Cuckoo Search Algorithm for Network Reconfiguration and Optimal Capacitor Allocation

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Abstract--**The efficient operation of electrical distribution systems is critical in modern industry, as it directly impacts the reliability, stability, and cost-effectiveness of delivering electricity to consumers. Capacitors are included in radial distribution systems to improve voltage profile and minimize losses by providing reactive power. Consequently, losses are reduced as the reactive power flow component is compensated. Furthermore, re-configuration of the distribution network, which involves altering the open/closed status of switches, is a vital approach that affects the steady flow of electricity through the network. Network reconfiguration and optimal capacitor placement are essential techniques for enhancing the performance of the distribution networks. This study utilizes the Cuckoo Search Algorithm (CSA) to solve the problems of network reconfiguration and optimal capacitor placement. The primary objective is to minimize power losses while ensuring that the voltage profile and reliability of the distribution system satisfy industry-level standards. The proposed method was tested on the IEEE 33 bus network. Five different scenarios were considered. The simulations were conducted in MATLAB software. The acquired improvements in the power loss reduction and voltage profile corroborate the effectiveness of this novel approach. Compared to previously explored methods, the results of the proposed scheme for solving optimal capacitor placement and network reconfiguration individually were found to be more effective in terms of reducing power loss (3.12% and 4.02%, respectively).**

Index Terms- **Optimal capacitor placement and sizing, Optimal reconfiguration, Power loss reduction, Power distribution network, Cuckoo Search Algorithm (CSA).**

I. INTRODUCTION

Effective and reliable electrical power distribution is a cornerstone of modern industry, underpinning economic development and ensuring high-quality life for innumerable people. Optimization of electrical distribution networks is an ongoing challenge, as it requires balancing the objectives of minimizing power losses, maintaining a stable voltage profile, and improving network reliability [1]. Reconfiguration of the distribution network, which involves altering the open/closed status of the switches, is a vital approach that impacts the flow of electricity through the network [2]. Switches can be classified into two types according to their open or closed condition: normally open and normally closed. The normally open switches are considered tie switches in the network [3]. These switches are optimally configured during the reconfiguration process. When the distribution network is optimally redesigned, power losses can be significantly reduced, and the system can be more efficient [3].

The most common usage of capacitors in distribution networks is to compensate for reactive power [4, 5]. Additionally, they are used to minimize power losses and improve voltage profiles [6, 7]. It is important to note that the benefits of this type of compensation depend on how and where the capacitors are placed within the system. Strategic placement of capacitors within the network has the potential to enhance power quality, improve voltage regulation, and reduce reactive power losses [7].

In recent years, the concurrent application of optimal capacitor placement and optimal reconfiguration of distribution networks has gained traction as a strategy to minimize power losses. The process of optimization is rendered more intricate when these methodologies are integrated. Numerous publications have explored the optimal placement of capacitors and feeder reconfiguration independently, and a variety of approaches have been used to model the network and optimize the solution.

A novel approach that was implemented to reconfigure feeders to minimize loss proposed to systematically activate the switches one after another [8]. Additionally, the algorithm is utilized for the restoration of service. This approach considered the power flow in the branches. The results demonstrated an enhanced voltage profile accompanied by an improved restoration strategy. Additionally, the computational load is decreased. Ref [9] analyzed various solution strategies for distribution network reconfiguration. The authors emphasized both classic and current approaches, such as power quality, capacitor replacement, reliability, and the integration of renewable energy sources. Ref [10] has investigated the effectiveness of the Cuckoo Search Algorithm (CSA) in reconfiguring the distribution network, taking into account changes in the output power of distribution generation (DG) units and loads. This study explores the generation profile of solar and wind units, as well as the variations in the load profile. Their findings clearly demonstrate that such a reconfiguration makes it possible to decrease the energy loss during 24 hours; hence the network's performance is improved compared to the original architecture. In another study, the dynamic reconfiguration of the distribution network that was connected to solar and wind turbines is evaluated [11]. The problem is

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formulated to minimize both voltage deviation and system operating cost in the IEEE 33-bus test system. An enhanced NSGA-II algorithm was employed, which considers the system restrictions when exploring the solution. The outcome demonstrates that the voltage distribution of the system may be efficiently altered by incorporating a load transformer and the Static Var Compensator (SVC) installation, resulting in enhanced system stability. The suggested algorithm exhibits superior convergence and constraint handling abilities, while also minimizing power loss.

