Location and Size of Distributed Generation to Reduce Power Losses using a Bat-inspired Algorithm

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***Abstract*— Several conventional and artificial algorithms have been used to find the location of distributed generation DG in power systems. Particle swarm optimization PSO is one of the most used, but some convergence problems have been reported in literature. In this paper, the use of the metaheuristic Bat-inspired algorithm BA is proposed to place different number and capacities of DG for meshed and radial distribution networks. The aim of this work was to solve an optimization problem defined as minimization of power losses installing generators at load busses. A binary combination is included to represent the states and locations of generators. The search for the minimum value is achieved using the movement of bats at iterations, considering location and size. IEEE 14-bus, IEEE 30-bus and IEEE 33-node systems were used to test the metaheuristic techniques using five cases of power increasing considering from 1 to 5 generators. Results showed that bat algorithm is a good method to locate and find size of DG and maintain convergence to improve power losses. Voltage level and power losses were improved for all cases maintaining consistent results.**

***Index Terms*—distributed generation, power losses, metaheuristic, particle swarm optimization, bat-inspired algorithm.**

I. INTRODUCTION

POWER losses have been a major issue for the electricity companies due to the energy efficiency of the transmission and distribution networks. Power losses are normally improved with feeder restructuring [1], DG placement in radial and meshed distribution networks [1]–[10], capacitor placement [1], [11], and network reconfiguration [12], [13].

DG placement and sizing is one of the major problems due to the combinations of possible buses, number of generators and size. Several algorithms have been proposed to place DG such as particle swarm optimization [14]–[16], ant colony [17], optimal power flow [18], analytical methods [19], [20], evolutionary algorithm [21]–[24], simulated annealing [25]–[27], among others [14], [28], [29].

Metaheuristic algorithms are preferred when large number of combinations is required, such as PSO [30], but finding a global optimum can be a problem [31]. New techniques have been reported in literature to solve better solutions and improve convergence, but not all have been tested for power system planning.

Bat-inspired has been proposed for solving several functions [32], being useful to find better solutions converging to the optimum. In this paper, BA was implemented and adjusted to solve placement and size of DG with the objective of minimizing power losses of meshed and radial distribution networks. Comparisons with the common used PSO were conducted with various cases to determine the best solutions found with both algorithms.

II. POWER LOSSES

The current circulating through the network parameters such as resistance and reactance produces technical power losses. Real and reactive power losses can be calculated as expressed in (1) and (2), respectively.

$$P_{loss} = \sum_{k=1}^{m} I_k^2 * R_k \qquad (1)$$

$$Q_{loss} = \sum_{k=1}^{m} I_k^2 * X_k \qquad (2)$$

Where, R_k and X_k are the resistance and reactance of branch k, respectively. Parameter I_k represents the series current circulating through the network. k is the branch number and m is the number of branches. The increasing power demand produces more power losses in the network when generators are not located close to the consumption centers. DG helps to reduce line congestion, power losses and improve voltage magnitudes.

III. LOCATION OF DISTRIBUTED GENERATION

The problem of finding the best location of DG can be formulated as a minimization of power losses with constraints, as shown in (3).

$$\underset{(P_{DG},\, Q_{DG})}{Min} \sum P_{loss} \qquad (3)$$

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Subject to:

$P_{Gi} - P_{Di} - P_{Li} = 0$	Real power balance
$Q_{Gi} - Q_{Di} - Q_{Li} = 0$	Reactive power balance
$P_{Gi}^{Min} \leq P_{Gi} \leq P_{Gi}^{Max}$	Real power limits
$Q_{Gi}^{Min} \leq Q_{Gi} \leq Q_{Gi}^{Max}$	Reactive power limits
$i_{ij} \leq i_{ij}^{Max}$	Line current from *i* to *j*
$i_{ji} \leq i_{ji}^{Max}$	Line current from *j* to *i*
$V_i^{Min} \leq V_i \leq V_i^{Max}$	Voltage level at bus *i*

Where, P_{DG} and Q_{DG} are the real and reactive power of DG, respectively. P_{loss} is the real power losses. P_{Gi} and Q_{Gi} are the real and reactive power generation, respectively. P_{Li} and Q_{Li} are the real and reactive power loads, respectively. $\mathrm{P_{Gi}^{min}}$ and $\mathrm{P_{Gi}^{max}}$ are the minimum and maximum real power generation, respectively. $\mathrm{P_{Gi}^{min}}$ and $\mathrm{P_{Gi}^{max}}$ are the minimum and maximum active power generation, respectively. $\mathrm{P_{Gi}^{min}}$ and $\mathrm{P_{Gi}^{max}}$ are the minimum and maximum reactive power generation, respectively. $i_{ij}^{Max}$and i_{ji}^{Max} are the maximum line currents from buses *i* to *j* and *j* to *i*, respectively. $\mathrm{V_i^{min}}$and V_i^{Max} are the minimum and maximum voltage at bus *i*, respectively.

