A method based on cuckoo search for optimal network reconfiguration

Zhengzhong Gao, Yujuan Xu*, Zongfu Li, Yuchen Sun and Guangjie Liu
College of Electrical Engineering and Automation, Shandong University of Science and Technology, Qingdao, Shandong Province, 266590, China
*Corresponding author’s e-mail: zzgao@sdust.edu.cn

Abstract. The optimal reconfiguration of the distribution network doesn’t require any cost and becomes an effective technique for reducing power loss. So this paper proposes an efficient cuckoo search algorithm for this problem. First, the mapping relationship between the cuckoo search algorithm and the distribution network is established; secondly, the algorithm generates the initial population based on the set of feasible solutions; finally, algorithm updates the nest position by the Lévy flight and nest parasitic behavior. A variable domain search algorithm is introduced to improve for the shortcomings of the cuckoo search algorithm in the process of solving the distribution network reconfiguration problem. Finally, it is verified that the algorithm has the ability to quickly solve the optimal solution by the IEEE33 model simulation analysis.

1. Introduction
In recent years, with the continuous development of clean energy, a large number of distributed generation (DG) have been connected to the distribution network, which has caused profound changes in the content of the distribution network. In order to adapt to the diversification of optimization goals, the reconfiguration of the distribution network needs to comprehensively consider system reliability, economy and renewable energy utilization efficiency and other factors[1]. The access of DG has caused obvious changes in the size and direction of the power flow of the distribution network[2]. In order to improve the efficiency of the distribution network, many experts and scholars have tried various methods[3], including deterministic algorithms, such as discrete branch and bound method and dynamic programming method. There are many shortcomings such as high complexity and low precision[4]. It also includes intelligent optimization algorithms derived from simulation mechanisms, such as genetic algorithm (GA) [5], cuckoo search algorithm (CS) [6], ant colony algorithm (AC) [7].
In this context, this paper proposes an improved algorithm that combines the advantages of the cuckoo algorithm and the variable neighborhood search algorithm for the reconstruction of the distribution network. First, the global optimization is performed through the cuckoo algorithm, and then the variable neighborhood search algorithm is used to optimize the local optimization of the optimal particles obtained from the upper layer. Finally, simulations verify the effectiveness of the method in different situations.
2. The model of distribution network reconstruction

2.1. Objective function—Minimum network loss

The size and direction of the power flow of the distribution network have changed after the incorporation of DG[8]. Reasonable configuration of distributed power capacity and location can reduce the flow of power in the system. It can reduce power loss, eliminate overload, balance load, and make power quality more superior[9].

\[
\begin{align*}
    f(x) &= \min \sum_{i=1}^{N} K_{i-j} R_{i-j} \frac{P_j^2 + Q_j^2}{U_j^2} \\
    \text{Where } N \text{ is the total number of branches in the distribution network; } K_{i-j} \text{ is the topology of branch } i-j, \text{ and its value is 1 or 0, which means that branch } i-j \text{ is closed or open; } R_{i-j} \text{ is the resistance of the branch } i-j; \text{ } P_j \text{ and } Q_j \text{ are the injected active power and reactive power of the } j \text{th node; } U_j \text{ is the voltage of the } j \text{th node.}
\end{align*}
\]

2.2. Constraints

(1) Meet the constraints of system operation[10].

\[
\begin{align*}
    &U_{\min} \leq U_i \leq U_{\max}, \quad I_{\min} \leq I_{i-j} \leq I_{\max} \\
    &S_i \leq S_{\max}, \quad P_i \leq P_{\max}^G, \quad Q_i = P_i \tan \phi_G
\end{align*}
\]

Where \( U_{\max} \) and \( U_{\min} \) are the upper and lower voltage limits of the \( i \)th node; \( I_{\max} \) and \( I_{\min} \) are the upper and lower limits of the current flowing through branch \( i-j \); \( S_{\max} \) is the maximum allowable power of the \( i \)th node; \( P_{\max}^G \) is the active power at the maximum output of the DG; \( Q_G \) is reactive power at the output of DG; \( \phi_G \) is the DG power factor angle.

(2) The power flow constraints are shown in Eq. (3)[11].

\[
\begin{align*}
    &P_i - P_G = U_i \sum_{j=1}^{N} U_j (G_{i-j} \cos \theta_{i-j} + B_{i-j} \sin \theta_{i-j}) \\
    &Q_i - Q_G = U_i \sum_{j=1}^{N} U_j (G_{i-j} \sin \theta_{i-j} + B_{i-j} \cos \theta_{i-j})
\end{align*}
\]

Where \( P_i \) and \( Q_i \) are DG injection of active and reactive power of the \( i \)th node; \( P_G \) and \( Q_G \) are the active and reactive power of node \( i \) load; \( G_{i-j} \) and \( B_{i-j} \) are the conductance and susceptance between node \( i \) and node \( j \); \( U_i \) is the voltage of node \( i \); \( \theta_{i-j} \) is the power factor angle of branch \( i-j \).

