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Applying Artificial Bee Colony (Abc) Algorithm to The Distribution Network Reconfiguration Problem with An Objective Function of Minimum Operating and Power Outage Costs

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Abstract: The distribution network, the problem of grid restructuring according to the change of load to reduce power loss has partly reduced the operation cost of the grid but will affect. to the power supply reliability of the load. In this research, we introduce a strategy utilizing the Artificial Bee Colony (ABC) algorithm to solve network reconfiguration challenges, with the primary goal being too lower both the operational and downtime costs within the electricity distribution network. Created by Karaboga in 2009, the ABC algorithm is a form of optimization algorithm influenced by the collective foraging patterns of bees in nature. The proposed method's efficacy has been validated on IEEE benchmark grids featuring 16 and 33 bus systems. The findings from these tests have reliably demonstrated the ABC algorithm's capability to efficiently tackle the issue of network reconfiguration.

Keywords: Distribution network;power loss; ABC, reliability, reconfiguration distribution network

1. INTRODUCTION

The distribution network, which delivers electricity to end users, typically operates with an open configuration despite being inherently closed in design. This approach offers several benefits over a closed system, including simplified network protection, reduced fault currents, and more straightforward voltage regulation and power distribution. Nonetheless, due to the low-voltage, high-current nature of these networks, they are prone to significant power losses and voltage drops, as noted in [1]. With annual power losses in the range of approximately 5-6.5%, it becomes imperative to focus on strategies that can effectively minimize these losses in the distribution network.

The key to solving the distribution network reconfiguration problem is, in fact, a network configuration with the greatest economic benefits but still technically guaranteed for its stable operation in both normal operating and fault conditions. The economic benefits cover the costs of loss on the network, transmission (electric switching), damages to customers caused by

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power outages, and the cost incurred due to failure to sell electricity by power companies. The power outage (interruption) and failure to sell electricity by power companies depend significantly on the power supply reliability of each element that makes up the distribution network configuration. It is reflected by the power supply reliability indicator of the ENS distribution network (electrical energy shortage). Thus, finding a solution to the network reconfiguration problem to improve the power supply reliability is also identifying a distribution network configuration with the lowest operating and power outage costs.

The distribution network reconfiguration problem was first proposed in 1975 by Merlin and Back [2]. Civanlar et al [3] employed the branch exchange method to reduce power loss based on selected electric switch pairs. Shirmohammadi and Hong [4] suggested a reconfiguration method to reduce power loss based on the method proposed by Merlin and Back. Later studies focused on the application of genetic algorithm (GA) [5]–[7], Particle Swarm Optimization (POS) algorithm [8]–[10], Fireworks Algorithm (FWA) [11], Improved Tabu Search (ITS) algorithm or Modified Tabu Search (MTS) algorithm [12], [13], Harmony Search Algorithm (HSA) [12], and Improved Adaptive Imperialist Competitive Algorithm (IAICA) for the network reconfiguration problem. These random approaches lack special requirements such as continuity of the objective function and efficiency in solving constrained optimization problems [12]. Nonetheless, the problem for general heuristic algorithms is that they can fall into local rather than global extremes, and some algorithms require many parameters to be adjusted in the implementation process. In this regard, preventing premature convergence to local extremes of general heuristic algorithms has, therefore, attracted much attention from various authors [12]. This article employed the ABC algorithm for the objective function optimization problem to reduce operating and power outage costs. The efficiency of the ABC algorithm for the reconfiguration problem was tested on the IEEE sample network. The study results show that the application of the ABC algorithm offers reliable results and the optimal configuration for the given problem.

2. THEORETICAL BASIS

A distribution network is reconfigured by opening section switches and closing switches so that the network configuration remains radial, and all customers are supplied with power. Hence, the power flow through the nodes, the power loss and the reliability of the distribution network also change. The distribution network reconfiguration is often carried out to reduce overloads on lines and transformers, reduce power loss and improve power supply reliability, in other words,reduce the power outage cost.