A. Particle Swarm Optimization

PSO is an iterative algorithm that initialize with a cluster of particles with random positions in a region of possible solutions. The position of each particle is evaluated to determine the solution and the best positioned particle in the cluster. Particles move to the best positioned particle and they have a memory to move around the best local position. The procedure implemented in this work was:

1) Define the initial number of particles of the cluster to search for the optimum position and the best objective. The number of particles selected in this work was 100.
2) Generate initial random positions for all the particles, specifying the position as active power, reactive power and bus [P_{DGi}^{0}, Q_{DGi}^{0}, Bus^{0}]. P_{Gi} changes value between P_{Gimax} and P_{Gimin}, Q_{Gi} changes value between Q_{Gimax} and Q_{Gimin}, and bus changes position among all possible PQ buses. Bus positions are generated as binary vector of node position [1, 0].
3) Generate random velocities for all particles between v_{min} *and* v_{max}. Where, v_{min} *and* v_{max} are the minimum and maximum velocities of each particle, respectively.
4) Evaluate the objective function of each particle and select the best located. The best positioned particle is used to adjust velocity and direction of other particles, in order to move for the best solution found.
5) While t is smaller than the maximum number of iteration, do:
    a. Generate new positions for each particles, changing real power, reactive power and bus [P_{DGi}^{k}, Q_{DGi}^{k}, Bus^{k}], by adjusting velocity according to (4) and (5). All particles move with trajectories toward the best local particles and the best positioned particle.
    b. Evaluate the objective function for all new position of each particle.
    c. If the new solution is better than the local solution, replace the local best.
    d. If the new solution of each particle is the global best, replace with the new particle.

Velocity v_i^k of each particle is calculated using (4) [30]. This equation considers a predefined factor w to adjust the previous velocity v_i^{k-1}. In addition, the previous and the best positions are used to update the steps.

Velocity is updated using the best local position of particles $xbest_i^k$ and the previous position of each particle x_{ki}. Factor *a* is used to adjust the velocity of best local position and to obtain better steps. A random number is used to generate various velocities for particles moving toward the local best.

Velocity is also updated with the differences between the best particle located in the solution and the previous position of each particle. Factor b is used to adjust velocities of the difference between the best positions of the clusters. A random number is used to generate various velocities for particles moving toward the global best.

In this work *a* and *b* were defined as 0.3 and 0.5, respectively.

$$v_i^k = w * v_i^{k-1} + a * rand * \left(xbest_i^k - x_{ki}\right) + b * rand * \left(g(x_i^k) - x_{ki}\right) \tag{4}$$

New position for each particle x_i^k, is updated after adding the new velocity $\mathrm{v_i^k}$ to the previous position x_i^{k-1}, as shown in (5) [30].

$$x_i^k = x_i^{k-1} + v_i^k \tag{5}$$

A vector of position, $x_i^k(PQ)$, is defined to allow location of generation at PQ buses. This vector of position is updated using a vector of velocities for each particle as expressed in (6).

$$x_i^k(PQ) = x_i^{k-1}(PQ) + v_i^k(PQ) * s(PQ) \tag{6}$$

where, $x_i^{k-1}(PQ)$ is the previous vector of position, $v_i^k(PQ)$ is the vector of velocities, and $s(PQ)$ is a binary combination vector created according to the number of generators to be installed.

B. Bat-inspired Algorithm

This algorithm is based on determining the minimum power losses by generating a random distribution of bats among predefined boundaries. Velocity and frequency are calculated, in order to move bats around the region with a separation along the displacements. All bats continue moving with trajectories according to the best location and adjust velocity, frequency, pulse rate and loudness [32].

A modification from the original algorithm is proposed in this work, including a binary search to move around the buses to search the best position. A search of a new best solution is achieved with the adjustment in position and new power capacities are tested.

The algorithm is based on the following steps as defined in [32]:

1) Define the initial population of bats to search for the optimum. The number of bats selected in this work was 100.
2) Generate the initial bats and positions represented for real power, reactive power and bus [P_{DGi}^{0}, Q_{DGi}^{0}, Bus^{0}]. P_{Gi} changes value between P_{Gmax} and P_{Gmin}. Q_{Gi} changes value between Q_{Gmax} and Q_{Gmin} Bus change position among the possible PQ buses. Bus positions are generated as binary vector of node position [1, 0].
3) Define the velocity for all bats according to the maximum value. This parameter will allow moving all bats according to the best positioned bat.
4) Define the pulse rates of bats at position. This will Initialize the pulse rates r_i, in order to select the bats that move to the best position. r_i was changed in a range between 0.3 and 0.6.
5) Initialize the loudness A_i to select only some bats as the best solution. The loudness was defined from 0.5 to 0.7.
6) Evaluate the objective function of each position and select the bat with the minimum power losses or best positioned.
7) While t is smaller than the maximum number of iteration, do:
    e. Generate new positions of bats [P_{DGi}^{k}, Q_{DGi}^{k}, Bus^{k}], by adjusting frequency and velocity. Bats can move from one bus to another in the search of the best position to improve the objective function.

    f. If the pulse rate is equal to a random number between 0 and 1, generate new solutions around the best. Some bats join the search near the best solution. Bats can fly randomly to search for new size and position.

    g. Evaluate new solutions and find power losses for each position of the bats.

    h. If a new solution is smaller than the best solution and a random number is greater the loudness A_i, save the new best solution. The r_i can be increased and the A_i can be reduced to find better solutions.

