

Simultaneous Optimal Placement and Sizing of Distributed Generation Resources and Shunt Capacitors in Radial Distribution Systems using Crow Search Algorithm

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The application of distributed generation resources and capacitor banks is increasing due to the distribution networks extension and also power demand growth. Determining the installation location and the capacity are two important and effective factors on the network power loss and the network performance improvement. If connected in the right place to the power network, distributed generation power plants and the capacitors have different effects such as loss reduction, voltage profile improvement, and network reliability augmentation. In this paper, in order to reduce the distribution system loss, simultaneous optimal placement of the distributed generation resources and capacitors in radial distribution systems is studied. Crow search algorithm is applied for this purpose. This algorithm works on this idea that the crows chase each other in order to find other crows' food hiding place. The simulation is done on IEEE-33 & IEEE-69 buses network in MATLAB software. The simulation results demonstrate the efficiency of crow search algorithm, comparing to other applied optimization algorithms, in the problem of simultaneous optimal placement of the distributed generation resources and capacitors in radial distribution systems to reduce loss and enhance voltage profile.

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I. INTRODUCTION

Nowadays voltage drop, high loss, and the voltage profile impropriety are among distribution networks problems. The topic of electric energy quality or power quality is one of the topics that are in the center of the operators' and the consumers' attention in recent years. Voltage drop is considered as the most important aspect of power quality; therefore, in recent years it has been tried to decrease it in electric networks.

In order to reduce the voltage drop and also to decrease the loss in the network, shunt capacitors could be used. On the other hand, installing capacitors in distribution network has caused reduction of the reactive

power component and with the decrease of the reactive current component, the current amplitude is declined and this causes loss reduction in the network and capacity release in the system. To employ shunt capacitors in the network so that they represent the best performance in decreasing the voltage drop, optimization algorithms are needed to determine their optimum location and size.

The increase of the consumers' number and how to supply the loads are considered among the most significant challenges of the power system. Since the expense of the construction or updating the transmission lines and the distribution networks are extremely high; moreover, among the different segments of the power systems the largest amount of loss is dedicated to the distribution network, due to the voltage low level and the current high level, one of the economical and affordable methods to solve this issue is to use distributed generation (DG) resources. Given this case, the distribution network optimal utilization and planning, considering the power system uncertainty, is of importance. In addition to economic concerns, power quality, reliability, energy saving, and also sustainability are improved to a significant extent¹; therefore, determining the capacity and the location of the DGs are substantial topics that various optimization methods, such as genetic algorithm, ant colony, particle swarm optimization algorithm, and continuous power flow are applied¹⁻⁵. In reference⁶ an analytical method and in references⁷⁻¹⁰ numerical methods are used to find the optimal location and size of different DGs. Furthermore, to improve the voltage profile and also to reduce the loss in power lines exploiting reactive power resources, such as shunt capacitors, is common. References¹¹⁻¹⁴ have resolved the shunt capacitors location and capacity with different purposes and algorithms. Considering the advantages of the DGs' usage and capacitors in distribution networks, many researchers have worked on simultaneously determining the placement and

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the size of the DGs and the capacitors and suggested various methods to enhance voltage stability, release system capacity, minimize energy losses, and increase system reliability. Reference¹⁵ has employed PSO algorithm to find the optimal location and size of the shunt capacitor and DG in IEEE standard networks with the goal of loss reduction. The 33-bus IEEE network in reference¹⁶, is used as a case study system to demonstrate the benefits of applying the improved genetic algorithm for finding the DG and capacitor installation place. In reference¹⁷, the same goal is pursued using the BFOA algorithm and the results are compared for three different cases which are: applying only one DG or applying a DG and a capacitor, and the third case, applying none of them. In reference¹⁸, the problem of locating DG and capacitor is solved using the BPSO algorithm wherein the purpose is considered loss reduction, voltage improvement, and network reliability. In reference¹⁹, bee colony algorithm and artificial immune system are combined together in order to optimally locate and determine the size of the capacitors and the DGs with the purpose of loss reduction and voltage profile improvement in distribution networks in which it is tested on 33-bus IEEE system for several cases. In reference²⁰, using DPSO algorithm, the capacitors and the DGs are located and their sizes are determined. Reference²¹, employed TLBO method to maximize the profit to cost ratio when capacitor and DG are used simultaneously. In reference²², IMDE algorithm is exploited to resolve simultaneously the placement and size of DGs and shunt capacitors in radial distribution networks. Although a significant number of different algorithms are presented and used to determine simultaneously the location and the size of DGs and shunt capacitors, according to No Free Lunch (NFL) theory based on that the success of an algorithm in solving a specific collection of optimization problems does not guarantee to solve other optimization problems with a different type and nature. In other words, all optimization techniques work in an equal way on average to solve all the optimization problems, although they perform better in solving some of the optimization problems; therefore, the NFL theory gives the researchers the opportunity to offer new optimization algorithms, or improve or change the current algorithms for solving subsets of problems in various areas²³.

In this paper, in order to locate and benefit simultaneously from capacitors and DGs in radial distribution networks a meta-heuristic optimization method based on the intelligent behavior of crows, called the crow search algorithm (CSA) is employed. CSA is a population-based method working on the idea that a crow keeps his excess food in secret places and retrieves it whenever the food is needed. From the optimization point of view, crows are the explorers, the environment is the search space, each position at the environment corresponds a possible solution, the quality of the food resource is the objective function and the best food resource of the environment is the global solution of the problem. According

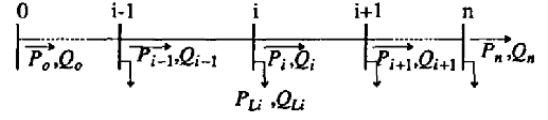


FIG. 1. The single-line diagram of the main feeder.

to these similarities, the CSA algorithm tries to simulate the crows' intelligent behavior to find the solution of the optimization problems. To implement the CSA algorithm, MATLAB software is used on 33 and 69-bus IEEE systems.

