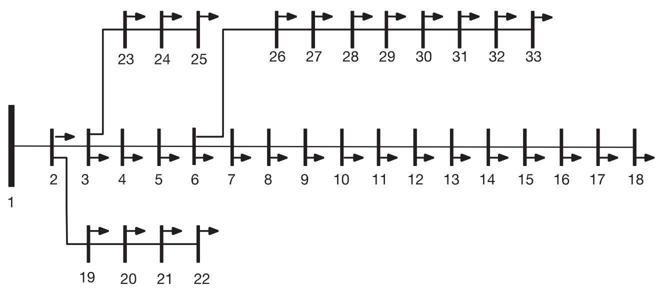

Figure 1. Diagram of the 33-node test feeder.
Source: [33]

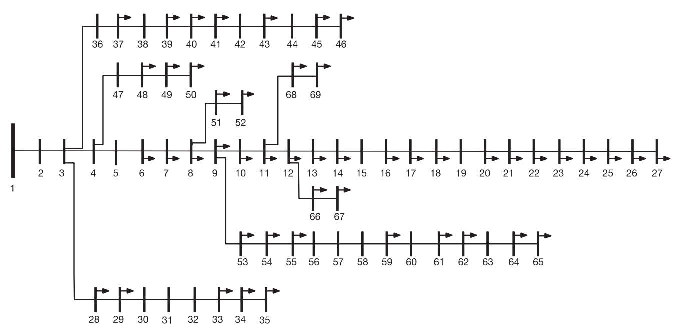

Figure 2. Diagram of the 69-node test feeder.
Source: [34]

Fig. 1 shows the diagram of the 33-node test feeder. This distribution network has 32 possible nodes to locate DG. The total load is 3715 kW and 2300 kVAr distributed in 32 nodes. The centralized generation supplies 3926 kW and 2443 kVAr, and the power losses are 210 kW and 143 kVAr. The voltage limits were defined as V_i^{Min}=0.9 p.u. and V_i^{Max}=1.1 p.u.

Fig. 2 shows the diagram of the 69-node test feeder. This radial distribution network has 68 possible nodes to locate DG. The total load is 4014 kW and 2845 kVAr, distributed in 49 nodes. The centralized generation supply 4265 kW and 2957 kVAR and the power losses are 265 kW and 112 kVAr. The voltage limits considered for this distribution network were defined as V_i^{Min}=0.9 p.u. and V_i^{Max}=1.1 p.u.

6.2. Scenarios for the simulation

Five scenarios of active and reactive power capacities of DG were tested to determine the best algorithm. Table 2 shows the five scenarios, the maximum active and reactive power per generator, and the total active and reactive power generation.

Table 2.
Scenarios defined for the test.

Scenario	P_{DGd}	Q_{DGd}	P_{DGT}	Q_{DGT}
1	500	164	500-	164-
2	750	246	750-	246-
3	1000	328	1000-	328-
4	1500	493	1500-	493-
5	2000	657	2000-	657-

Source: The Authors.

where, P_{DGd} and Q_{DGd} are the active and reactive power of generator d, respectively. P_{DGT} and Q_{DGT} are the total active and reactive power of all generators to be installed in the distribution network, respectively.

6.3. General parameter of the algorithms

PSO and BA were compared in this research to determine the best location and size of DG in distribution networks. Comparisons of the minimum objective functions were carried out, considering the following parameters:

- 200 individuals
- 100 iterations
- The same initial population
- The same programming structure.
- Comparable velocities for updating positions.

The test consisted in achieving similar characteristics for the algorithms to obtain the efficiency of each technique. Furthermore, the test was based on determining the best solutions according to the number of generators and capacities.

7. Results and Discussion

7.1. Location and size of DG

Tables 3 and 4 show the results of DG location and size for the five scenarios and the seven generators installed in the 33-node and 69-node test feeders, respectively.

P_T is the total power supplied by the new generators located in the network. P_{Loss} is the total power losses of the distribution network obtained for each scenario.

Table 3.
Location and Size of DG in the IEEE 33-node test feeder.