The frequency is calculated using (7) to maintain a separation of each bat while moving in a trajectory. The frequency is defined between maximum value f_{max} and minimum value f_{min} and it is multiplied by a random number β.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (7)$$

Velocity of bats is calculated using (8). This is achieved using the velocity *k-1* and the difference between previous position x_i and the best x_0 is multiplied by the frequency.

$$v_i^k = v_i^{k-1} + (x_i^k - x_0)f_i \quad (8)$$

New position for each bat, x_i^k, is updated after adding the new velocity v_i^k to the previous position x_i^{k-1}, as shown in (5) [32].

This new position is evaluated to determine the fulfillment of the objective function. The vector of buses is included in the velocity, as shown in (6).

IV. TEST SYSTEMS AND SIMULATIONS

A. Test System Cases

IEEE 14-bus, IEEE 30-bus and IEEE33-node systems were selected to evaluate the location and size of distributed generation using BA and PSO. General information about these three systems is presented in Table 1.

TABLE I
INFORMATION OF IEEE TEST SYSTEM CASES

Specifications	IEEE 14 (Meshed)	IEEE 30 (Meshed)	IEEE 33 (Radial)
Buses	14	30	33
Lines	16	34	32
Generators/Feeders	5	6	1
Transformers	4	7	0
Loads	12	29	32
Slack bus	1	1	1
PV buses	2,3,6,8	2,5,8,11,13	0
PQ buses	4,5,7,9,10,11,12,13,14	3,4,6,7,9,10,12,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33

IEEE 14-bus system considered a total load of 362.6 MW and 113.96 MVAR and a total generation of 392.05 MW and 205.54 MVAR. Voltage limits at load buses were considered as 5% of rated voltage or V_{Min}=0.95 p.u. and V_{Max}=1.05 p.u. Fig. 1 shows the IEEE 14-bus system used to evaluate location and size of DG and reduce power losses in a meshed transmission and distribution network.

IEEE 30-bus power system considered a total load of 1892 MW and 1252 MVAR and a total generation of 1989 MW and 1352.7 MVAR. Voltage limits at load buses were considered as 5% of rated voltage or V_{Min}=0.95 p.u. and V_{Max}=1.05 p.u. Fig. 2 shows the IEEE 30-bus system used to evaluate location and size of DG and reduce power losses in a meshed transmission and distribution network.

IEEE 33-node test feeder considered a total load of 3715 KW and 2300 KVAR and a total generation 3926 KW and 2443 KVAR. Voltage limits at load buses were considered as 10% of rated voltage or V_{Min}=0.9 p.u. and V_{Max}=1.1 p.u. Fig. 3 shows the IEEE 33-node system used to evaluate location and size of DG and reduce power losses in a radial distribution network.

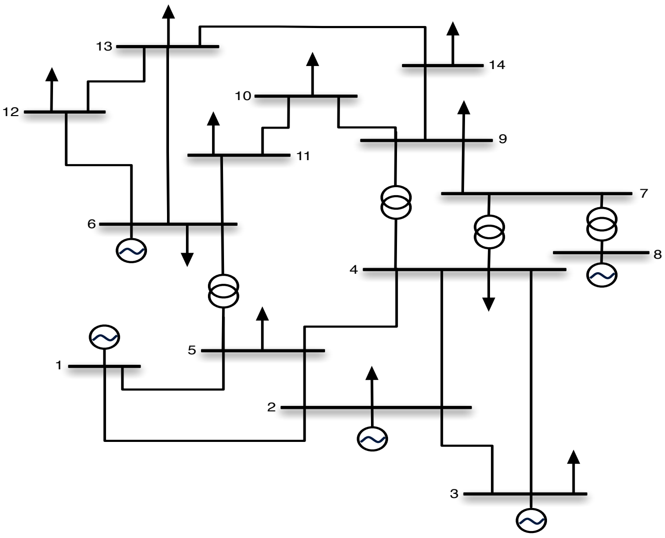

Fig. 1. IEEE 14-bus power system [33]