Organization of the rest of the paper is: formulating the optimization problem, crow search algorithm, implementing CSA to locate and determine the size of the capacitor and DG, computer simulation results, analyzing them and conclusion.

II. FORMULATING THE OPTIMIZATION PROBLEM

Determining the location and the size of DGs and capacitors is a complex discrete optimization problem which is in need of an effective method. In this paper, the crow search algorithm is used to solve this problem.

A. Formulating the Power Flow

Some efficient methods to find a solution for the power flow problem in radial distribution networks is available in the references. These methods are divided into two general groups: the total power method, known as "Forward- Backward Sweep", and methods based on "Implicit Nodal Impedance". In this study, the power flow problem is solved with the total power method based on Forward-Backward Sweep algorithm by using the following recursive equations which are obtained from the single-phase diagram demonstrated in Fig. 1²².

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1} \frac{P_i^2 + Q_i^2}{|V_i^2|} \quad (1)$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1} \frac{P_i^2 + Q_i^2}{|V_i^2|} \quad (2)$$

$$V_{i+1}^2 = V_i^2 - 2(R_{i,i+1} \cdot P_i + X_{i,i+1} \cdot Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2) \cdot \frac{P_i^2 + Q_i^2}{|V_i^2|} \quad (3)$$

In which P_i and Q_i are the active and reactive power of the i th bus, respectively. Also, P_{Li} and Q_{Li} are the active and reactive load power in the i th bus. The line resistance and reactance between buses i and $i + 1$ are shown by $R_{i,i+1}$ and $X_{i,i+1}$.

The power loss in this line can be calculated adopting the following equations:

$$P_L = R_{i,i+1} \cdot \frac{P_i^2 + Q_i^2}{|V_i^2|} \quad (4)$$

$$Q_L = X_{i,i+1} \cdot \frac{P_i^2 + Q_i^2}{|V_i^2|} \quad (5)$$

The total power loss P_{TL} in the feeder can be achieved by adding the power loss in the lines. As shown in the following formula:

$$TP_{loss} = \sum_{i=0}^{n-1} P_L(i, i+1) \quad (6)$$

$$TQ_{loss} = \sum_{i=0}^{n-1} Q_L(i, i+1) \quad (7)$$

in which, TP_{loss} and TQ_{loss} are the active and reactive losses in the system, respectively. The recursive equation given in equations (1) and (2) should be modified as follows:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1} \frac{P_i^2 + Q_i^2}{|V_i^2|} + \mu_p \cdot AP_{i+1} \quad (8)$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1} \frac{P_i^2 + Q_i^2}{|V_i^2|} + \mu_q \cdot RP_{i+1} \quad (9)$$

In Eq. (8), μ_p is the active power factor. When an active power source exists μ_p equals to one, otherwise it is zero. Similarly, in Eq. (9), μ_q is the reactive power factor. When a reactive power source exists μ_q equals to one, otherwise it is zero. Also, AP_{i+1} is the amplitude of the active power injected in bus $i+1$ and RP_{i+1} is the amplitude of the reactive power injected in bus $i+1$.

B. Objective Function

The objective function is the total active power loss in the system²²:

$$\min \cdot F = P_{Loss} \quad (10)$$

1. The Problem Constraints

The constraints that are considered in this optimization problem are the bus voltage limits, the lines load flow, and the minimum and the maximum of the available capacity for installing the capacitor banks and DGs. These constraints are demonstrated below:

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (11)$$

$$I_{ij} \leq I_{ij}^{\max} \quad (12)$$

$$P_{DG}^{\min} \leq P_{DG} \leq P_{DG}^{\max} \quad (13)$$

$$Q_c^{\min} \leq Q_c \leq Q_c^{\max} \quad (14)$$

in which I_{ij} is the current passing from bus i to bus j , P_{DG} and Q_c are the active and reactive power of each DG and capacitor that are between their maximum and minimum amount.

III. CROW SEARCH ALGORITHM

Crows are considered intelligent birds. They have the largest brain relative to their body size. According to their brain to body ratio, their brain is only a little smaller than a human brain. There is a lot of evidence for crows' cleverness. Crows can remember their faces and warn each other when an unfamiliar one approaches. Besides, they can use tools, communicate in complex ways, and recall their secret food places up to several months later²⁴.

It has turned out that crows watch other birds, observe the places that other birds hide their food, and steal it once the bird leaves. If a crow committed theft, it takes extra precautions such as moving the hiding place in order to prevent being the next victim. In fact, they use their own personal experience as a thief to predict a thief's behavior and they can perform the safest methods to protect their savings from being stolen.

The principals of crow search algorithm (CSA) are as follows:

1. Crows live in flock form.
2. Crows remember their hidden places positions.
3. Crows follow each other to steal.
4. Crows protect their stocked stores from thievery by a probability.

It is assumed that there is a d-dimension environment including a number of crows. The number of the crows (the size of the flock) is N and the position of crow i at the time (iteration) $iter$ in the search space is determined by a vector x_i and $iter_{max}$ is the maximum number of iterations. Each crow has a memory that the position of its hiding place is memorized. In iteration $iter$, the position of the hiding place of crow i is shown by $m_i^{i,iter}$. This is the best position that crow i has achieved so far. In fact, in each crow's memory, the position of its best experience is memorized. The crows move in the environment and seek the best food sources (hiding places).