Number of Generators	Scenario	PSO			BAT		
		P_T (kW)	Nodes	P_{Loss} (kW)	P_T (kW)	Nodes	P_{Loss} (kW)
0	0	0	0	210.99	0	0	210.99
1	1	500	15	145.89	500	15	145.89
	2	750	14	127.85	750	14	127.85
	3	1000	12	116.72	1000	12	116.72
	4	1500	30	101.90	1500	30	101.90
	5	2000	27	96.62	2000	27	96.62
2	1	1000	15-32	97.51	1000	15-32	97.51
	2	1500	14-31	71.47	1500	14-31	71.47
	3	2000	12-30	60.60	2000	12-30	60.60
	4	2210	13-30	58.07	2206	13-30	58.07
	5	2130	14-29	59.48	2199	13-30	58.13
3	1	1500	15-30-32	71.45	1500	15-30-32	71.45
	2	2250	14-25-31	52.52	2250	14-25-31	52.52
	3	3000	13-24-30	44.02	3000	12-24-30	43.59
	4	3486	14-24-30	43.11	3178	13-24-30	42.10
	5	2613	6-14-32	49.68	3182	13-24-30	41.91
4	1	2000	8-15-30-31	54.41	2000	8-15-30-32	54.32
	2	3000	7-14-24-31	38.98	2995	7-14-25-31	38.36
	3	3516	6-12-24-32	40.51	3497	7-14-24-30	37.14
	4	3268	7-14-25-33	42.59	3363	6-13-24-30	38.96
	5	2998	7-13-25-33	41.25	3536	6-14-24-31	37.39
5	1	2500	9-14-25-29-32	41.77	2500	8-15-25-29-32	41.38
	2	3091	7-11-18-25-32	37.15	3250	8-14-25-27-31	36.99
	3	3547	2-6-13-31-25	38.66	3365	6-8-15-31-25	37.12
	4	3080	2-8-16-24-32	41.27	3494	7-11-16-24-30	36.76
	5	3589	2-6-14-25-31	38.51	3431	7-14-24-28-32	36.34
6	1	2953	6-8-16-25-30-33	37.13	3000	6-8-16-25-30-32	36.75
	2	3340	3-7-14-25-30-33	37.02	4107	2-3-7-14-25-31	36.55
	3	3457	7-11-13-15-24-30	37.85	4083	2-6-10-15-24-30	36.28
	4	3640	7-13-17-20-24-30	38.75	3967	6-12-16-21-24-31	36.42
	5	4118	2-13-24-26-29-33	38.02	3947	6-8-16-24-25-32	37.72
7	1	3070	3-7-11-15-25-29-32	37.27	3500	6-8-14-24-25-29-33	34.05
	2	3080	6-8-13-17-25-30-33	34.75	3519	7-11-15-21-25-30-32	33.36
	3	4141	2-10-13-18-24-27-30	36.57	3694	7-12-15-24-25-27-31	35.21
	4	3443	5-7-13-15-21-25-31	37.10	3733	11-16-20-25-27-30-33	35.35
	5	3316	8-12-14-24-25-26-32	35.68	3605	8-11-15-21-25-26-31	34.23

Source: The Authors.

From the results shown in the two tables, the algorithm PSO obtained good results for the location of a small number of generators and small capacities. When the number of generators and the capacity increase, the convergence was affected and the solutions were not what was expected.

BA obtained similar results to PSO for a small number of generators and capacities, but when the problem increased the solutions were improved using BA. BA determined a better reduction in power losses and the results were consistent according to the number, capacity and location of generators.

The two algorithms found compensations according to the maximum power inclusions of each node. The results show the power generation for cases with the maximum power generation, the algorithms found solutions where not all capacity is needed and the power losses increase with more injection from generators.

The algorithms found different solutions around the maximum power inclusion for each node according to the power losses reduction. Some scenarios supply more real power, but the power losses are higher.

7.2. Convergence of the algorithms

Fig. 3 shows the convergence of the algorithms using the scenario of maximum active power and five generators. The test was conducted using 200 individuals and 100 iterations. The average of all solutions were used to evaluate the behavior of the individuals and the evolution of all values.