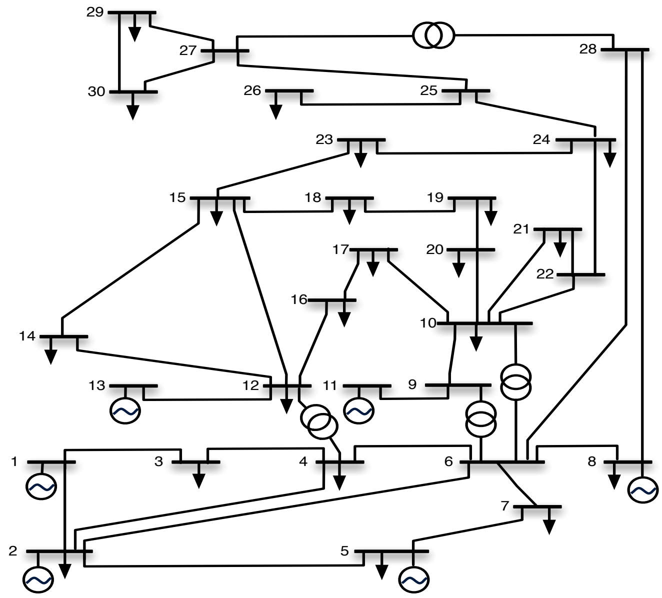

Fig. 2. IEEE 30-bus power system [33]

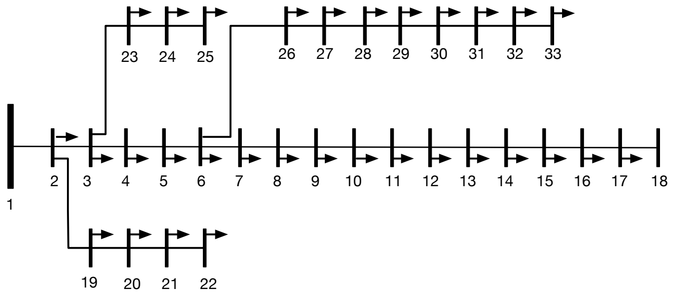

Fig. 3. IEEE 33-node test feeder

B. Distributed Generation Models

Real and reactive power injection models were used to represent distributed generation in the PQ buses. Generators are installed in the network with a switch to represent the operating states. The generation model evaluate the size and position for all the iterations in the metaheuristics as defined in (9) and (10).

$$P_{DGi} = (P_{DGi} + \Delta P_{DGi}) * s_i \tag{9}$$

$$Q_{DGi} = (Q_{DGi} + \Delta Q_{DGi}) * s_i \tag{10}$$

where P_{DGi} and Q_{DGi} are the real and reactive power compensated from distributed generators. ΔP_{DGi} and ΔQ_{DGi} are the changes in real and reactive power to represent variation during the search. s_i is the state of the switch with binary combination for each generator as [0, 1]. The state 0 represents a generator off and 1 a generator supplying real and reactive power at bus *i*.

All generators were considered to supply a maximum real power with a power factor 0.95 for the meshed distribution systems and a maximum real power with power factor of 0.98 for the radial distribution network. Real and reactive power constraints were considered as defined in (11) and (12).

$$0 \leq P_{DGi} \leq P_{DGi}^{Max} \tag{11}$$

$$0 \leq Q_{DGi} \leq Q_{Gi}^{Max} \tag{12}$$

Where, P_{DGi}^{Max} is the maximum real power of a generator at node i, and Q_{Gi}^{Max} is the maximum reactive power of generator at node i calculated with the maximum power factor $P_{DGi}^{Max} * \tan(\emptyset)$.

C. Simulations

Five cases were defined in this work to test PSO and BA with maximum real power, maximum reactive power and from 1 to 5 distributed generators. Table 2 shows the five cases evaluated in this paper, the maximum active power P_{Gi}, the maximum reactive power Q_{Gi}, the maximum total real power P_T, and the maximum total reactive power Q_T.

TABLE II
CASES FOR THE MESH POWER SYSTEMS

Case	$P_{Gi\,Max}$ (MW)	$Q_{Gi\,Max}$ (MVAR)	P_T (MW) 1-5 Gen	Q_T (MVAR) 1-5 Gen
1	5	1.643	5-25	1.643-8.215
2	10	3.286	10-50	3.286-16.430
3	20	6.573	20-100	6.573-32.865
4	30	9.860	30-150	9.860-49.300
5	40	13.147	40-200	13.147-65.735

Five cases were defined in this work to test PSO and BA in a radial distribution network with maximum real power, maximum reactive power and from 1 to 5 distributed generators. Table 3 shows the five cases evaluated in this paper, the maximum active power P_{Gi}, the maximum reactive power Q_{Gi}, the maximum total real power P_T, and the maximum total reactive power Q_T.

TABLA III

CASES FOR THE RADIAL DISTRIBUTION SYSTEM

Case	$P_{Gi\ Max}$ (KW)	$Q_{Gi\ Max}$ (KVAR)	P_T (KW) 1-5 Gen	Q_T (KVAR) 1-5 Gen
1	500	164	500-2500	164-820
2	750	246	750-3750	246-1230
3	1000	328	1000-5000	328-1640
4	1500	493	1500-7500	493-2465
5	2000	657	2000-10000	657-3285

The best size of generators to reduce power losses is searched changing the real and reactive power between the limits specified in (11) and (12). The maximum compensation during the search will be P_T and Q_T according to the number of generators defined to locate.