Assume that in iteration $iter$, the crow j wants to visit its hiding place, $m_i^{i,iter}$. In this iteration, the crow i decides to follow crow j to approach the hiding place of crow j . In this situation, two states might happen:

1. The first state Crow j does not know that crow i is following him. As a result, crow i will approach the hiding place of crow j . In this state the new position of crow i is obtained as follows:

$$x^{i,iter+1} = x^{i,iter} + r_i \times fl^{i,iter} \times (m^{j,iter} - X^{i,iter}) \quad (15)$$

In which r_i is a random number with uniform distribution between zero and one and $fl^{i,iter}$ illustrates the flight length of crow i in iteration $iter$. Fig. 2

indicates the general scheme of this state and its effect on search functionality. Small values of fl lead to local search (in the vicinity of $x^{i,iter}$) and large values lead to global search (far away from $x^{i,iter}$).

2. The second state: The crow j knows that crow i follows him; therefore, in order to protect his cache, crow j deceives crow i by going to another position in the search space.

Generally, states one and two can be expressed as follows:

$$X^{i,iter+1} = \begin{cases} X^{i,iter} + r_i \times fl^{i,iter} \times (m^{j,iter} - X^{i,iter}), & r_j \geq AP^{j,iter} \\ \text{a random position,} & \text{otherwise} \end{cases} \quad (16)$$

in which $AP^{j,iter}$ denotes the probability of the crow j awareness in the iteration $iter$.

Meta-heuristic algorithms should build a good balance between diversification and intensification. In CSA, intensification and diversification are mainly controlled by awareness probability (AP) parameter. By reducing the awareness probability value, CSA tends to do the search in a local area in which a proper solution has been found. As a result, by using the small values of AP, intensification increases. On the other hand, by awareness probability value increase, the search probability in the current proper solutions region decreases and CSA tends to check the search space on a global scale (random). Hence, employing large values of AP causes an increase in the diversification.

A. Implementing CSA for Optimization Problems

The step-by-step approach to CSA implementation is²⁴:

Step 1: Initializing the problem and the adjustable parameters.

The optimization problem, decision variables, and the constraints are defined. Then the adjustable parameters of CSA (flock size (N), the maximum number of iterations ($iter_{max}$), flight length (fl), and the awareness probability (AP)) are set.

Step 2: Initializing position and the crows' memory

N crows are positioned randomly in a d -dimensional search space as flock members. Each crow is a feasible solution to the problem and d is the number of decision

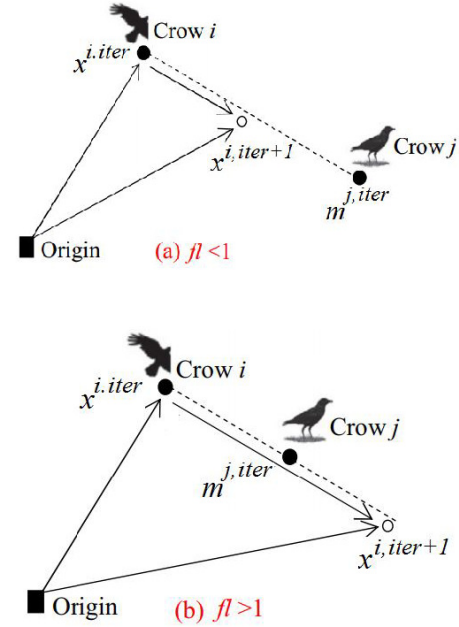


FIG. 2. The general scheme of search capability of crow i (crow i can go to all places on the dashed line).

variables.

$$\text{Crows} = \begin{pmatrix} x_1^1 & \cdots & x_d^1 \\ \vdots & \ddots & \vdots \\ x_1^N & \cdots & x_d^N \end{pmatrix} \quad (17)$$

Each crow's memory is initialized. Since in the first iteration, Crows do not have any experiences, it is assumed

that they have hidden their food at their initial positions.

Step 3: Objective Function Assessment

For each crow, by putting the decision variables value in the objective function the quality of its position is calculated.

$$\text{Memory} = \begin{pmatrix} m_1^1 & \cdots & m_d^1 \\ \vdots & \ddots & \vdots \\ m_1^N & \cdots & m_d^N \end{pmatrix} \quad (18)$$

Step 4: generating new positions

Crows generate new positions in the search space as follows: suppose that the crow i wants to generate a new position. For this purpose, this crow randomly chooses a crow from the flock (for example crow j) and follows it to find the position of the food that is hidden by this

crow (m^j). The new position of crow i is obtained by Eq. (2). This process will be repeated for all of the crows.

Step 5: Checking the feasibility of new positions

The feasibility of the new position of each crow will be checked. If a crow's new position is feasible, the crow updates its position. Otherwise, the crow stays in the current position and does not move to generate a new position.

Step 6: Evaluating the objective function of the new positions

The value of the fitness function for each crow's new position is calculated.

Step 7: Updating the memory

The crows update their memory as follows:

$$m^{i,iter+1} = \begin{cases} X^{i,iter+1}, & f(X^{i,iter+1}) \text{ is better than } f(X^{i,iter}) \\ m^{i,iter}, & \text{otherwise} \end{cases} \quad (19)$$

It is seen that if the new position objective function value is better than the memorized position objective function value, the crow updates its memory by the new position.

Step 8: Checking the termination condition

The steps 4 – 7 are repeated until $iter_{\max}$ is obtained. When the termination condition is met, the best memory position from the fitness function value point of view is reported as the optimization problem solution.