Another method has been presented in [12] that utilizes an enhanced Genetic Algorithm (GA) to modify the structure of the network with minimal losses and exhibits notable improvements in convergence and crossover behavior. The active power loss was reduced to 139.55 kW. However, the CSA proposed in this paper diminished the active power loss to 129.9043 kW. The Harmony Search Algorithm (HSA) and its suitability for reconfiguration have been studied under a variety of load conditions in [13]. The active power loss was reduced to 138.06 kW. Based on the reported observations, HAS outperforms GA. The objective of [14] was to explore the optimal allocation of capacitors using various traditional, classical, and meta-heuristic optimization methods. In [15], the author proposed an analytical approach for determining the optimal allocation of capacitors in primary distribution feeders to maximize the reduction in annual losses. A technique called the Equal Area Criterion has been utilized in [16] to ensure that capacitor sizing and location are optimized to maximize net savings through a reduction in power loss. In [17], a reconfiguration approach using a CSA has been introduced that maximizes voltage magnitude while minimizing active power loss. After comparing the results of the proposed CSA with those of existing approaches in the literature, the authors tested it on three distinct distribution network systems to evaluate its efficiency. According to the simulation results, the CSA has proven potential to be considered an effective and promising solution for issues related to distribution network reconfiguration.

In [18], a Binary Particle Swarm Optimization (BPSO) was suggested to solve the distribution network reconfiguration and capacitor placement to diminish network loss. In [19], the Adaptive Whale Optimization (AWO) was proposed to minimize power loss and operating costs. The Simulated Annealing (SA) method was proposed in [20] to minimize network loss and improve voltage profile by rearranging the distribution network and configuring capacitors. An optimization algorithm based on biogeography has been developed in [21] to reconfigure distribution networks and allocate capacitors to reduce network losses and improve voltage profiles. Reconfiguring distribution networks to improve voltage profiles and decrease active power losses in the presence of distributed generation sources is made possible by a new method that combines the Teaching-Learning-Based-Optimization (TLBO) and Black-Hole (BH) algorithms, as suggested in [22]. The IEEE 33-bus radial distribution system has been tested in a wide range of publications using the proposed technique. Based on the outcomes, it is clear that the hybrid TLBO-BH algorithm is capable of rapidly reaching global optimum while simultaneously improving voltage profiles and reducing losses.

This paper aims to evaluate the performance of the Cuckoo Search Algorithm (CSA) for network reconfiguration and optimal capacitor placement within the electrical distribution network. The CSA method outperforms competing approaches in optimization problems while requiring fewer control parameters. The IEEE 33-bus system is utilized to assess the proposed method and compare the results with further optimization algorithms. Based on the results of the study, capacitor allocation and network reconfiguration together improve voltage profile and diminish power losses. Furthermore, the proposed optimization algorithm was superior to other algorithms previously studied in the literature in terms of loss reduction. The main objectives of this research are as follows:

- To consider the capacitor allocation problem and network reconfiguration in five different scenarios.
- To implement the CSA method to identify the best placement and capacity of capacitor, and optimize the switching states of network elements.
- To evaluate the efficacy of the proposed method by running comprehensive simulations on the IEEE 33 bus test system.
- To compare the results obtained from this study with the other optimization algorithms to verify the superiority of the suggested technique.

The remainder of this paper is organized as follows: Section II describes the optimization model's objective function and constraints. Section III provides an in-depth description of the CSA and its adaptation to solve the reconfiguration and capacitor allocation problem. Section IV presents the validation methodology and performance analysis using the IEEE 33-bus test system and discusses the implications of the results. Finally, Section V summarizes the results of this paper.