2.1 Distribution network operating cost

It is assumed that the single-line diagram of a line has the following form:

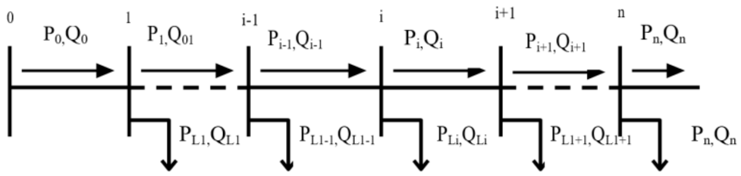

Figure 1. Single-line diagram of a line

The active power and reactive power on the branch (i+1) are in turn calculated according to the following approximate power:

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

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

The active power loss of part of the line between node i and node i +1 is:

$$\Delta P_{(i,i+1)} = R_{i,i+1}\left[\frac{P_i^2+Q_i^2}{|V_i^2|}\right] \quad (3)$$

Assuming that reactive power and load power are as shown in the load graph

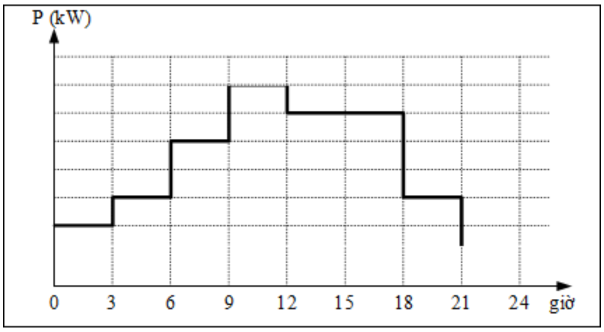

Figure 2. Daily load graph of the distribution network in a season.

The operating cost function for the distribution network in one season of the year.

$$Cost_1 = C_0 . m. \sum_{j=1}^{24} \Delta P_i t_j = C_0 . m. \sum_{j=1}^{n} \frac{P_i^2+Q_i^2}{V_i^2} t_j \quad (4)$$

Where:

ΔP_i active power loss at time ij.

P_i, Q_i : active and reactive power on branch i.

V_i : the connection node voltage of the branch-on-branch i.

The constraint condition to be satisfied by the distribution network is that the voltage and current must be maintained within the permissible limits.

$$V_{i,min} \le |V_i| \le V_{i,max} \quad (5)$$

$$|I_i| \le I_{i,max} \quad (6)$$

Flowchart for calculating the operating costs of the distribution network in a season (Figure 3). The steps are as follows:

Step 1: Read the active and reactive power values from the load graph.

Step 2: Solve the power distribution problem using the Newton Raphson method at time tj.

Step 3: Check if the power has been distributed at time tj = 24. If not, go back to step 2. If yes, calculate the operating cost of the distribution network.

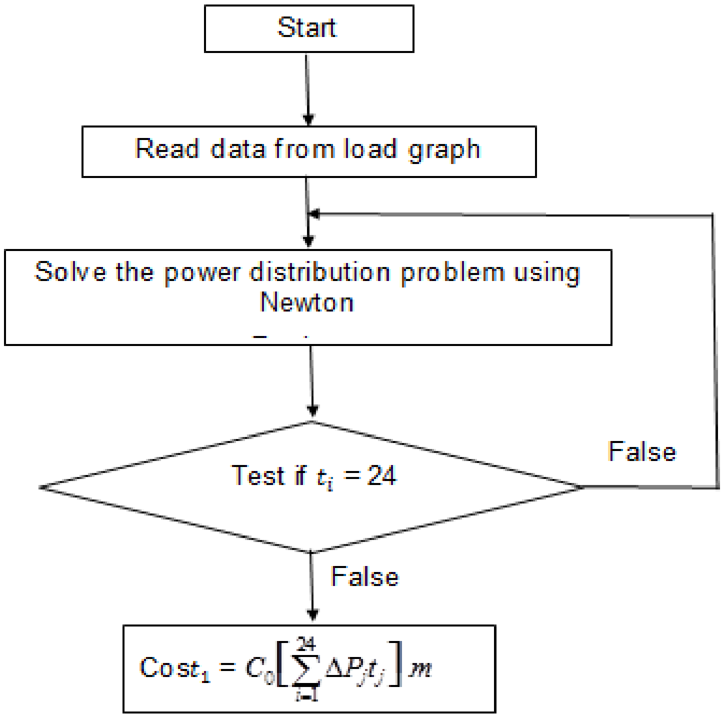

Figure 3: Algorithm for calculating operating costs in a season/year.

2.2. Power outage cost.

Consider a simple single-source distribution network.