B. Implementing CSA to determine the location and size of the capacitor and DG

The implementation steps are:

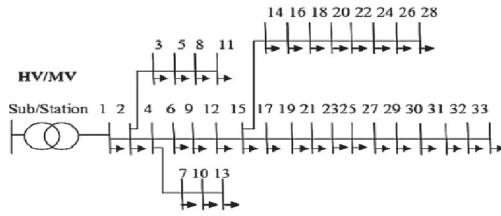
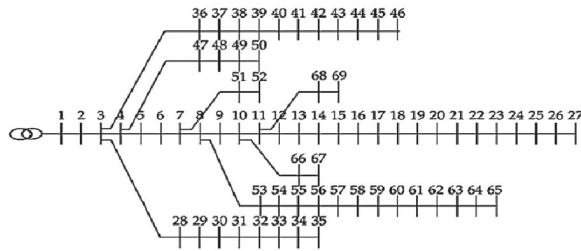
1. Reading the total information of the network including the number of buses, feeders, etc.
2. Setting the adjustable parameters of CSA including the flight length fl and the awareness probability AP and the maximum iteration number.
3. Generating the initial population and initializing the crows' positions in the search space: the decision variables of the problem such as the candidate bus for installing each DG and capacitor and the active power corresponding to each DG and the reactive power corresponding to each capacitor.
4. Initializing the memory of each crow.
5. Evaluating the objective function corresponding with the position and the memory of each crow by

running the forward-backward sweep load flow program.

6. Randomly generating the candidate crows for the chase.
7. Updating the position of each crow based on Eq. (14).
8. Checking the feasibility of the updated position of every crow and not violating the searching space
9. Evaluating the objective function corresponding to the new position of each crow by executing the forward-backward sweep load flow.
10. Updating the memory of each crow based on Eq. (17).
11. Repeating the steps 7 to 10 until reaching the termination criteria (maximum number of iteration).
12. Reporting the best value of the memory.
13. The end.

IV. SIMULATION RESULTS AND DISCUSSION

In order to study the functionality of crow search algorithm in the problem of simultaneously optimal locating of capacitor and distributed generation resources in radial distribution systems with the goal of minimizing the

FIG. 3. IEEE 33-bus standard distribution system²².FIG. 4. IEEE 69-bus standard distribution system²².

loss and with considering the mentioned constraints, the simulation is conducted on the IEEE 33 & 69-Bus systems (figures 3-4) in MATLAB software. In implementing the crow search algorithm the following parameters are considered: the flight length 2, the awareness factor (awareness probability) 0.1, the initial population 50, and the number of iteration 100.

In this study, several scenarios are considered. Tables I, II, demonstrates the conducted scenarios and their abbreviation signs on the 33 & 69 networks, respectively.

In this paper, computer simulations on placement problem are done with constant load (peak load) for implementation of CSA algorithm and validation and comparison of results with other algorithms and references such as^{22,25-29}. Simulation results with variable load and for a period of the network operation can be considered as the next step in research work.

A. The IEEE 33-Bus System CSA for Optimization Problems

The data of the IEEE 33-bus system is taken from reference²². The system load value is 3.7 MW and 2.3 MVar. The results of simulating this system for the first scenario is conducted when there exist no capacitors and no DGs and the voltage of the weakest bus is 0.904 pu and it is on bus No. 18. Total loss of the base system is 211 kW.

Table III illustrates the results of the computer simulation of implementing CSA for different scenarios on IEEE 33-bus network. In Table III, for each scenario, the network active power loss (kW), the decrease percent of the loss comparing to the base state, voltage (pu), and the location of the weakest bus, the size (MVar) and location of the capacitors and also the size and location of the DGs are shown. In all of the scenarios the active power loss is decreased compared to the base case and in cases (3 DG-PQ) and (3 Cap., 3 DG-PQ) the largest loss reduction is shown which are respectively 94.43% and 94.67%. Besides, the weakest bus voltage amplitude has improved in all the scenarios compared to the base case and the largest improvement is for cases (3 DG-PQ) and (3 Cap., 3 DG-PQ) which are 0.9922 and 0.9961 pu, respectively.

Figures 5 and 6, demonstrates the voltage profile comparison, the active power loss comparison, and the weakest bus voltage of the IEEE 33-bus network comparison in different scenarios.

Fig. 7, illustrates the convergence curve of the implementing CSA on IEEE 33-bus network for some of the scenarios and it shows a very good convergence and optimizing for the use of crow search algorithm.

In order to validate and assess the performance of CSA deployment, the results obtained from it regarding the locating, and solo and concurrent size determination of the shunt capacitors and the DGs from the viewpoint of active power loss value and voltage and the weakest bus position are compared to the three existing scenarios in other references including IMDE²², FGA²⁵, BPSO²⁶, and BFOA²⁷ algorithms and are shown in Tables IV and V, so that in locating and simultaneous size determination of the capacitors and DGs, CSA has presented better results comparing to other algorithms.

B. The IEEE 69-Bus System CSA for Optimization Problems

The data of the IEEE 69-bus system is taken from reference²². The system load value is 3.8 MW and 2.69 MVar. The results of simulating this system for the first scenario is conducted when there exist no capacitors and no DGs and the voltage of the weakest bus is 0.9102 and it is on bus No. 65. Total loss of the base system is 224.59 kW.

