Research on Grid Planning of Dual Power Distribution Network Based on Parallel Ant Colony Optimization Algorithm

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Abstract: A distribution network plays an extremely important role in the safe and efficient operation of a power grid. As the core part of a power grid’s operation, a distribution network will have a significant impact on the safety and reliability of residential electricity consumption. It is necessary to actively plan and modify the distribution network’s structure in the power grid, improve the quality of the distribution network, and optimize the planning of the distribution network, so that the network can be fully utilized to meet the needs of electricity consumption. In this paper, a distribution network grid planning algorithm based on the reliability of electricity consumption was completed using an ant colony algorithm. For the distribution network structure planning of dual power sources, the parallel ant colony algorithm was used to prove that the premise of parallelism is the interactive process of ant colonies, and the dual power distribution network structure model is established based on the principle of the lowest cost. The artificial ants in the algorithm were compared with real ants in nature, and the basic steps and working principle of the ant colony optimization algorithm was studied with the help of the travelling salesman problem (TSP). Then, the limitations of the ant colony algorithm were analyzed, and an improvement strategy was proposed by using python for digital simulation. The results demonstrated the reliability of model-building and algorithm improvement.

Keywords: Parallel ant colony optimization algorithm; Dual power sources; Distribution network; Grid planning

Online publication: May 17, 2023

1. Introduction

The purpose of designing the distribution network is to receive electric energy from the transmission station and distribute power to users through power distribution facilities according to the principle of locality or voltage distribution. The distribution of electricity involves distribution lines, transformers, cables, and various auxiliary equipment, etc. The design of the power network planning can be optimized to save cost and reduce unnecessary waste of resources while ensuring quality [1-3]. Since the “14th Five-Year Power Grid Development Plan,” the development of power grids has undergone drastic changes. According to the principles of distribution network planning and design, the network frame is planned and designed according to the electricity demand. Grid planning is implemented for distribution networks with different voltage requirements [5]. The optimal planning and design of weak grid structures can be used as a short-term solution for grid problems, but it should be reasonable without wasting power resources. For the planning of the long-term distribution network structure, it is necessary to have a long-term vision, determine the main design concept, and coordinate the operation of various regions to ensure that the entire planning system is reasonable and efficient, and there are transitional stages in the planning process. The
challenge of using dual power supply is to classify each node \[6\]. It is necessary to determine which power supply the user belongs to by accessing different power supplies. Therefore, it is necessary to plan the network structure for the two power sources at the same time. Since the connected user groups are the same, and there is a maximum limit in the power supply, parallel ant colony optimization algorithm can be used to solve the problems faced in dual power distribution network structure planning.

2. Parallel ant colony optimization algorithm

Parallel ant colony optimization algorithm is a relatively common algorithm \[7\]. The principle of the algorithm is that each ant maintains an independent state during while running, and they communicate through pheromones \[8\]. Running independently while performing different points in the required space can increase the reliability of the algorithm and have a better global search effect \[9\].

There are a few guidelines for parallel ant colony optimization algorithm. (1) A variety of pheromones are used, where each pheromone represents a different category. After the categories are created, each independent individual will release the pheromone to be delivered. (2) By introducing the method of pseudo-random probability transition, the state transition rules are improved, and the random probability transition rules in the algorithm are replaced. (3) Through the introduction of analysis tools such as correlation, the required path can be optimized to achieve the goals set.

3. Model establishment

Distribution network planning itself is dynamic and non-linear, and environmental changes needs to be considered, making it completely different from other linear plannings. Active distribution network planning is a combinatorial optimization planning problem, which involves the needs of users. For dual power supplies, the number of power supply access overload nodes should not exceed 50; the power of the second power supply is limited, and there is an expansion fee for expansion. Therefore, in the objective function, the related penalty coefficient problem of power expansion cost should be increased \[10-13\].

3.1. Objective function of dual power distribution network

The objective function of the dual power distribution network is as follows:

\[
F(X) = \min \left( f_1 + f_2 + f_3 \right)
\]

where \(f_1\) is the line cost function, \(f_2\) is the switch cost function, and \(f_3\) is the multi-power supply constraint power expansion function.