V. RESULTS AND DISCUSSION

PSO and BA were compared to determine the best solutions of both algorithms when locating and sizing distributed generation. Moreover, convergence of algorithms, voltage magnitudes, and the power losses reduction are shown for a study case.

A. *PSO and BA comparisons*

Tables 4, 5 and 6 show the results of location and size of DG for the five cases defined in Table 2 and 3 and all generators installed in the IEEE 14-bus, the IEEE 30-bus and IEEE 33-node systems, respectively.

BA found better location and size of DG for meshed and radial distribution systems. With BA, power losses were more reduced and the solutions were consistent according to the number, capacity and location of generators. BA found greater power generation to supply at each node than the PSO.

PSO was not able to find good solution for some cases in the three power systems, especially for the large capacities and the maximum number of generators tested in this work. This is due to the solution space to generate particles and move between the minimum and maximum limits. Some solutions were not consistent for this algorithm when changing number and size of generators.

For the cases with large maximum capacities of generation, algorithms found compensations according to the maximum power inclusions of each node. The results show that power generation was obtained lower to the maximum power generation available for each node. For these cases, different solutions were found due to the possible combination of real, reactive power and number of nodes of each power system.

TABLE IV

LOCATION AND SIZE OF DG USING PSO AND BA IN THE IEEE 14-BUS POWER SYSTEM

		PSO				BA			
Case	Num Gen	Ptot (MW)	Qtot (MVAR)	Buses	Ploss (MW)	Ptot (MW)	Qtot (MVAR)	Buses	Ploss (MW)
0	0	0.00	0.00	0	29.56	0.00	0.00	0	29.56
1	1	4.92	0.47	14	28.39	5.00	1.64	14	28.33
	2	9.67	1.77	4 14	27.58	10.00	3.29	10 14	27.41
	3	12.74	3.39	5 13 14	27.11	15.00	4.93	9 10 14	26.53
	4	15.94	4.16	4 5 13 14	26.63	20.00	6.57	9 10 13 14	25.67
	5	20.66	3.86	4 7 10 11 13	25.86	25.00	8.22	7 9 10 13 14	24.85
2	1	9.98	0.10	14	27.39	10.00	3.29	14	27.30
	2	16.93	2.72	9 11	26.56	20.00	6.57	10 14	25.54
	3	24.38	5.44	7 11 14	25.01	30.00	9.86	9 10 14	23.91
	4	34.97	9.06	4 9 11 13	23.63	40.00	13.15	4 9 10 14	22.40
	5	35.08	11.87	14 10 5 9 11	23.35	50.00	16.43	4 5 9 10 14	21.17
3	1	19.04	1.36	14	25.74	20.00	6.57	14	25.46
	2	36.75	0.45	10 13	23.44	40.00	12.95	14 7	22.33
	3	56.20	2.31	4 7 14	20.28	60.00	16.43	4 10 14	19.52
	4	61.84	17.18	4 5 7 10	20.06	80.00	10.90	4 14 9 10	17.19
	5	75.94	11.75	4 7 5 10 13	18.39	100.00	14.76	4 5 7 11 13	15.93
4	1	27,30	5,36	14	24,36	30,00	5,32	14	23,9754
	2	55,01	8,68	4 10	20,88	60,00	9,86	4 14	19,758
	3	66,84	13,22	4 7 5	19,59	90,00	19,72	4 5 14	16,6124
	4	68,56	18,81	4 5 7 14	18,95	110,88	9,86	4 9 10 14	16,0347
	5	75,82	15,23	4 7 9 10 11	17,98	77,05	17,56	4 5 9 10 11	16,0322
5	1	39,78	2,86	14	22,79	40,00	2,90	14	22,7631
	2	63,30	14,98	4 10	19,74	80,00	15,53	4 9	17,42
	3	76,79	10,68	5 11 14	18,60	120,00	26,29	4 5 14	14,12
	4	49,13	14,71	5 7 9 13	21,80	94,03	23,39	4 5 9 14	13,3
	5	82,00	15,49	4 5 7 11 13	17,30	100,21	16,32	4 5 7 10 14	15,25