Table VI illustrates the results of the computer simulation of implementing CSA for different scenarios on IEEE 69-bus network. In Table VI, for each scenario, the network active power loss (kW), the decrease percent of the loss comparing to the base state, voltage (pu), and the location of the weakest bus, the size (MVar) and location of the capacitors and also the size and location of the DGs are shown. In all of the scenarios the active power loss is decreased compared to the base case and in cases (2 DG-P, 2 Cap) and (3DG-PQ, 3 Cap) the largest loss reduction is shown which are respectively 96.78% and 98.16%. Besides, the weakest bus voltage amplitude

TABLE I. The simulated CASES on 33-BUS network

Scenarios	
Without Cap & Without DG	Base Case
One Capacitor	1 Cap
Two Capacitors	2 Cap
One DG with $p_f = 1$	1 DG-P
Two DGs with $p_f = 1$	2 DG-P
Three DGs with $p_f = 1$	3 DG-P
Three DGs with $p_f < 13$	DG-PQ
One Capacitor & One DG with $p_f = 1$	1 DG-P, 1 Cap
Two Capacitors & Two DGs with $p_f = 1$	2 DG-P, 2 Cap
Three Capacitors & Three DGs with $p_f < 1$	3 DG-PQ, 3 Cap

TABLE II. The simulated CASES on 69-BUS network

Scenarios	
Without Cap & Without DG	Base Case
One Capacitor	1 Cap
One DG with $p_f = 1$	1 DG-P
Two DGs with $p_f = 1$	2 DG-P
Three DGs with $p_f = 1$	3 DG-P
One Capacitor & One DG with $p_f = 1$	1 DG-P, 1 Cap
Two Capacitors & Two DGs with $p_f = 1$	2 DG-P, 2 Cap
Three Capacitors & Three DGs with $p_f < 1$	3 DG-PQ, 3 Cap

has improved in all the scenarios compared to the base case and the largest improvement is for cases (2 DG-P, 2 Cap.) and (3 DG-PQ, 3 Cap.) which are 0.9943 and 0.9963 pu , respectively.

Fig. 9, illustrates the convergence curve of the implementing CSA on IEEE 69-bus network for some of the scenarios and it shows a very good convergence and optimizing for the use of crow search algorithm. Figures 10-12, demonstrates the voltage profile comparison, the active power loss comparison, and the weakest bus voltage of the IEEE 69-bus network comparison in different scenarios.

In order to validate and assess the performance of CSA deployment, the results obtained from it regarding the locating, and solo and concurrent size determination of the shunt capacitors and the DGs from the viewpoint of active power loss value and voltage and the weakest bus position are compared to the three existing scenarios in other references including IMDE²² and PSO²⁹ algorithms and are shown in Tables VII and VIII, so that in locating and simultaneous size determination of the capacitors and DGs, CSA has presented good results comparing to other algorithms.

TABLE III. The simulation results of the IEEE 33-BUS network for different scenarios

Scenarios	Base Case	1 Cap	2 Cap	1 DG-P	2 DG-P	3 DG-P	3 DG-PQ	1 DG-P, 1 Cap	2 DG-P, 2 Cap	3 DG-PQ, 3 Cap
Power Losses (Kw)	211	151.36	141.83	111.02	87.17	72.7	11.76	58.49	28.51	11.25
Loss reduction (%)	-	28.27	32.78	47.38	58.67	65.50	94.43	72.28	86.49	94.67
Vworst in pu (Bus No)	0.904 (18)	0.9165 (18)	0.9304 (17)	0.9424 (18)	0.9686 (18)	0.9687 (18)	0.9922 (8)	0.9534 (18)	0.9804 (25)	0.9961 (22)
C1 size in $Mvar$ (Bus No)	-	1.285 (30)	0.4652 (12)	-	-	-	-	1.2175 (30)	0.4488 (12)	0.4233 (8)
C2 size in $Mvar$ (Bus No)	-	-	1.063 (30)	-	-	-	-	-	1.0468 (30)	0.1610 (21)
C3 size in $Mvar$ (Bus No)	-	-	-	-	-	-	-	-	-	0.1500 (32)
DG1-P size in MW (Bus No)	-	-	-	2.59 (6)	0.852 (13)	0.8018 (13)	-	2.5363 (6)	0.8656 (13)	-
DG2-P size in MW (Bus No)	-	-	-	-	1.158 (30)	1.0913 (24)	-	-	1.1253 (30)	-
DG3-P size in MW (Bus No)	-	-	-	-	-	1.0536 (30)	-	-	-	-
DG1-PQ size in MVA (Bus No)	-	-	-	-	-	-	0.8832 $p_f = 0.9049$ (13)	-	-	0.8364 $p_f = 0.9544$ (14)
DG2-PQ size in MVA (Bus No)	-	-	-	-	-	-	1.2151 $p_f = 0.8928$ (24)	-	-	1.1633 $p_f = 0.8810$ (24)
DG3-PQ size in MVA (Bus No)	-	-	-	-	-	-	1.4313 $p_f = 0.7144$ (30)	-	-	1.3209 $p_f = 0.8382$ (30)

V. CONCLUSIONS

Because of distribution networks expansion and also the increase of power demand, utilizing the distributed generation resources and capacitor banks are increasing

day by day. Determining the installation location and the capacity of these instruments are two important and effective factors to the network power loss and the network performance improvement. If connected to the network in the right place, the distributed generating

TABLE IV. Comparing the voltage (pu) and the place of the weakest bus in IEEE 33-BUS network with different algorithms

Scenarios	1 DG-P	3 DG-P	1 DG-P, 1 Cap	2 Cap	2 DG-P	2 DG-P, 2 Cap
CSA	0.9424 (18)	0.9687 (18)	0.9534 (18)	0.9304 (17)	0.9686 (18)	0.9804 (25)
IMDE ²²	-	-	-	0.942 (18)	0.971 (33)	0.979 (25)
FGA ²²	-	-	-	0.929 (18)	0.935 (18)	0.96 (18)
BPSO ²⁶	-	-	-	0.935 (18)	0.919 (18)	0.969 (18)
BFOA ²⁷	-	-	-	0.9361	0.9645	0.9783

TABLE V. Comparing the active power loss (KW) in IEEE 33-BUS network with different algorithms