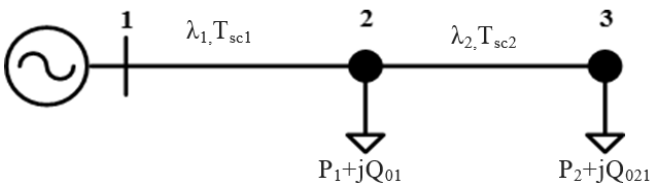

Figure 4. Diagram of a single-source two-load distribution network

If each network section has a section device, the power outage time of each loadis as follows:

$T_{mđ1} = \lambda_1 T_{sc1}$

$T_{mđ2} = \lambda_2 T_{sc2} + T_{mđ1}$

or $T_{mđi} = \lambda_i T_{sci} + T_{mđi-1}$ (7)

Where, λ_i, T_{sci}, and $T_{mđi-1}$ represent fault intensity, fault time at node i, and time of power outage from source, or circuit breaker to node i – 1, respectively.

The power that cannot be supplied to customers now is:

$$A = T_{mđ1}P_1 + T_{mđ2}P_2 \quad (8)$$

The power outage cost of the distribution network can be calculated through the damage caused by the fault to customers with interrupted power supply.

$$Cost_2 = C_1A = C_1 \sum_{i=1}^{n} P_i\lambda_{sci}T_{sci} \quad (9)$$

Where:

n is the number of loads in the power network.

$C_1$is the power unit price at the power outage, also known as the unit price applicable to a violation of the power supply contract of load i ($/kWh), which is often many times higher than the normal power selling price C_0.

A is the amount of power that cannot be supplied to customers.

P_i is the active power at node i (kW)

T_{sci} is the repair time of load i (h).

λ_{sci} is the fault intensity of the load node on the line (times/year).

The steps of the algorithm to calculate the power outage cost are as follows:

Step 1: Enter network parameters (e.g., node, branch, intensity and fault time).

Step 2: Enter the radial network configuration (to be changed by changing linking switches).

Step 3: Create a source file and a load file from the network configuration.

Step 4: Create a source connection file and a load file from the network configuration.

Step 5: Power outage time for each connection

Step 6: Transfer the selected load file (node i) to the source file.

Step 7: Check if the network is radial.

If not, remove the connection created from the updated source and go back to step 4 and repeat the process.

- If yes, move to step 8.

Step 8: Calculate the power outage cost of the existing network configuration.

```
Start
// Enter grid parameters
grid_params = input("Enter grid parameters (Node parameter, branch, magnitude, and
crash time): ")
// Import ray/grid structure
// (This structure is created by changing the electric locks)
ray_grid_structure = import_ray_grid_structure(grid_params)
// Create source set and load set from grid structure
source_set = create_source_set(ray_grid_structure)
load_set = create_load_set(ray_grid_structure)
// Generating source and load file from grid structure
// (The grid structure indicates the ability to connect the grid)
source_load_file = generate_source_load_file(source_set, load_set)
// Calculate outage time for connection set
total_outage_time = calculate_outage_time(source_set, load_set)
// Loop for toggling the download button and updating the source file
while not is_load_empty(load_set):
   // Toggle the newly selected download button (in button)
   // From download file to source file
   toggle_download_button()
   update_source_file(source_load_file)
   // Update the load set as some loads might have been served
   load_set = update_load_set(load_set)
// Check if the load is empty after toggling the download button
if is_load_empty(load_set):
   // Calculate outage costs for existing grid
   total_cost = calculate_outage_costs(grid_params, total_outage_time)
// Output the total cost
output(total_cost)
End
```

Figure 5. The pseudocode to calculate power outage cost for each configuration

2.3 Objective function of the math problem

An objective function for the network reconfiguration problem, considering the power supply reliability, can be derived from the objective of the problem of reducing the operating and power outage costs of customers as follows:

$$\text{COST} = \min\{\text{Cost}_1 + \text{Cost}_2\} = \min\{[\alpha_1 C_0 \sum_{j=1}^{24} \Delta P_j t_j].m + C_1 \sum^{n} P_i \lambda_{sci} T_{sci}\} \quad (10)$$

Where:

m the number of survey days in a year.

P_i the power consumed at node i (kW)

ΔP_j is the total power loss on the network at time j

t_j is the survey time in a day.

T_{sci} is the repair time of load i (h).

λ_{sci} is the fault intensity of load node on the line (times/year or times/season)

C_0 is normal power unit price of load i ($/kWh)

C_1 is power unit price at the power outage of load i ($/kWh)

α_1, α_2 are factors for selecting the objective function.