TABLE V

LOCATION AND SIZE OF DG USING PSO AND BA IN THE IEEE 30-BUS POWER SYSTEM

		PSO				BA			
Case	Num Gen	Ptot (MW)	Qtot (MVAR)	Buses	Ploss (MW)	Ptot (MW)	Qtot (MVAR)	Buses	Ploss (MW)
0	0	0.00	0.00	0	9.71	0.00	0.00	0	9.71
1	1	4.99	1.59	29	9.08	5.00	1.64	30	8.98
	2	9.96	1.93	10 29	8.62	10.00	3.29	24 30	8.36
	3	12.06	2.52	14 24 30	8.21	15.00	4.93	19 24 30	7.78
	4	13.97	3.29	7 17 25 30	8.12	20.00	6.57	19 24 26 30	7.26
	5	17.55	3.88	9 16 26 29 30	7.73	25.00	8.22	20 21 23 24 30	6.82
2	1	9.99	3.21	29	8.61	10.00	3.29	30	8.44
	2	16.30	2.00	18 30	7.75	20.00	6.57	19 30	7.32
	3	28.31	6.70	10 15 25	6.98	30.00	9.86	19 24 30	6.30
	4	35.38	4.96	19 20 29 30	6.26	40.00	13.15	19 22 24 30	5.47
	5	43.63	9.81	3 20 23 27 30	5.73	50.00	16.43	19 22 23 24 30	4.75
3	1	15.93	4.35	24	7.93	20.00	6.57	24	7.56
	2	36.65	5.19	23 28	6.40	40.00	13.15	19 24	5.84
	3	48.68	6.12	16 19 24	5.43	60.00	16.64	19 24 30	4.47
	4	65.98	8.60	4 16 20 28	4.72	80.00	26.29	15 19 21 30	3.39
	5	77.86	12.09	7 16 19 27 30	3.81	100.00	32.87	9 12 19 22 30	2.68
4	1	27.64	7.84	25	7.56	30.00	9.86	24	6.87
	2	53.36	16.24	15 28	5.37	60.00	19.72	15 21	4.84
	3	65.92	16.48	6 15 27	4.71	90.00	29.58	15 21 28	3.29
	4	104.41	20.87	15 16 25 28	3.38	120.00	39.44	10 15 21 27	2.34
	5	99.89	22.02	6 7 21 24 25	3.09	150.00	49.30	4 7 15 21 28	1.90
5	1	37.42	5.97	24	6.57	40.00	13.15	21	6.28
	2	71.09	13.43	17 24	4.71	80.00	22.14	21 28	3.97
	3	84.52	34.58	6 19 22	3.62	120.00	39.44	15 21 28	2.60
	4	115.31	20.41	7 15 25 28	2.88	152.19	44.78	6 15 21 28	2.10
	5	132.38	33.41	4 6 12 28 23	2.57	151.04	45.27	7 12 17 19 30	1.93

TABLE VI

LOCATION AND SIZE OF DG USING PSO AND BA IN THE IEEE 33-NODE TEST FEEDER

IEEE33									
		PSO				BAT			
Case	Num Gen	Ptot (KW)	Qtot (KVAR)	Nodes	Ploss (KW)	Ptot (KW)	Qtot (KVAR)	Nodes	Ploss (KW)
0	0	0.00	0.00	0	210.99	0.00	0.00	0	210.99
1	1	493	100	13	147.40	500	102	14	146.00
	2	979	203	15 30	100.70	1000	203	12 30	98.44
	3	1182	240	11 18 27	100.00	1500	305	17 31 32	74.80
	4	1301	264	12 16 29 31	80.10	2000	406	7 10 15 29	62.40
	5	1944	395	15 18 20 28 32	67.10	2500	508	12 16 24 26 33	47.90
2	1	750	152	32	133.10	750	152	14	127.80
	2	1288	262	13 33	82.50	1500	305	18 31	78.60
	3	1569	319	14 24 32	70.50	2250	457	7 13 31	52.90
	4	2653	539	3 14 19 32	67.10	2998	609	4 13 27 32	47.70
	5	2567	521	12 16 24 26 29	52.00	3622	735	15 19 25 28 33	41.10
3	1	930	189	14	119.90	1000	203	11	117.00
	2	1714	348	6 14	86.20	1851	376	16 29	66.70
	3	2369	481	32 26 18	57.00	2687	546	18 24 33	55.00
	4	2329	473	25 33 16 8	52.30	3107	631	13 24 28 31	41.20
	5	3550	721	2 23 30 16 27	45.00	3195	649	8 17 24 27 32	39.40
4	1	1417	288	9	105.60	1500	305	30	101.90
	2	1814	368	14 30	64.00	2419	491	12 28	62.30
	3	2695	547	11 24 32	57.30	3061	622	9 25 32	48.10
	4	3104	630	11 24 26 30	43.30	3224	655	17 25 27 30	41.60
	5	3695	750	5 9 18 25 30	47.80	3284	667	6 10 24 30 32	40.30
5	1	1996	405	7	96.80	2000	406	27	96.60
	2	2884	586	8 29	67.10	2274	462	12 30	58.20
	3	2068	420	14 25 32	55.80	3087	627	17 24 29	47.30
	4	3224	655	12 13 23 31	55.40	3382	688	6 15 25 30	38.50
	5	4845	984	2 9 19 23 30	52.50	3427	696	6 12 24 26 29	42.60

Fig. 4 shows the convergence to the minimum power losses using BA and PSO. This figure shows that BA found better solutions after each solution and iterations, while PSO found a local solution and not other reduction is achieved for the rest of evaluations.