Scenarios	1 DG-P	3 DG-P	1 DG-P, 1 Cap	2 Cap	2 DG-P	2 DG-P, 2 Cap
CSA	111.02	72.7	58.49	141.83	87.17	28.51
IMDE ²²	-	-	-	139.7	84.28	32.08
FGA ²²	-	-	-	141.3	119.7	59.5
BPSO ²⁶	-	-	-	151.7	111.5	57.3
BFOA ²⁷	-	-	-	144.04	98.3	41.41
HAS-ABCA ²⁸	111.03	72.81	58.45	-	-	-

power plants and the capacitors will have various effects including loss reduction, voltage profile improvement, and network reliability increase. In this paper, in order to determine, solo and concurrent, the optimal location and size of the distributed generation resources and shunt capacitors in radial distribution systems the crow search algorithm, which is based on simulating the intelligent behavior of the crows in search of food, is used. To check the efficiency of the applied method, the simulation was conducted on case study networks for different scenarios and with proper convergence and speed, desirable results were gained, and comparing the results to other algorithms expresses the good performance of CSA in optimization problems.

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TABLE VI. The simulation results of the IEEE 69-BUS network for different scenarios

Scenarios	Base Case	1 Cap	1 DG-P	2 DG-P	3 DG-P	1 DG-P, 1 Cap	2 DG-P, 2 Cap	3 DG-PQ, 3 Cap
Power Losses (KW)	224.59	152.04	83.224	71.677	69.429	23.17	7.233	4.123
Loss reduction (%)	-	32.30	62.94	68.09	69.09	89.68	96.78	98.16
Vworst in <i>pu</i> (Bus No)	0.9102 (65)	0.9307 (65)	0.9683 (27)	0.9789 (65)	0.9790 (65)	0.9725 (27)	0.9943 (50)	0.9963 (50)
C1 size in <i>MVar</i> (Bus No)	-	1.330 (61)	-	-	-	1.300 (61)	0.375 (17)	0.219 (3)
C2 size in <i>MVar</i> (Bus No)	-	-	-	-	-	-	1.253 (61)	0.050 (29)
C3 size in <i>MVar</i> (Bus No)	-	-	-	-	-	-	-	0.355 (49)
DG1-P size in <i>MW</i> (Bus No)	-	-	1.873 (61)	0.532 (17)	0.5351 (11)	1.828 (61)	0.520 (17)	-
DG2-P size in <i>MW</i> (Bus No)	-	-	-	1.781 (61)	0.3770 (18)	-	1.731 (61)	-
DG3-P size in <i>MW</i> (Bus No)	-	-	-	-	1.7175 (61)	-	-	-
DG1-PQ size in <i>MVA</i> (Bus No)	-	-	-	-	-	-	-	0.7063 $p_f = 0.7342$ (11)
DG2-PQ size in <i>MVA</i> (Bus No)	-	-	-	-	-	-	-	0.391 $p_f = 0.8558$ (17)
DG3-PQ size in <i>MVA</i> (Bus No)	-	-	-	-	-	-	-	2.1322 $p_f = 0.830$ (61)

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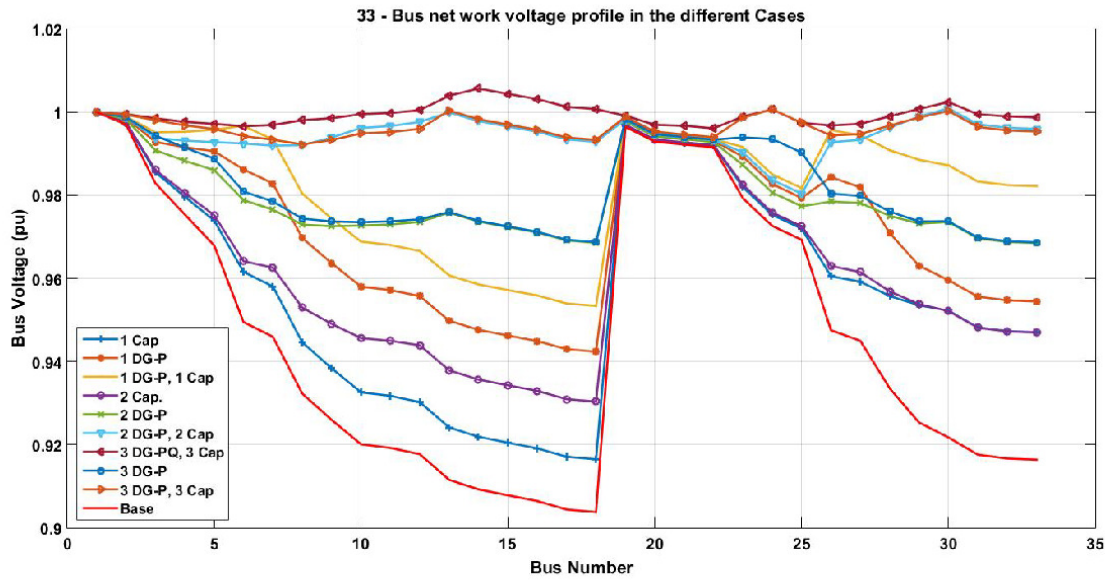


FIG. 5. Voltage profile of the IEEE 33-bus network in different scenarios.