II. PROBLEM FORMULATION

A. Objective function

Under a specified load pattern, it is intended to minimize network power losses by considering constraints. This can be expressed mathematically as follows [23]:

$$Min\ OF = Min\,(P_{T,Loss} + \lambda_V \times S_{C_V} + \lambda_I \times S_{C_I}) \quad (1)$$

where, $P_{T,Loss}$ is the network total real power loss. λ_V and λ_I show penalty constants, S_{C_V} is squared sum of the violated voltage constraints, and S_{C_I} is squared sum of the violated current constraints [23]. $\lambda_V \times S_{C_V} + \lambda_I \times S_{C_I}$ is utilized to apply constraints on the objective function. The magnitude of voltage in each bus must remain within its permissible range. Consequently, the intervals are given below [24]:

$$v_i^{\min} \le v_i \le v_i^{\max}\,,\ i = 1,2,\ldots N_{bus} \quad (2)$$

where, V_i is the voltage magnitude of i^{th} bus. The magnitude of voltage changes of the transmission network busbar is bounded by a $\pm 5\%$ tolerance, which is represented in Eq (2) [25]. Maintaining the voltage within the specified range helps prevent voltage collapse, voltage instability, and other undesirable phenomena that can lead to system-wide failures. The branch current limits must also be satisfied by each branch's current.

$$\left|I_i\right| \le \left|I_i^{\max}\right| \qquad i = 1,2,\ldots N_{Line} \tag{3}$$

$|I_i|$ is the current magnitude and I_i^{max} is the maximum current limit of the branch i. Therefore, the penalty constants are calculated as follows:

1. λ_V and/or λ_I equal to 0, if the associated voltage/ current constraint is not violated.
2. Whenever the voltage or current constraint is violated, a significant value is assigned to λ_V and/or λ_I; this leads to the objective function of avoiding undesirable outcomes [23]. Prior to the optimization process, this significant value is equivalent to the quantity of the objective function (in this study, initial power loss was measured on the test network) multiplied by a large number (for example 10^4). The developed program performs this process automatically.

B. Power balance equations

The power balance equation is given by [26]:

$$P_{ss} = \sum_{m=2}^{b-1} P_{Lm} + \sum_{m=1}^{b-1} P_{Loss}(m, m+1) - \sum_{m=2}^{b-1} P_{cap,m} \tag{4}$$

$$Q_{ss} = \sum_{m=2}^{b-1} Q_{Lm} + \sum_{m=1}^{b-1} Q_{Loss}(m, m+1) - \sum_{m=2}^{b-1} Q_{cap,m} \tag{5}$$

where P_{ss} and Q_{ss} are real and reactive power from the substation, respectively; P_{Loss} and Q_{Loss} are real load and reactive load at bus m, respectively; $P_{cap,m}$ and $Q_{cap,m}$ injected real and reactive power after capacitor allocation at bus m, respectively.

C. Capacitor Allocation Limits

Due to the direct impact of the installed capacitor capacity (i.e., kVAr) on the network power loss, all reactive power injected into the network needs to be utilized.

$$\sum_{k=1}^{N_{cap}} Q_{cap,k} \le \sum_{m=1}^{b} Q_{l,m} \qquad \forall m = 1,2,\ldots,b \tag{6}$$

D. Radial configuration of the system and isolation constraints

The most significant limitation in the distribution network reconfiguration problem is the requirement that all buses be contained within a radial distribution system layout. In this paper, the system configuration is verified using the method proposed in [27].

E. Backward–forward load flow

In Fig. 1 a radial diagram in which complex bus voltages and complex load demands are modeled, with lines represented by series impedances zi, respectively, by $E_i = e_i + jf_i$ and S_i, $\forall i = 1, \ldots, n$. Substation voltage is represented by the complex voltage symbol E_0, and its bus is known as the zero bus. It should be noted that the index i is used to specify both the bus and the line upstream of this bus [28].

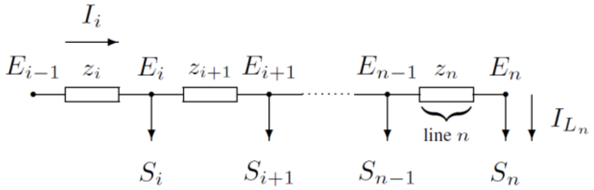

Fig. 1. Schematic of the radial distribution network.

The substation bus is typically considered the slack bus, with a constant real voltage E_0, in load flow analysis of distribution networks. Starting with an initial solution for all buses, the algorithm then iteratively performs three fundamental steps to reach the convergence criterion.