3. APPLICATION OF ABC ALGORITHM FOR RECONFIGURATION WITH THE OPERATING COST OPTIMIZATION FUNCTION AND TAKING INTO ACCOUNT THE POWER OUTAGE COST

It is proposed to apply the ABC algorithm to the reconfiguration problem with the objective function to reduce the operating and power outage cost.

3.1 . Introduction to ABC algorithm

The artificial bee colony (ABC) algorithm, proposed by Karaboga, is an optimization technique. that simulates the intelligent foraging behavior of honeybees, a relatively new direction in swarm knowledge. Through the behavior of groups of bees during finding food sources including employed bees, onlooker bees and scout bees, the honeybee colony uses some techniques such as waggle dances to identify the best food sources and find new sources. On this basis, new smart search algorithms have been developed.

3.1.1. Initialization of food source positions [15]

The limit of food sources x_{mi} is initialized (m=1, …SN, in which SN denotes the swarm size). From each food source, $\overrightarrow{x_m}$ is a vector for the optimization problem, each $\overrightarrow{x_m}$ vector has the values xmi (i = 1, 2…n) corresponding to the parameters of a solution of the optimization problem and n is the number of optimal parameters. The initial sources are determined by.

$$x_{mi} = l_i + rand(0,1) * (u_i - l_i) \tag{11}$$

Where: l_i and u_i are upper and lower boundaries of parameter xmi, respectively.

3.1.2. Employed bee phase [15]

Employed bees go to find new food sources $(\overrightarrow{v_m})$ and get more nectar in the neighbourhood of food sources $(\overrightarrow{x_m})$ in their memory. They find a neighbor around them and evaluate the food source's value. For example, they can identify a neighbouring food source using Equation (12) and evaluate probability using Equation (14).

$$v_{mi} = x_{mi} + \varphi_{mi}(x_{mi} - x_{ki}) \tag{12}$$

Where: $\overrightarrow{x_k}$ is a randomly selected food source; i is a random parameter index; ϕ_{mi} a random number within [-a, a]

After finding a new food source $(\overrightarrow{v_m})$, its value is calculated, and the selection is applied between $\overrightarrow{v_m}$ and $\overrightarrow{x_m}$

The value can be applied to solve the optimization problems of finding the max value or min value with the constrained conditions according to the following formula:

$$f_{itm}(\overrightarrow{x_m}) = \begin{cases} \dfrac{1}{1+f_m(\overrightarrow{x_m})} & \text{if} \quad f_m(\overrightarrow{x_m}) \geq 0 \\ 1+abs(f_m(\overrightarrow{x_m})) & \text{if} \quad f_m(\overrightarrow{x_m}) \leq 0 \end{cases} \quad (13)$$

Where: $f_m(\overrightarrow{x_m})$ is the cost value of the objective functions for the solutions $\overrightarrow{x_m}$.

3.1.3 Onlooker bees [15]

In the ABC algorithm, an onlooker bee selects a food source depending on probability values using the valuable information provided by employed bees. For this purpose, a selection technique-based method can be used.

Probability values are $\overrightarrow{x_m}$ and p_m, in which $\overrightarrow{x_m}$ selected by an onlooker bee can be calculated using the expression given in (14)

$$p_m = \frac{f_{itm}(\overrightarrow{x_m})}{\sum_{m=1}^{SN} f_{itm}(\overrightarrow{x_m})} \quad (14)$$

After a food source $\overrightarrow{x_m}$ is selected by an onlooker bee, a neighboring source $\overrightarrow{v_m}$ is determined using formula (12) and then its value is the nectar amount determined based on the behavior simulation. As in the employed bees' phase, a set of candidate solutions is selected between $\overrightarrow{x_m}$ and $\overrightarrow{v_m}$.

3.1.4 Scout bees [16]

A few employed bees that abandon their food source and search for new ones become scout bees. First, in the ABC algorithm, employee bees that do not find a better solution through cycles become scout bees. Next, they begin to look for new, random solutions. For example, ifsolutions x_m has been omitted, the new solutions discovered by scout bees x_m can be determinedby the formula (12). The cycle number is an important control parameter known as the "omission limit or criterion".