PSO slowly reduced the average of the solutions and the number of evaluations made to solve the problem was not enough to find better solutions.

BA converged faster than PSO and found better solutions for the same number of iterations. During the first ten iterations, this technique reached good solutions and the search is centered on reducing to the minimum value.

Table 4.
Location and Size of DG in the IEEE 69-node test feeder.

Number of Generators	Scenario	PSO			BAT		
		P_T (kW)	Nodes	P_{Loss} (kW)	P_T (kW)	Nodes	P_{Loss} (kW)
0	0	0,00	0	265.00	0.00	0	265.00
1	1	500	64	170.48	500	64	170.48
	2	750	61	141.07	750	61	141.07
	3	1000	61	117.04	1000	61	117.04
	4	1500	61	85.31	1500	61	85.31
	5	2000	61	73.28	2000	61	73.28
2	1	1000	61-64	116.53	1000	61-64	116.53
	2	1500	61-62	85.33	1500	61-62	85.33
	3	2000	61-62	73.48	2000	61-62	73.48
	4	2351	21-61	49.38	2351	21-61	49.38
	5	2786	21-61	42.71	2742	22-61	42.61
3	1	1500	25-61-64	82.90	1500	24-61-64	82.62
	2	2250	22-62-63	50.77	2250	21-61-62	49.88
	3	3000	17-60-62	45.97	2745	21-61-62	42.82
	4	3017	17-61-62	44.68	2550	21-61-62	43.32
	5	2800	2-21-61	42.72	3640	19-49-61	41.13
4	1	2000	27-61-62-63	57.05	2000	24-61-62-64	54.90
	2	3000	22-55-62-64	45.20	3000	9-22-61-62	44.19
	3	3220	24-61-62-69	41.93	3040	11-21-61-62	39.72
	4	2630	24-60-63-69	45.01	3109	16-61-62-69	41.85
	5	3145	14-23-61-69	40.66	3293	11-21-29-61	39.57
5	1	2500	23-57-62-63-69	54.49	2500	12-21-61-62-64	45.95
	2	3000	22-54-62-64-69	45.27	3750	10-22-28-61-62	44.28
	3	4059	17-37-50-61-62	41.55	3197	8-24-61-62-69	40.97
	4	3385	20-46-53-61-62	41.78	5362	7-24-49-61-64	41.38
	5	3218	18-21-39-61-63	42.75	3748	13-19-49-61-69	39.36
6	1	2414	15-26-56-61-62-64	47.19	3000	12-24-58-61-63-64	40.73
	2	2630	17-26-60-61-62-69	44.38	4347	8-21-36-58-61-63	42.73
	3	5435	4-18-50-53-61-62	42.08	3614	9-22-31-61-62-67	39.93
	4	3930	19-49-58-61-63-69	40.88	4006	9-20-28-40-61-65	40.74
	5	3760	17-40-50-61-63-67	43.19	4580	10-20-38-49-61-64	37.75
7	1	3452	12-21-29-57-60-63-65	44.27	3500	12-20-50-58-61-62-63	39.59
	2	5155	9-21-37-50-61-62-69	43.77	4598	2-11-22-28-58-61-62	39.97
	3	4525	11-23-37-44-54-61-62	42.95	3612	22-27-50-55-61-64-69	39.17
	4	4896	6-23-36-49-62-64-69	40.43	4196	10-21-29-49-60-61-64	39.84
	5	5961	4-15-21-48-50-61-62	41.66	4336	2-9-23-49-61-62-69	37.92

Source: The Authors.