3. Cuckoo search algorithm Research

3.1. Cuckoo search algorithm

The cuckoo search algorithm (CSA) is proposed based on imitating the parasitic brooding behavior of cuckoo. It has a series of advantages such as few parameters, easy coupling with other algorithms, and strong robustness.
(1) Population initialization method
The initial population obtained in this paper is divided into two stages. Firstly, the stage of population generation: randomly generate a nest library, and record the fitness value of each nest. Secondly, the stage of population screening: select N better nests according to the fitness value.

(2) Lévy flight updates populations and est parasitic behavior
Lévy flight is a global search method. Through irregular intermittent search, the search range can be easily expanded to achieve global search, thereby jumping out of the local optimum[12].

\[ X_{i+1}^t = X_i^t + \alpha \odot \text{Levy}(\lambda) \]  

(4)

Where \( X_i^t \) is the position of the \( i \)th bird's nest in the \( t \)-th generation, \( X_{i+1}^t \) is the position of the \( i \)th bird's nest in the \((t+1)\)th generation, \( \alpha \) is the scaling factor of step size, and \( \text{Levy}(\lambda) \) is the Lévy random search path. Expressed as:

\[ \text{Levy}(\lambda) = \frac{\phi u}{|v|^{\lambda}} \]  

(5)

Where \( u \) and \( v \) obey normal distribution, \( 0 < \lambda < 2 \), when \( \beta = 1.5, u \sim N(0,1), v \sim N(0,1) \).

The cuckoo puts its eggs in the host's nest, and the host finds the foreign eggs with probability \( P \). Then randomly changes the position of the found bird's nest, and obtains a new set of bird's nest positions[13].

\[ X_{i+1}^t = X_i^t + r \odot \text{Heaviside}(Pa - \eta) \odot (X_i^t - X_j^t) \]  

(6)

Where \( r \) and \( \eta \) are random numbers that obey a uniform distribution, \( \text{Heaviside}(x) \) is the step function, \( X_i^t \) and \( X_j^t \) are any other two bird nests.

3.2. Improved algorithm
Unlike other meta-heuristic algorithms, the cuckoo algorithm updates the population in two ways. So they have limitations in local search and cannot generate new solutions based on the current optimal solution. Therefore, in order to improve the convergence speed and optimization accuracy of the algorithm, the variable neighborhood search algorithm is introduced. The original update mechanism of the cuckoo search algorithm is improved, and the hybrid variable neighborhood cuckoo algorithm is formed.

When the algorithm falls into the local optimum, the variable neighborhood algorithm is introduced. The main method is: in the original CSA, recording the optimal nests fitness value during each iteration, and then using Eq. (19) to calculate the nests fitness change rate. If the change rate is less than a certain fixed value \( \varepsilon \) and the current iteration number is less than \( T_{\text{max}} \), then select part of the nest to use the variable neighborhood algorithm to update the location.

\[ \Delta f = \left| \frac{f(X_{\text{gbest}}(i-1)) - f(X_{\text{gbest}}(i))}{f(X_{\text{gbest}}(i-1))} \right| < \varepsilon \]  

(7)

Where \( f(X_{\text{gbest}}(i-1)) \) and \( f(X_{\text{gbest}}(i)) \) are the fitness function values of the optimal solution in \((i-1)\)th iteration and \(i\)th iteration.

In summary, the flowchart of improved CSA as follows:
4. Case analysis

4.1. Simulation parameters

In the improved CSA, the number of nests is set to 20, the maximum number of iterations $T_{\text{max}}=50$, and the probability of discovery $P_a=0.2$. The calculation example takes the IEEE33-node power distribution system as an example. The rated voltage of the system is 12.66kV, The total load is 3715kW+j2300kvar, the literature for detailed can be obtained from parameters[9]. The IEEE33 system network is shown in Figure 2 below.

![Figure 2. IEEE33-node system.](image)

4.2. Reconfiguration without DG

Table 1. Comparison of Reconstruction Data of Standard IEEE33 Node System.

| Algorithm          | Before reconstruction | Literature[9] | After reconstruction |
|--------------------|-----------------------|---------------|----------------------|
| Active power loss (kW) | 202.64                | 139.44        | 139.47               |
| Minimum node voltage (p.u) | 0.913                | 0.939         | 0.938                |
| Switch combination  | [33, 34, 35, 36, 37]  | [7, 9, 14, 32, 37] | [7, 9, 14, 32, 37]   |

Table 1 is the comparison of the results of standard IEEE33 node system reconstruction data. The optimal switch combination obtained by the improved CSA is consistent with the literature[9], and the open switches are all 7, 9, 14, 32, 37. After the distribution network is reconstructed through the
algorithm, the active power loss is greatly reduced, about 31.18%. The minimum node voltage is increased from 0.913p.u. to 0.938p.u., which is about 2.74%.