1) Line cost function

The line cost function is represented by the equation below:

\[
f_1 = \sum_{i=1}^{m} \sum_{j=1}^{m} X_{ij} C_{ij} L_{ij}
\]

where \(X_{ij}\) indicates whether there is a path between two nodes \((i, j)\) and the number of wire connections, \(C_{ij}\) indicates \((i, j)\) the unit cost of line selection, \(m\) is the number of nodes, and \(L_{ij}\) is the distance of the connecting line.

\(X_{ij}\) is the incidence matrix:
\begin{equation}
X_{ij} = \begin{bmatrix}
X_{ii} & \cdots & X_{in} \\
\vdots & \ddots & \vdots \\
X_{in} & \cdots & X_{nn}
\end{bmatrix}
\end{equation}

The distance of the connecting line, \( L_{ij} \), is calculated using the equation below.

\[ L_{ij} = \sqrt{(y_i - y_j)^2 + (x_i - x_j)^2} \]

(2) Switch constraints
The switch constraints are represented by the equation below.

\[ f_2 = \sum_{i=1}^{n} \text{type}_i C_{kai} \]

\text{type}_i \) indicates the user \( i \)'s access line type. \( C_{kai} \) indicates the charge for the type of switch used on this line.

(3) Multiple power constraints
Compared to single power supply, the grid planning of multi-power distribution network is more complicated, in which it requires the addition of substation or power capacity-load ratio on the basis of single power supply constraints.

\[
k(P_G) = \begin{cases} 
K_r (P_{G_{\min}} - P_L) & P_G < P_{L_{\min}} \\
K_r (P_{G_{\max}} - P_L) & P_G > P_{L_{\max}} \\
0 & P_{L_{\min}} \leq P_G \leq P_{L_{\max}} 
\end{cases}
\]

In the equation above, \( k \) represents the penalty factor. \( P_L, P_{G_{\min}}, P_{G_{\max}} \) are the capacity of the power supply and the upper and lower limits of the capacity.
Under the constraints, the objective function becomes as follows:

\[ f_3 = K_r (P_{G_{\max}} - P_L) \]

\[ P_L = \sum_{i=0}^{n} B_{i-L} \]

3.2. Calculation method of user reliability
The user reliability is calculated in the same way as the reliability of a single power supply, except that each user node is connected to a different power supply. Therefore, it is necessary to record the type of access power in the user. The network transformation graph established by the above model is described as \( G = (V,A) \), and the adjacency is \( C \) defined as follows:

\[ C = \{c_{ij}\}_{n \times n} \in \{0, \infty\} \]
Based on the equation above, \( \text{\(length\)} \) is the length of the connection of the two paths. The user reliability is calculated using the equation below:

\[
p_i = \sum_{j=2}^{n} \sum_{j=1}^{n} w_{ij} \cdot c_{ij} + \sum_{j=1}^{n} v_{ij}\text{type}_i,
\]

where \( w_i \) is the reliability of different lines, and \( v_i \) is the reliability of different switches.

3.3. The process of building a network structure using the parallel ant colony algorithm

The spanning tree strategy was used to guide the search behavior of the artificial ant colony, and the grid planning scheme corresponding to the road that the ants pass was limited to the tree shape corresponding to the radial structure \[14\]. This method of ant colony grid planning meets the requirements of grid planning in the distribution network and the objective function economy.

The first step was to build a parallel ant colony, that is, to mark each ant. As shown in Figure 1, there were two information sources for power source 1 and power source 2, so two ant colonies were set up.

![Figure 1. The establishment process of dual power distribution network](image)

4. Solution of the model

The grid model of the dual power distribution network was generally similar to that of the single power source, but due to the use of the parallel ant colony algorithm, the interactive process of two kinds of ant colonies was added in the process \[15\]. The process of solving the model is as follows:

(1) Step 1
The initial value was set for all environmental variables, node information, load information, weights of various types of wires. All user nodes were added set A and the initial value of pheromone for each path was set (time, \( t = 0 \) s).