3.1.5 Application of ABC algorithm to optimization problems.

Constrained optimization problems aim to find a vector $\vec{x}$ according to the formula (15) to ensure that the objective function $f(\vec{x})$ reaches the min or max value with the constrained conditions (16), (17)) (18):

Minimize $f(\vec{x})$, $\vec{x}=(x_1, x_2, x_3, x_4,\ldots x_n) \in R^n$ (15)

$l_i \leq x_i \leq u_i$ $i = 1,2, \ldots n$ (16)

Constrained function: $g_j(\vec{x}) \leq 0$ with j=1,2,..q (17)

$h_j(\vec{x}) = 0$ with j=q+1, ...m (18)

The objective function f(x) is defined on a search space, S is defined as the n-dimensional space in R^n ($S \subseteq R^n$). The domain of variables is defined by their lower and upper boundaries (16)

The steps of the ABC algorithm describe the code [13]:

```
Begin Algorithm
Perform Initial Setup
Set iteration count to 1
Loop Until Specified Number of Iterations is Reached
  Begin Employed Bees Phase
  Compute Selection Probabilities for Onlooker Bees
  Start Onlooker Bees Phase
  Initiate Scout Bees Phase
  Record the Optimal Solution Found Up to This Point
  Increment the iteration count
End Loop When Iteration Count Equals Predefined Maximum
```

3.2 Proposal of ABC algorithm for power network reconfiguration problem

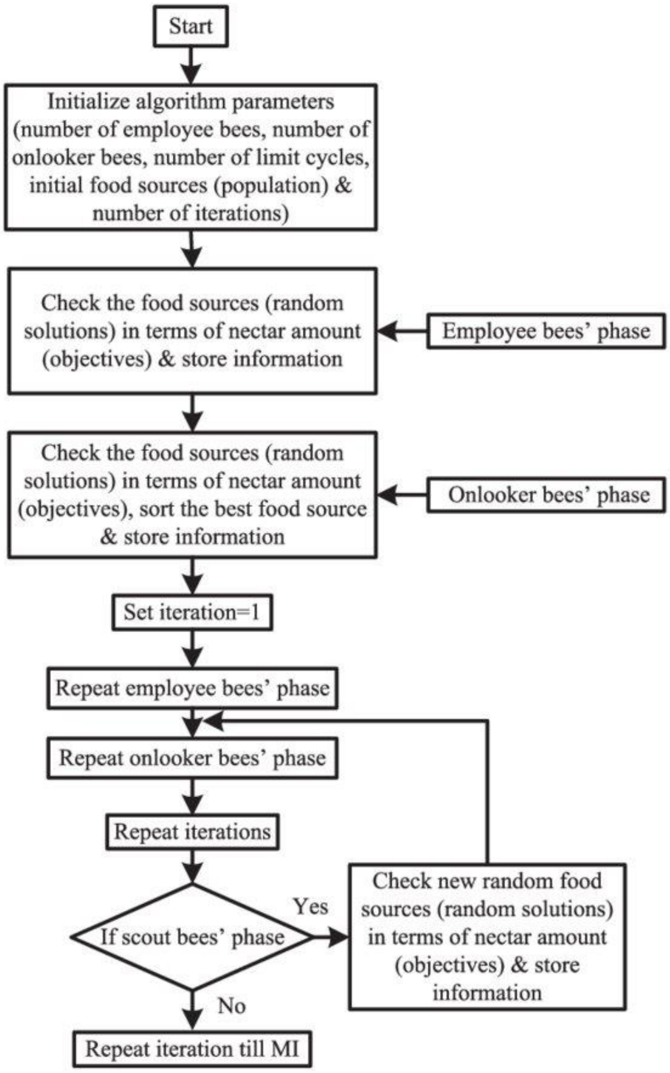

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Figure 6. ABC algorithm for power network reconfiguration problem

The ABC algorithm applied to the power network reconfiguration problem with the objective function of reducing the operating and outage costs is presented in Figure 6.

4. CALCULATION AND SIMULATION RESULTS

The power loss reduction reconfiguration problem based on the application of the ABC algorithm is tested on the 33-node distribution network. The calculation program is built as “File.m” and runs on the “Command Window” of MATLAB software on a computer with IntelCore i7 TM 7500 architecture CPU @ 2.70 GHz, 1 CPU, Motherboard Aspire 4740, 8 GB DDR3 RAM, Hard Drive ST9250320AS (1TB), Windows 10 (64-bit).

Cases of the operating and power outage costs of the power network on one day in the dry season and one day in the rainy season are considered. If the power network operates in the dry season, the fault intensity and the repair time on the lines are the same, and in contrast, when the power network operates in the rainy season, the fault intensity and the repair time on the lines are not the same. The minimum operating and power outage costs are calculated according to the objective function (10). The power network has a power unit price in the normal operation of C_0 = \$ 0.1 and a compensation unit price at the power outage is C_1 = \$0.5. To check the accuracy of the optimization algorithm in the ABC field, there are three network operation cases.