- The current injection $I_{L_i}^{(k+1)}$ at bus i and iteration $k+1$ is calculated as $I_{L_i}^{(k+1)} = \frac{S_i^*}{E_i^{*(k)}}$, where $E_i^{(k)}$ is the complex voltage at bus i calculated during the k^{th} iteration;
- Beginning with the farthest branches and moving toward the one connected to the substation bus, the current at branch i can be calculated by $I_i^{(k+1)} = I_{L_i}^{(k+1)} + \sum_{r\in\Delta i} I_{L_r}^{(k+1)} = \sum_{r\in\Lambda i} I_{L_r}^{(k+1)}$, where Δi refers to the set of downstream buses of bus i, and Λi refers to the set of elements of Δi including the i^{th} bus, i.e. $\Lambda i \triangleq \Delta i \cup \{i\}$.
- During a forward sweep, bus voltages are updated beginning with the first branch and progressing to the ends by $E_i^{(k+1)} = E_{ui}^{(k+1)} - z_i I_i^{(k+1)}$, where u_i shows the upstream bus of the i^{th} bus.

The maximum absolute power imbalance across all buses is one of the most fundamental convergence criteria. Other criteria, such as the largest absolute difference between successive voltage iterates, can also be used to verify convergence.

III. CUCKOO SEARCH ALGORITHM

The Cuckoo Search Algorithm (CSA) was developed by Yang and Deb [29]. CSA is a heuristic evolutionary algorithm for solving optimization problems based on population-based heuristics with the advantage of a simple implementation procedure and few parameter controls. A combination of the obligate brood parasitic behavior of some cuckoo species and the Lévy flight behavior of certain birds and fruit flies was used to develop this algorithm [17, 30]. A unique feature of the algorithm is that it creates two new solutions populations in each generation by using Lévy light and random walks. Specifically, the former plays a significant role in exploring the search space as below:

$$X_i^{new} = Xbest_i + \alpha \times (Xbest_i - Gbest) \times Levy(\beta) \tag{7}$$

where, $Xbest_i$ is the best solution of the ith individual in population, α is a coefficient between 0 and 1, $Gbest$ is the best solution for the population in the current generation. The distribution coefficient β is defined as a value between 0 and 2.

The random walk mechanism is exploited by discovering an alien egg within a host's nest using the following description:

$$X_i^{new} = Xbest_i + rand \times K(i,:) \otimes \left(Xbest_j - Xbest_k\right) \tag{8}$$

where, K is an $(N \times D)$ matrix where elements of matrix are 0 or 1 determined by $K = rand\,(N, D) > P_a$. P_a is probability of detecting the alien egg of the host birds. $Xbest_j$ and $Xbest_k$ are two solutions selected randomly in the current population, $rand$ is a random number in range of [0, 1]. The product $\otimes$ denotes entry-wise multiplications [31]. Fig. 2 illustrates the flowchart of the proposed method.

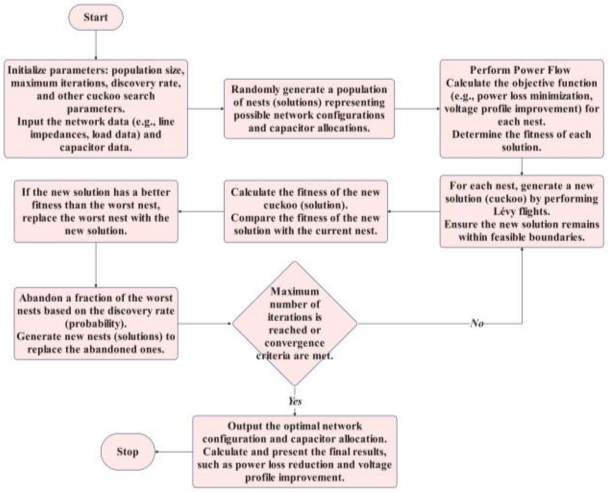

Fig. 2. Flowchart of CSA.

IV. SIMULATION RESULTS AND DISCUSSION

Optimal reconfiguration and capacitor placement are performed using the proposed algorithm on the IEEE 33-bus system. The data for this 33-bus network is available in [22]. The test system is shown in Fig. 3. This network has a nominal voltage of 12.66 kV and the active and reactive loads installed in this network are equal to 3715 kW and 2300 kVAr, respectively. The total active power loss is equal to 202.67 kW. The system has 37 branches, 32 sectionalizing switches, and 5 tie switches. The switches 37, 36, 35 and 34 are open before the reconfiguration of the system.