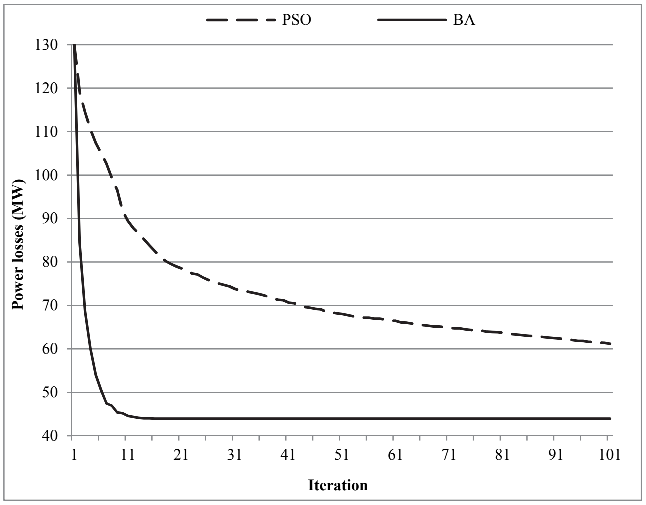

Figure 3. Convergence of PSO and BA.
Source: The Authors.

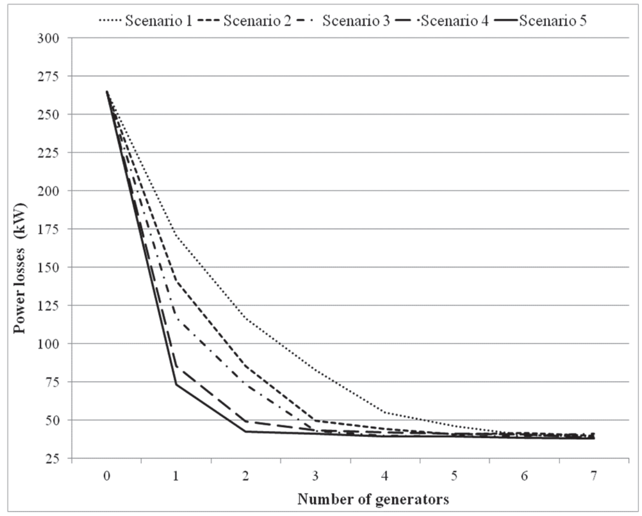

Figure 5. Power losses reduction with DG in the 69-node test feeder.
Source: The Authors.

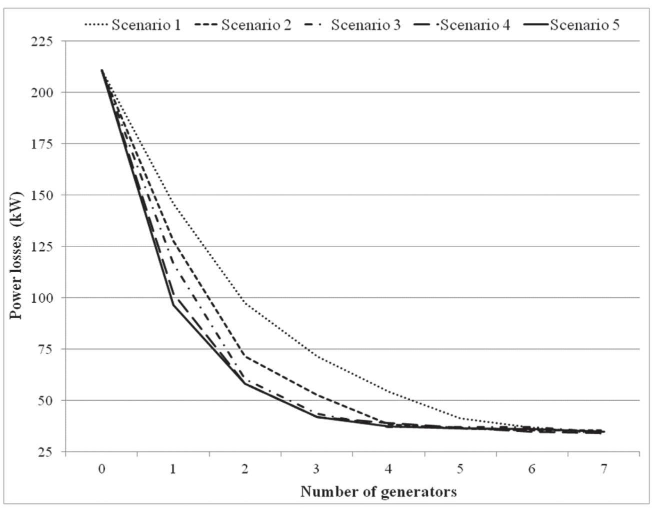

Figure 4. Power losses reduction with DG in the 33-node test feeder.
Source: The Authors.

7.3. Power losses reduction

Fig. 4 and 5 show the results of BA to reduce power losses with DG in the 33-node and the 69-node test feeders, respectively.

Fig. 4 shows that the active power losses were reduced according to the number, capacities and locations of generators. The maximum active power injection to reduce power losses was found for all five scenarios in the 33-node test feeder.

Fig. 5 shows similar results for power loss reduction in the 69-node test feeder, but the maximum power injection was found for a smaller number of generators and capacities.

8. Conclusions

PSO and BA were tested to find location and size of DG in two radial distribution networks. PSO found good results with a small number of generators and capacities, but for more difficult problems the search was not successful. BA showed good results for minimizing power losses for the five scenarios, obtaining consistent results when changing capacities, locations, and the number of generators. BA converged faster than PSO and found better solutions for all scenarios. Power losses were reduced according to the number of generators and capacities, but the maximum reduction was found depending on the number of generators and capacities.

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