Case 1: The network operates so that the network operating cost is the lowest using the ABC algorithm, regardless of the power outage cost or the priority factor of the objective function currently, or the operating cost is the lowest. The objective function of the problem.

$$COST = min\left\{\left[C_0\sum_{j=1}^{24}\Delta P_j t_j\right]\cdot 180 + 0\cdot C_1\sum_{i=1}^{n}P_i\lambda_{sci}T_{sci}\right\} \quad (19)$$

The network operating cost is :

$$COST = min\left\{\left[C_0\sum_{j=1}^{24}\Delta P_j t_j\right]\cdot 180\right\} \quad (20)$$

Case 2: The power network operates in the dry season with the same fault intensity on the lines and the same repair time or an objective function whose priority factor is $\alpha_1 = \alpha_2 = 1$

Case 3: The power network operates in the dry season with the different fault intensity on the lines and the same repair time or an objective function whose priority factor is $\alpha_1 = \alpha_2 = 1$

IEEE 3-source power network includes 13 nodes as shown in Figure 8

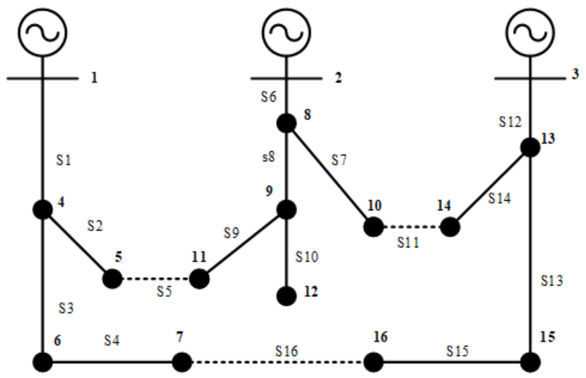

Figure 8 : IEEE 3-source power network with 16 nodes

The standard 3-source network [9], for testing two algorithms, has 3 upstream busbars, 13 load nodes, a voltage of 22.8kV, total load capacity of 28.7 MW. The initial opening switches are S5, S11 and S16 as shown in Figure 8 and the load graph of the network is shown in Table 1 with 8-time steps on a day and time t_j = 3.

Table 1: Load factor at the nodes in a day.

Node	Load graph in a day							
	0– 3	3 – 6	6– 9	9– 12	12– 15	15– 18	18– 21	21– 24
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0,5
4	0.6	0.8	1	1.1	1	1	0.6	0.5
5	0.6	0.8	1	1.1	1	1	0.6	0.5
6	0.6	0.8	1	1.1	1	1	0.6	0.5
7	0.6	0.8	1	1.1	1	1	0.6	0.5
8	0.6	0.8	1	1.1	1	1	0.6	0.5
9	0.6	0.8	1	1.1	1	1	0.6	0.5
10	0.6	0.8	1	1.1	1	1	0.6	0.5
11	0.6	0.8	1	1.1	1	1	0.6	0.5
12	0.6	0.8	1	1.1	1	1	0.6	0.5
13	0.6	0.8	1	1.1	1	1	0.6	0.5
14	0.6	0.8	1	1.1	1	1	0.6	0.5
15	0.6	0.8	1	1.1	1	1	0.6	0.5
16	0.6	0.8	1	1.1	1	1	0.6	0.5

The power network is considered in the following three cases:

Case 1: The network operates so that the network operating cost using the ABC algorithm without considering the power outage cost follows the objective function 16.

The calculation results after 20 cycles and the initial number of objects n = 10 show that the minimum operating and power outage cost is Cost = $ 148,350 and the opening switches at this time are S9, S7, and S16 and ΔA = 1,483,500 kWh and the network configuration after reconfiguration is shown in Figure 9.