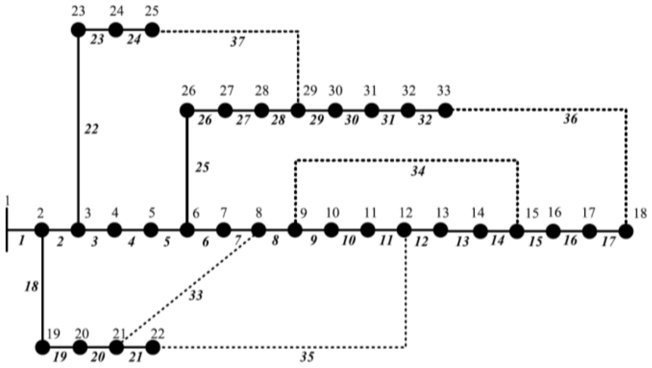

Fig. 3. The IEEE 33-bus distribution system.

In all cases, the number of iterations and population size are considered, 50 and 50, respectively. Six types of capacitors 300, 600, 900, 1,200, 1,500, and 1,800 kVAr are used in capacitor placement. One capacitor is considered for all cases. The following cases are considered:

1. Solely network reconfiguration;
2. Solely capacitor placement;
3. Initially, network reconfiguration followed by capacitor placement;
4. Initially, capacitor placement followed by network reconfiguration;
5. Simultaneous network reconfiguration and optimal capacitor placement;

According to Table I, the use of CSA in network reconfiguration resulted in a 35.9% reduction in power loss. The active power loss was reduced from 202.6771 kW to 129.9043 kW. According to Table I, after reconfiguration, the opened switches are 11 – 37 – 14 – 33 – 25. Optimizing the switching states of network elements leads to a reduction in power losses in the network, ultimately enhancing system efficiency. Fig. 4 shows the impact of applying the proposed method in this case on the network voltage profile. It is obvious in Fig. 4, the network voltage profile has significantly enhanced after network reconfiguration. The CSA convergence curve for this case can be seen in Fig. 5. It can be seen that CSA converges to the optimal global solution after 26 iterations.

In the second case, only capacitor placement is considered. The simulation results indicated that bus No. 27 is the most suitable location for the capacitor, with a capacity of 1200 kVAr. The active power loss was reduced from 202.6771 kW to 127.6171 kW, which showed a reduction of 37.03%. It is obvious in Fig. 4, that the voltage profile of the network has been significantly enhanced after capacitor placement. The optimal global solution is reached by CSA after the first iteration, as shown in Fig. 5. This scenario showed better performance in terms of loss reduction compared to the first case.

The third scenario involves the reconfiguration of the network before the placement of capacitors. Table I demonstrates that the opened switches are 11 – 37 – 14 – 33 – 25, similar to the first case. In this case, bus No. 25 is the optimal location for the capacitor and its capacity is 300 kVAr. The active power loss was reduced from 202.6771 kW to 114.676 kW, showing a 43.41% reduction. It is obvious in Fig. 4, the network voltage profile has been significantly enhanced after considering this scenario. It can be seen in Fig. 5 that the CSA converges to the optimal global solution after 30 iterations.

Reconfiguration of the network after the placement of capacitors is the fourth scenario. The results in Table I show that the opened switches are 37 – 32 – 12 – 7 – 8. In this case, bus No. 27 is the optimal location for the capacitor, and its capacity is 1200 kVAr. There was a decrease in active power loss from 202.6771 kW to 101.0061 kW, representing a reduction of 50.16%. Based on Fig. 4, it can be observed that the voltage profile of the network has been substantially enhanced. CSA converges to the optimal global solution after 47 iterations, as depicted in Fig. 5.

The final scenario is to simultaneously reconfigure the network and placement of the capacitors. The results in Table I indicates that the opened switches are 12 – 32 – 5 – 28 – 8. Bus No. 6 is the ideal location for the capacitor in this scenario, with a capacity of 1500 kVAr. The active power loss was reduced from 202.6771 kW to 93.6368 kW, which showed a 53.8% reduction. It is obvious in Fig. 4, the network voltage profile has been significantly enhanced after considering this scenario. It can be seen that CSA converges to the optimal global solution after 10 iterations.