TABLE VII. Comparing the active power loss (KW) in IEEE 69-BUS network with different algorithms

Scenarios	Base Case	1 DG-P	2 DG-P	3 DG-P	2 DG-P, 2 Cap
CSA	224.59	83.224	71.677	69.429	7.233
IMDE ²²	-	-	70.92	-	13.833
PSO ²⁹	-	83.17	71.96	69.89	25.9

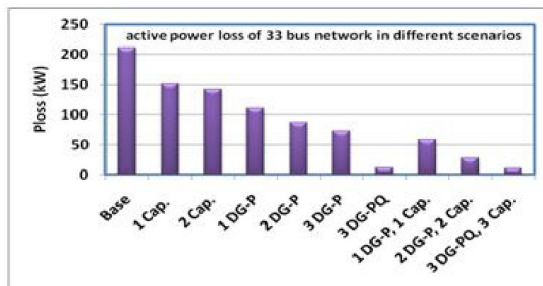


FIG. 6. Comparing the active power loss of the IEEE 33-bus network in different scenarios.

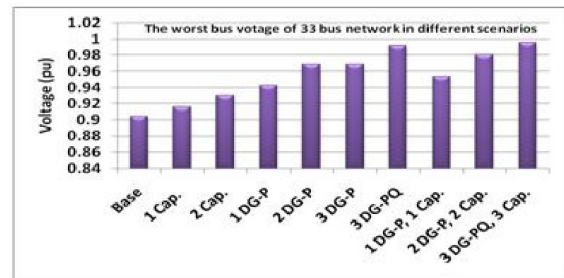


FIG. 7. Comparing the weakest bus voltage of the IEEE 33-bus network in different scenarios.

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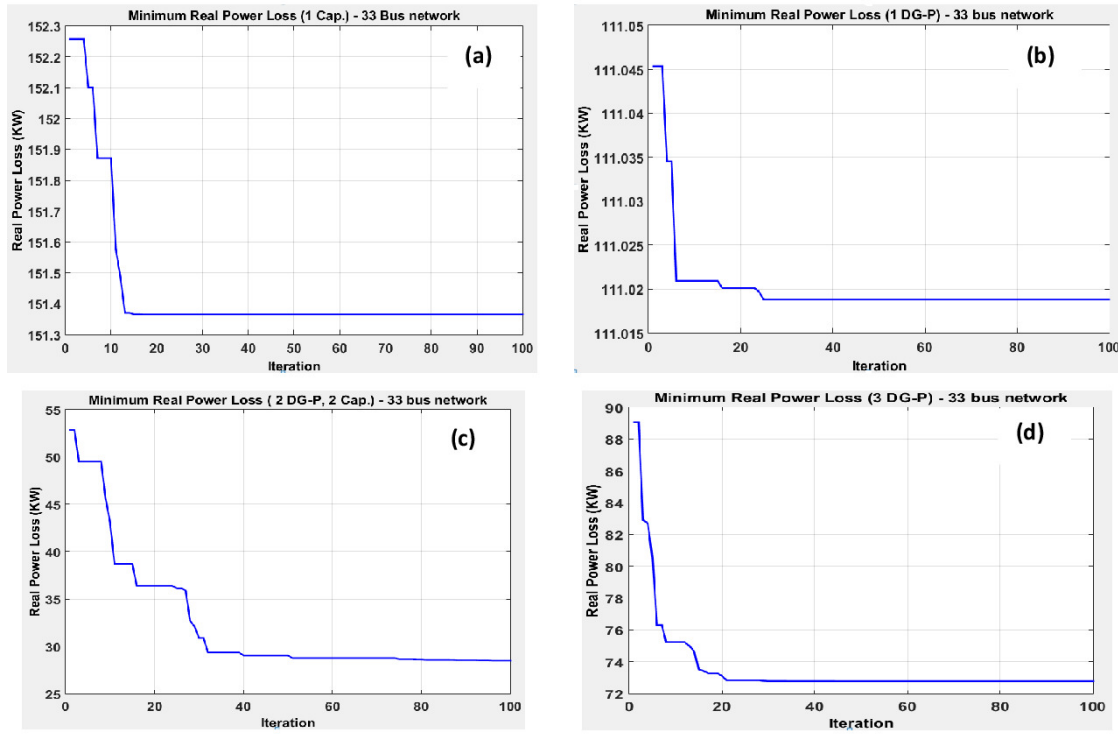


FIG. 8. Convergence curve of implementing CSA to the IEEE 33-bus network: (a) case 1 Cap (b) case 1 DG-P (c) case 2 DG-P, 2 Cap (d) 3 DG-P.

TABLE VIII. Comparing the voltage (pu) and the place of the weakest bus in IEEE 69-BUS network with different algorithms

Scenarios	Base Case	1 DG-P	2 DG-P	3 DG-P	2 DG-P, 2 Cap
CSA	09102 (65)	0.9683 (27)	0.9789 (65)	09790 (65)	0.9943 (50)
IMDE ²²	-	-	0.9808 (65)	-	0.9915 (68)
PSO ²⁹	-	-	-	-	0.97 (27)