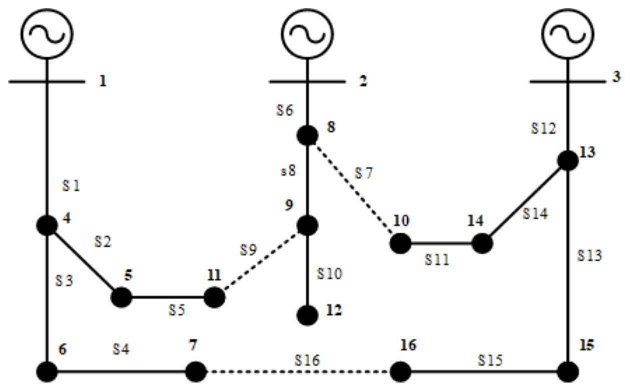

Figure 9 Network configuration after reconfiguration - case 1

Case 2: As the power network works in the dry season, it is assumed that the fault intensity on the lines is the same λsc = 0.1 (times/season) with the same repair time (tsc = 5 hours), and the significance of the loads is the same.

With the initial number of objects equal to 10, the results of testing the ABC algorithm in the power network reconfiguration problem after 20 cycles show that the minimum operating and power outage costs for customers Cost = $346,680 and opening switches are S9, S7, and S16 and ΔA = 1,483,500 kWh. The network configuration after reconfiguration is shown in Figure 10 and the convergence of the problem objective function is shown in Figure 11.

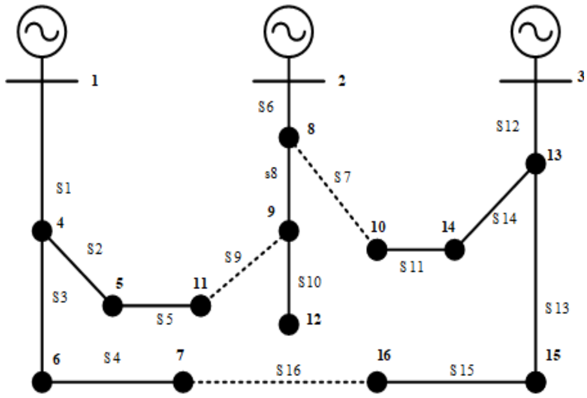

Figure 10: Power network configuration after reconfiguration - case 2

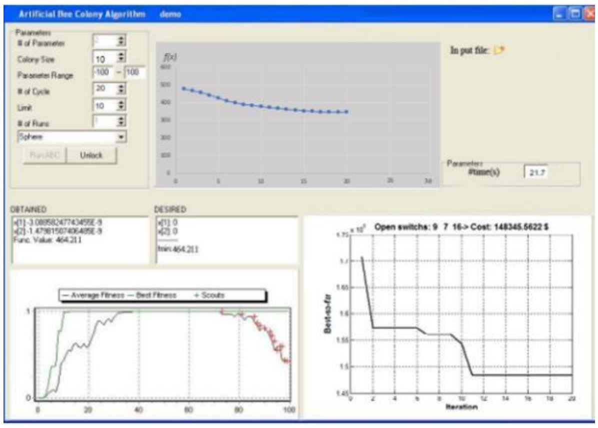

Figure 11. Convergence and value of the objective function - case 2

Case 3: The power network works in the rainy season, resulting in a different power outage time on different lines, as shown in Table 2. The remaining lines have zero power outage time.

Table 2: Power outage time on lines - case 3

Branch	Power outage time (hours)	Branch	Power outage time (hours)
1-4	0.5	8-9	0.5
2-8	0.5	9-11	0.5
3-13	20	9-12	0.5
4-5	0.5	8-10	0.5
4-6	0.5	10-14	20
5-11	0.5	13-14	20
6-7	0.5	13-15	0.5
7-16	0.5	15-16	0.5

The calculation results after 20 cycles and the initial number of objects n = 10 show that the minimum operating and power outage cost is Cost = $ 658,160 and opening switches are S9, S14, and S13 and ΔA = 1,856,000 kWh. The network configuration after reconfiguration is shown in Figure 12 and the convergence of the problem objective function is shown in Figure 13.