Table II exhibits the results obtained by applying alternative optimization algorithms to the simultaneous problems of network reconfiguration and optimal capacitor placement. Other algorithms like modified flower pollination algorithm (MFPA) [32], simulated annealing (SA) [33], harmony search algorithm (HSA) [33], and modified bacterial foraging-based optimization (MBFO) [21] had 49.79%, 38.67%, 40.92% and 51.98% decrease in power loss, respectively. However, the method proposed in this paper achieved a 53.8% reduction in power loss compared to the normal network condition, which clearly demonstrates the superiority of CSA over the optimization algorithms.

The outcomes of the other optimization algorithms for resolving the capacitor placement issue alone are displayed in Table III. Other algorithms like MFPA [32], SA [33], HSA [33], water cycle algorithm (WCA) [34], grey wolf optimizer (GWO) [34] and gravitational search algorithm (GSA) [35] are studied in this paper. As can be seen in Table II, the mentioned algorithms had 31.13%, 32.84%, 33.33%, 33.88%, 33.91%, and 33.64% decrease in power loss, respectively. Compared to the CSA, which is proposed in this paper, the mentioned algorithms showed inferior performance. The proposed method demonstrated its superiority, as it achieved a 3.12% greater reduction in power loss compared to GWO. On the other hand, installing three capacitors with a higher capacity increases the cost of the power system.

Table IV shows the results of the other optimization algorithms to solve only network reconfiguration. Various algorithms are investigated, including MFPA [32], SA [33], HSA [13], GWO [36] and Refined GA [37]. As can be seen in Table IV, the mentioned algorithms had 31.14%, 29.63%, 31.88%, 31.14% and 31.154% decrease in power loss, respectively. In contrast, CSA reduced power loss by 35.9% compared to the normal network condition, which indicates that the CSA has a superior performance over the mentioned optimization algorithms when dealing with only network reconfiguration. CSA decreased power loss 4.02% more than HSA.

TABLE I

The Details of The Different Scenarios Using the Cuckoo Search Algorithm

	Normal network condition	Case 1	Case 2	Case 3	Case 4	Case 5
Minimum voltage (p.u.)	0.91306	0.95	0.95	0.95	0.95	0.95
Maximum voltage (p.u.)	1	1	1	1	1	1.0034
Capacitor size	-	-	1200	300	1200	1500
Capacitor location	-	-	27	25	27	6
Power loss (kW)	202.6771	129.9043	127.6171	114.676	101.0061	93.6368
Loss reduction %	-	35.9	37.03	43.41	50.16	53.8
Tie switches	33-34-35-36-37	11-37-14-33-25	33-34-35-36-37	11-37-14-33-25	37-32-12-7-8	12-32-5-28-8
Iteration	-	26	1	30	47	10

TABLE II

The Obtained Results of IEEE 33-Bus by Further Optimization Algorithms: Case 5

	Proposed Method	Modified Bacterial Foraging-Based Optimization [21]	Modified Flower Pollination Algorithm [32]	Simulated Annealing [33]	Harmony Search Algorithm [33]
Capacitor size	1500	900-600-750	200-200-550	1050-450-300-300-150	900-300-600-300-300
Capacitor location	6	5-27-2	28-29-30	6-28-29-30-9	6-28-29-30-9
Power loss (kW)	93.6368	97.30	101.77	124.29	119.72
Loss reduction %	53.8	51.98	49.79	38.67	40.92
Tie switches	12-32-5-28-8	8-37-14-7-36	7-14-9-36-37	7-14-9-32-37	33-14-8-32-28

TABLE III

The Obtained Results of IEEE 33-Bus by Further Optimization Algorithms: Case 2

	Modified Flower Pollination Algorithm [32]	Simulated Annealing [33]	Harmony Search Algorithm [33]	Water Cycle Algorithm [34]	Grey Wolf Optimizer [34]	Gravitational Search Algorithm [35]
Capacitor size	750-150-850	1050-450-300-300	900-300-600-300	750-300-750	750-300-750	350-450-800
Capacitor location	6-28-29	6-28-29-30	6-28-29-30	5-12-29	5-13-29	26-13-15
Power loss (kW)	139.57	136.11	135.16	134.00	133.94	134.5
Loss reduction %	31.13	32.84	33.33	33.88	33.91	33.64

TABLE IV
The Results Obtained from the IEEE 33-Bus by Further Optimization Algorithms: Case 1