![Figure 3. Node voltages after reconfiguration without DG.](image)

### 4.3. Reconfiguration with DG

Table 2. Access location and parameters of DG.

| The access node | DG type        | Node type | Parameter                  |
|-----------------|----------------|-----------|----------------------------|
| 17              | PV             | PI        | 100kW, 50A                 |
| 25              | Wind Turbines  | PQ        | 100kW, \(\cos \theta = 0.9\) |
| 30              | PV             | PI        | 100kW, 50A                 |
| 32              | Wind Turbines  | PQ        | 100kW, \(\cos \theta = 0.9\) |

The node voltage comparison is shown in Figure 4.

![Figure 4. Node voltages after reconfiguration with DG.](image)

It can be seen the network loss is 202.64kW before connecting to DG, then it becomes 110.08kW, which is 45.67% lower than the network loss without DG. Reasonable access to DG in the distribution network can also reduce network loss. After the reconstruction of the improved cuckoo algorithm, the active power loss of the network is reduced again to 77.98kW, which is 29.16% higher than before.
optimization. The minimum node voltage rises from 0.9131 p.u. to 0.965 p.u. The open switch combination changed from 33, 34, 35, 36, 37 to 7, 28, 9, 14, 16.

5. Conclusion
Aiming at the optimization problem of distribution network reconfiguration, this paper proposes an improved cuckoo optimization algorithm, which improves the local search ability of cuckoo algorithm. The simulation results show that the algorithm can search for the global optimal solution in a short time, and after DG is connected, the reconstruction can effectively reduce the active power loss and increase the node voltage level.

Acknowledgments.
This article is one of the phased achievements of the Shandong Provincial Natural Science Foundation of China, "Research on Hierarchical Filtering of Wireless Sensor Networks under the Multi-factor Constraints of the Greenhouse Environment" (ZR2020ME071).

References
[1] Farhad, S., Ali, A., Gerard, L. (2019) Electric Distribution Network Planning. China Electric Power Press, Beijing.
[2] Cui, H., Guo, Y., Xia, C. (2010) Study on Distributed Power Supply Optimal Configuration Considering Environmental Benefits. J. Northeast Electric Power., 38(12): 1968-1971.
[3] Merlin, A., Back, H. (1975) Search for a minimal loss operating spanning tree configuration in an urban power distribution system, in: Proceeding 5th power Syst. J. PSCC, Cambridge, UK., vol. 1–18.
[4] Thuan, T.N., Thang, T.N. (2019) An improved cuckoo search algorithm for the problem of electric distribution network reconfiguration. Applid Soft Computing, 84:1-28.
[5] Dorigo, M., Gambardella, L. M. (1996) A study of some properties of ant-Q. In: tFourth International Conference on Parallel Problem Solving From Nature, Berlin. 656–665.
[6] Krishnand, K.N., Ghose, D. (2005) Detection of multiple source location using aglow worm metaphor with applications to collective robotics. In: IEEE Swarm Intelligence Symposium. Piscataway. 84-91.
[7] Liu, X.Y., Gao, Z.Z., Tian, S., et al. (2019) Optimized reconfiguration of distribution network with distributed power. China Sciencepaper, 14: 815-860.
[8] Xu, Y. (2020) Application of Improved Particle Swarm Algorithm in Optimal Reconfiguration of Distribution Network Containing Distributed Power Sources. https://kns.cnki.net/kcms/detail/23.1202.TH.20200806.1431.008.html.
[9] Xu, Z., Pan, J.S., Fan, S.X., et al. (2018) A distribution network reconfiguration method with distributed generation based on improved firefly algorithm. Power System Protection and Control, 46: 26-32.
[10] Xu, X.Q., Wang, B., Zhao, H.S., et al. (2020) Two-voltage level distribution network reconstruction method based on cuckoo search and simulated annealing algorithm. Power System Protection and Control, 48: 84-91.
[11] Jiang, D., Liu, K.P. (2018) Research on double-layer real-time optimization game of active distribution network. Electrical Measurement & Instrumentation, 55: 50-56.
[12] Liu, Y.Y., Su, J.W. (2018) A Distributed Power Electronic Ring Network Topology and Clock Synchronization Algorithm. Electrical Measurement & Instrumentation, 55: 37-42.
[13] Ju, W.J., Wang, X.P., An, L.L. (2005) Disassembly sequence planning method based on discrete cuckoo search algorithm. Modular Machine Tool & Automatic Manufacturing Technique, 10: 14-17.