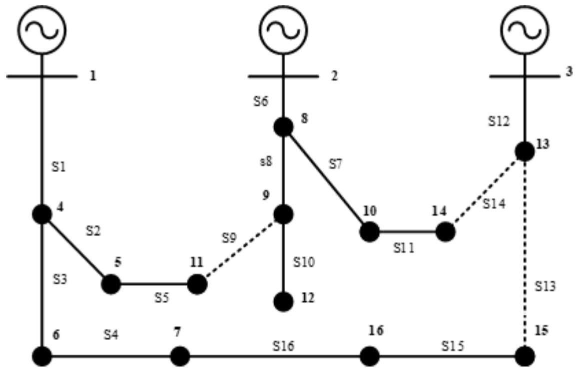

Figure 12: Power network configuration after reconfiguration - case 3

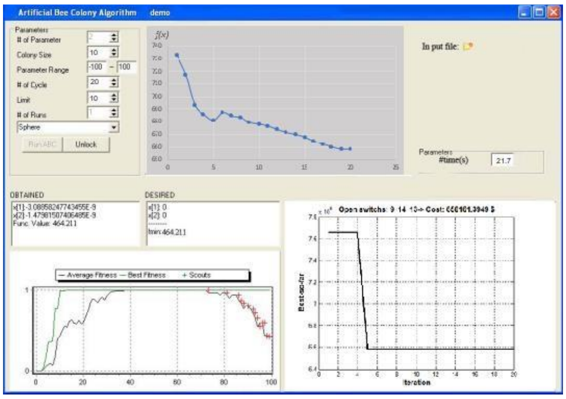

Figure 13. Convergence and value of the objective function - case 3

Table 3: Comparison of pre- and post-reconfiguration results.

	Cost according to objective function$/season)	Opening switches	Power loss in season (Kwh)
Initial	Case 1: 162,930 Case 2: 357,960 Case 3: 1,143,000	S5 S11 S16	1,629,300
Case 1	148,350	S9 S7 S16	1,483,500
Case 2	346,680	S9 S7 S16	1,483,500
Case 3	658,160	S9 S14 S13	1,856,000

The total initial power loss is 1,629,300 kWh and the initial opening switches are S5, S11 and S16. After the power network reconfiguration, the minimum operating and power outage costs can be calculated in different operation cases. It is identified that the power loss on the network is reduced by 8.9%. Particularly in case 3, the power loss does not decrease but significantly increases (-13.9%) since due to a large compensation for power outages, a larger power loss is accepted to reduce the cost in the objective function of the problem. Similarly, the test is done on the IEEE 33-node single-source sample network (figure 14) with parameters as shown in [9]. It is assumed that the fault time on all lines is the same and equal to 1 hour per year. The initial configuration has a total load capacity of 3.72 MW, with opening switches of S33, S34, S35, S36, and S37 and an initial power loss of ΔA= 900,320 kWh.

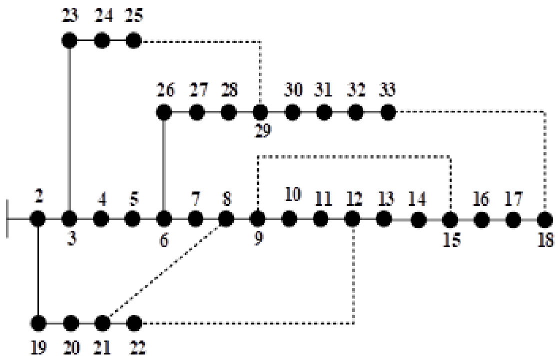

Figure 14: IEEE 33-node sample distribution network

Similarly, the power network is considered in 3 operation cases with the results as inTable 4.

Table 4: Comparison of pre- and post-configuration results

	Cost according to objective function ($/season)	Opening switches	Power loss in a season (Kwh)
Initial	Case 1: 90,032 Case 2: 306,190 Case 3: 354,750	S33,S34,S35,S36,S37	900,320
Case 1	60,007	S7,S37,S9,S14,S32	600,070
Case 2	228,740	S7, S28,S10,S14,S32	607,770
Case 3	310,390	S33,S28,S10,S14,S36	654,290

The total initial grid power loss is 900,320 kWh corresponding to the opening switches S33, S34, S35, S36 and S37. After the network reconfiguration, the minimum operating and power outage costs can be calculated. It is found that the power loss on the network is reduced by 33.34% and 32.49%, respectively, for cases 1 and 3. Particularly in case 3, the power loss is larger than that in cases 1 and 3 because at this time, with a large compensation cost for power outages, a larger power loss must be accepted to reduce the cost for the objective function of the problem.

The simulation results have revealed that the ABC algorithm has been successfully applied to solve the distribution network reconfiguration problem. The proposed method has been tested on 13 and 33 node systems in 3 operation cases with different outage frequencies to evaluate the effect on the cost function. It is shown through calculation results that the quality of the solution obtained brings about the optimal reconfiguration plan to ensure the lowest operating cost. This is a network reconfiguration problem with the aim to consider the influence of power supply during the network operation. This is, thus, a potential and effective tool to solve the distribution network reconfiguration problem that can be applied in operation.

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