	Harmony Search Algorithm [13]	Modified Flower Pollination Algorithm [32]	Simulated Annealing [33]	Grey Wolf Optimizer [36]	Refined GA [37]
Power loss (kW)	138.06	139.54	142.60	139.55	139.532
Loss reduction %	31.88	31.14	29.63	31.14	31.154
Tie switches	7-9-14-32-37	7-14-9-32-37	7-14-9-32-37	7-9-14-32-37	7-9-14-32-37

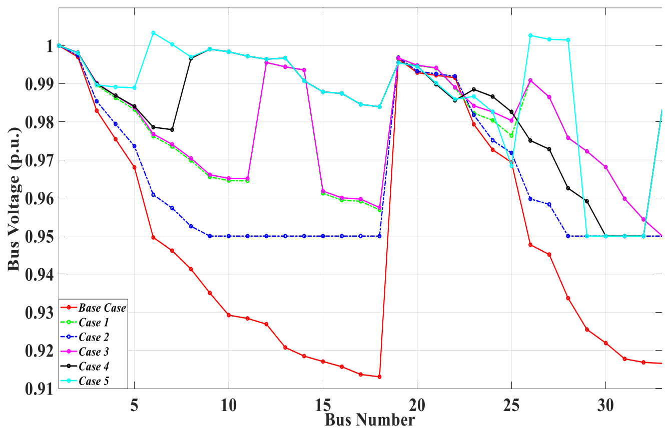

Fig. 4. The voltage profile of the system

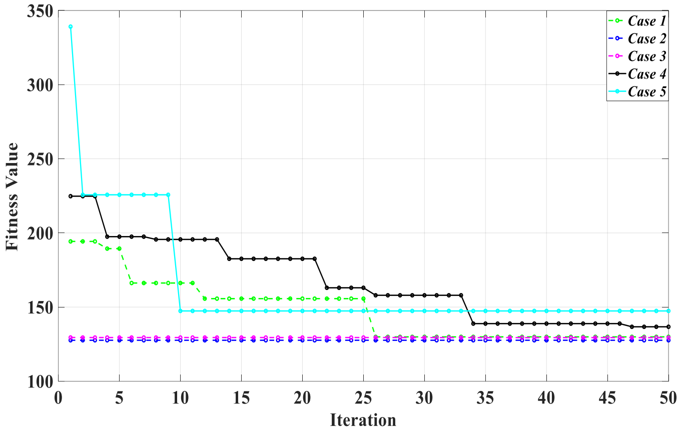

Fig. 5. Convergence of CSA

V. CONCLUSION

Optimal reconfiguration and capacitor placement problems are discussed in this paper in order to optimize the voltage profile and minimize the amount of power loss in the distribution network. The Cuckoo Search Algorithm (CSA) has been used to evaluate its efficacy on the IEEE 33-bus network.

In comparison with the earlier studies using other intelligent methods, simultaneous solving of these two problems results in better achievements than solving them separately. The proposed method is compared with other methods in the literature such as modified flower pollination algorithm, simulated annealing, harmony search algorithm, modified bacterial foraging-based optimization and so on. The performance of the suggested method is clearly superior, as shown by the numerical data in all scenarios studied.

The most optimal condition of a network is achieved by reconfiguring and placing capacitors simultaneously based on simulations and comparisons. Furthermore, the voltage profile of each busbar was enhanced. The following optimization cases are prioritized according to the amount of reduction in power loss: (1) optimal network reconfiguration and capacitor placement simultaneously, which had 53.8% decrease in power loss; (2) first, capacitor placement and then network reconfiguration, which had 50.16% decrease in power loss; (3) first, network reconfiguration and then capacitor placement, which had 43.41% decrease in power loss. The above results can be used by distribution utilities to prioritize network improvements.

Integrating renewable energy sources into the optimization framework and expanding the method to larger and more complicated distribution networks could be areas of future research. Additionally, it is worth investigating hybrid algorithms that combine CSA with other optimization techniques to further improve performance in convergence speed and solution quality. Furthermore, the development of a dynamic reconfiguration approach that makes use of real-time data from the advanced metering infrastructure (AMI) can be investigated. CSA will be able to create more adaptive and resilient power distribution networks by optimizing network configuration and capacitor placement in real-time in response to changes in load demand and system conditions.

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