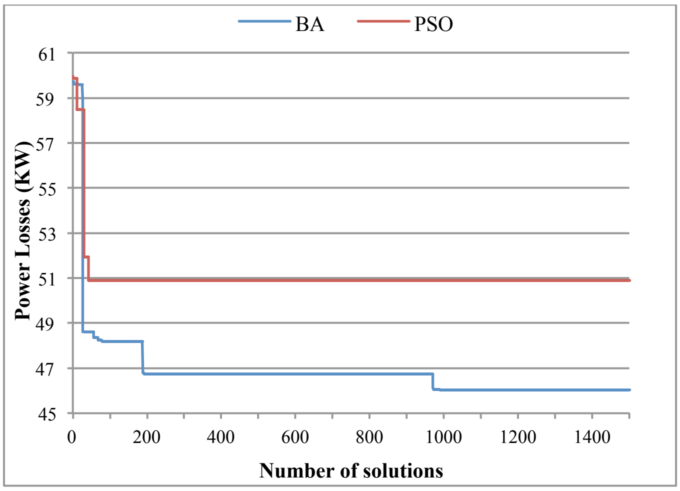

Fig. 4. BA and PSO convergences for case 4 with 4 generators

Fig. 5, 6 and 7 show the voltage profiles for the base and the five cases studied in the IEEE 14-bus, IEEE 30-bus and IEEE 33-node systems, respectively. For these tests, 4 generators were located using BA and the results were presented in Tables 4, 5 and 6.

Location of distributed generation for small power compensation was achieved with no voltage limits problems. Voltage profiles were improved for all cases tested in different power systems. For large power compensation the power was distributed to meet voltage limits.