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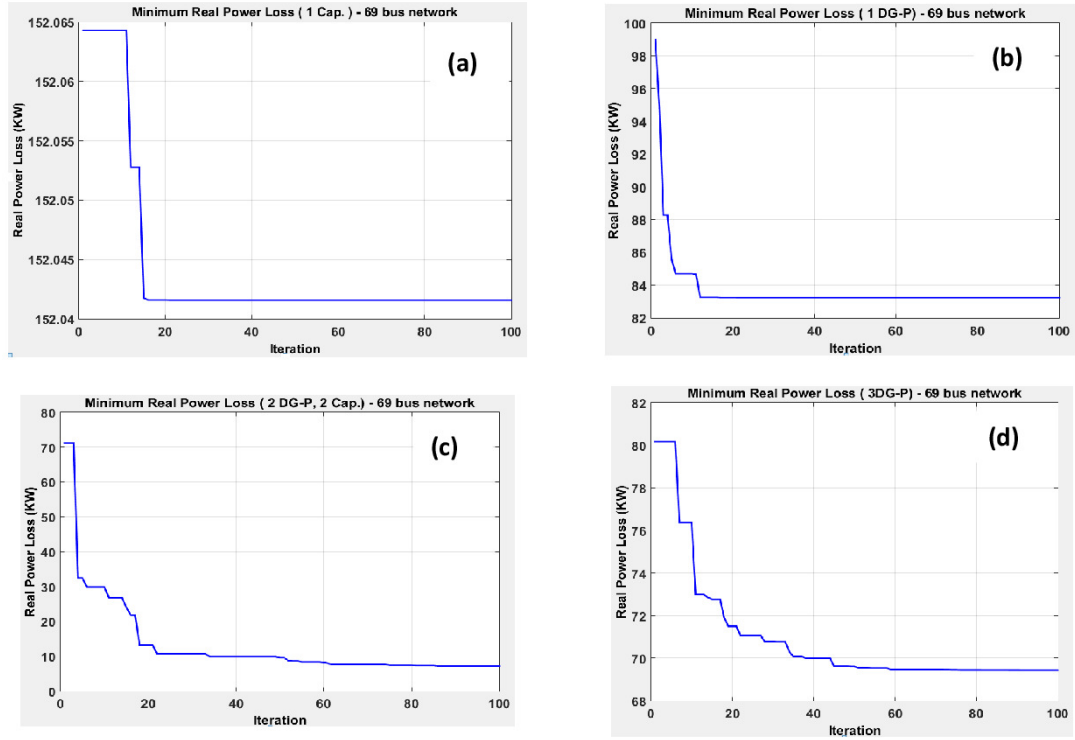


FIG. 9. Convergence curve of implementing CSA to the IEEE 69-bus network: (a) case 1 Cap (b) case 1 DG-P (c) case 2 DG-P, 2 Cap (d) 3 DG-P.

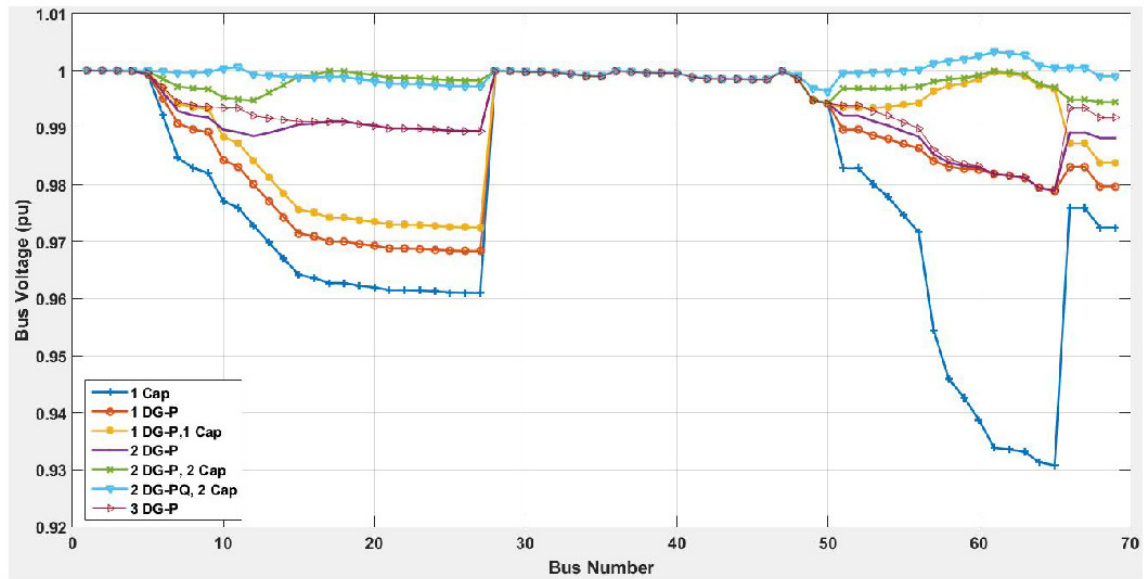


FIG. 10. Voltage profile of the IEEE 69-bus network in different scenarios.

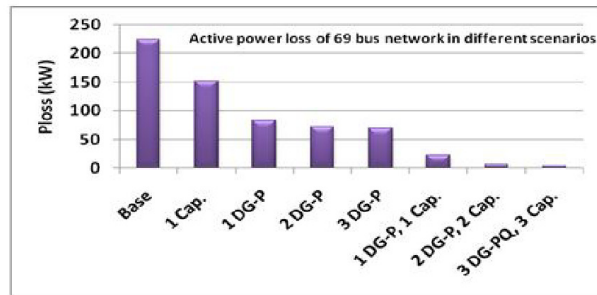


FIG. 11. Comparing the active power loss of the IEEE 69-bus network in different scenarios.

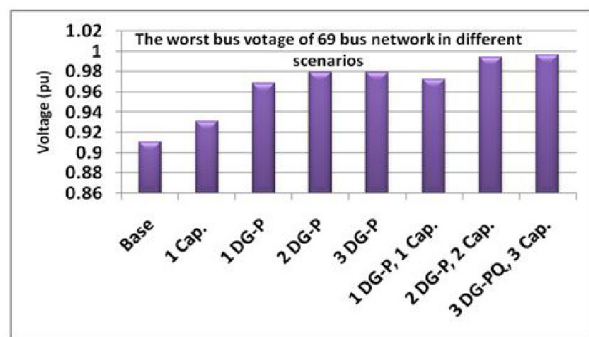


FIG. 12. Comparing the weakest bus voltage of the IEEE 69-bus network in different scenarios.

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