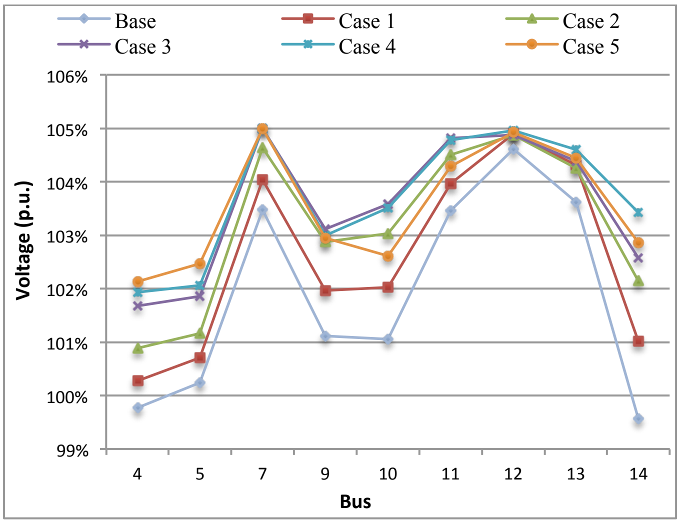

Fig. 5. Voltage before and after location of DG for IEEE 14-bus

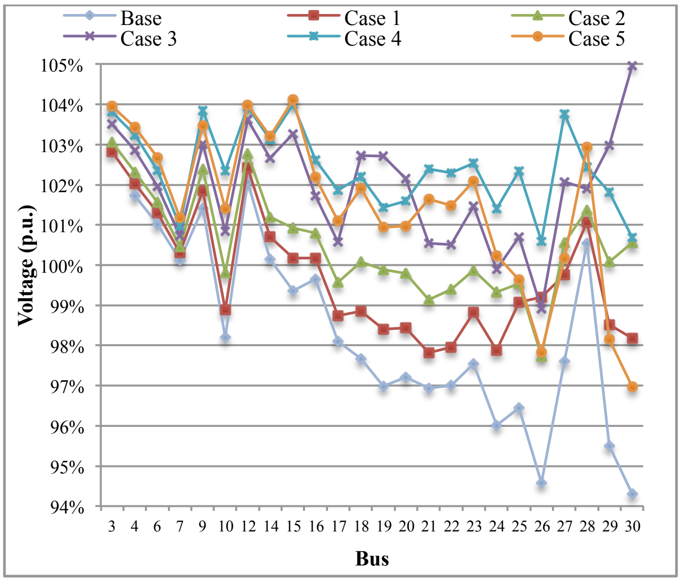

Fig. 6. Voltage before and after location of DG for IEEE 30-bus

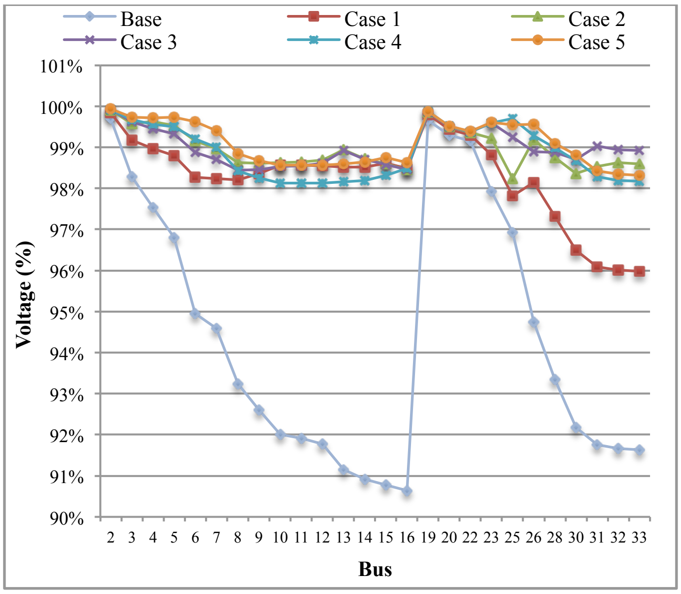

Fig. 7. Voltage before and after location of DG for IEEE 33-node

Fig. 8, 9 and 10 show the power losses reduction according to the number of generators located in the system using BA, for IEEE 14-bus, IEEE 30-bus and IEEE 33-node systems, respectively.

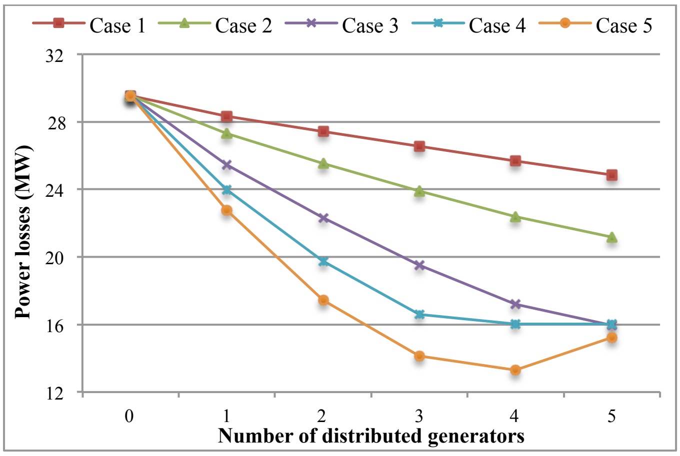

Fig. 8. Power losses reduction using BA for the IEEE 14-bus

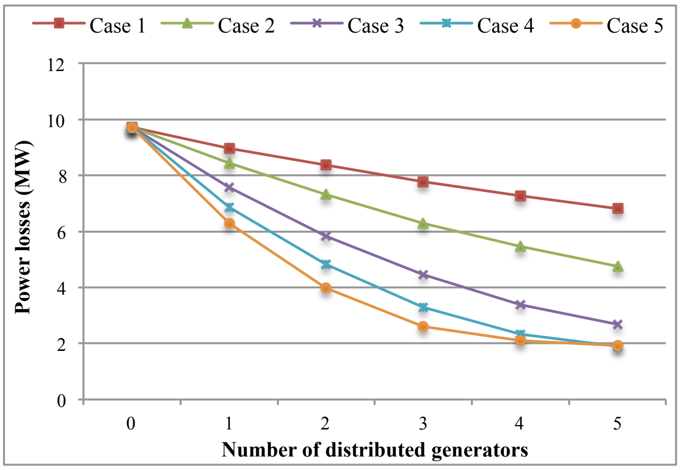

Fig. 9. Power losses reduction using BA for the IEEE 30-bus

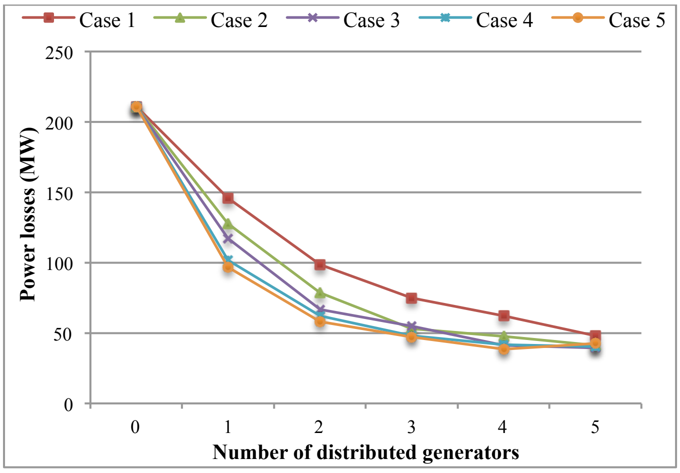

Fig. 10. Power losses reduction using BA for the IEEE 33-node test feeder

For all cases, real power losses were reduced according to the number, capacities and locations of generators. Fig. 8, 9 and 10 show that a maximum inclusion of power was found, but the optimum solution was difficult to find for greater capacities and number of generators, due to the number of possible combinations.

VI. CONCLUSION

Bat-inspired and Particle Swarm Optimization algorithms were used to find location and size of DG. BA showed better results for minimizing power losses for the five cases with different number of generators. BA obtained consistent results for minimizing power losses when changing size, locations, and number of generators. Some few problems with BA were found when searching for the minimum power losses at the maximum power inclusion capacity, especially for cases using greater size and number of generators. BA allows adjusting parameters to find better solutions for the different power systems, but a robust test is needed to determine convergence to the global optimum.

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