(2) Step 2
The number of ants, \( N_{ant} \), were initialized; the maximum number of cycles, \( N_{c,max} \), was set; the ants were labeled as \( k = 1 \), and the ants were classified into two populations of power source 1 and power source 2.
(3) Step 3
The ants selected a path \((k)\) from the generated optional path set \(B_k^t\), and the path was recorded in the information table. The pheromone and other information of the path were also recorded, and the information was shared between two ant colonies.

(4) Step 4
It was determined whether the constructed nodes are equal to all nodes. If they are equal, it means that the ants have visited all load nodes in the network. If not, go to Step 5.

(5) Step 5
The set of optional paths \(A\) were updated, \(t = t + 1\); go to Step 3.

(6) Step 6
The planned structure of the network was recorded.

(7) Step 7
The access point was optimized with a geometric algorithm.

(8) Step 8
The user’s power consumption reliability were calculated.

(9) Step 9
End of operation.

5. Results of model

5.1 Power supply types
The power supply type is shown in Table 1 below:

<table>
<thead>
<tr>
<th>Power supply name</th>
<th>Coordinate x (km)</th>
<th>Coordinate y (km)</th>
<th>Outgoing voltage (kV)</th>
<th>Rated power supply (MW)</th>
<th>Scalable power supply</th>
<th>Extended supply price</th>
</tr>
</thead>
<tbody>
<tr>
<td>soc0</td>
<td>95</td>
<td>38</td>
<td>10kV</td>
<td>Sum of load demand*1.1</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>soc1</td>
<td>-5</td>
<td>40</td>
<td>10kV</td>
<td>50</td>
<td>50%</td>
<td>100/watt</td>
</tr>
</tbody>
</table>

5.2. User and reliability
Users and reliability are shown in Table 2 below:

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Username</th>
<th>Coordinate x (km)</th>
<th>Coordinate y (km)</th>
<th>Demand (MW)</th>
<th>Reliability</th>
<th>Corresponding power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>usr0</td>
<td>34</td>
<td>33</td>
<td>66</td>
<td>0.832149771</td>
<td>soc0</td>
</tr>
<tr>
<td>2</td>
<td>usr5</td>
<td>39</td>
<td>-30</td>
<td>28</td>
<td>0.762052365</td>
<td>soc0</td>
</tr>
<tr>
<td>3</td>
<td>usr8</td>
<td>17</td>
<td>-5</td>
<td>47</td>
<td>0.760062309</td>
<td>soc0</td>
</tr>
<tr>
<td>4</td>
<td>usr9</td>
<td>15</td>
<td>75</td>
<td>95</td>
<td>0.738663343</td>
<td>soc0</td>
</tr>
<tr>
<td>5</td>
<td>usr12</td>
<td>89</td>
<td>-39</td>
<td>19</td>
<td>0.783048185</td>
<td>soc0</td>
</tr>
<tr>
<td>6</td>
<td>usr13</td>
<td>34</td>
<td>-1</td>
<td>77</td>
<td>0.803693833</td>
<td>soc0</td>
</tr>
<tr>
<td>7</td>
<td>usr15</td>
<td>67</td>
<td>7</td>
<td>91</td>
<td>0.88557098</td>
<td>soc0</td>
</tr>
</tbody>
</table>

(Continued on next page)
5.3. Bifurcation point results
The bifurcation point results are shown in Table 3.

Table 3. Bifurcation point results

<table>
<thead>
<tr>
<th>Bifurcation point</th>
<th>Node</th>
<th>Coordinate x (km)</th>
<th>Coordinate y (km)</th>
<th>Corresponding power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dot2</td>
<td>87.83067093</td>
<td>30.23322684</td>
<td>soc0</td>
</tr>
<tr>
<td>2</td>
<td>dot4</td>
<td>74</td>
<td>43</td>
<td>soc0</td>
</tr>
<tr>
<td>3</td>
<td>dot6</td>
<td>83</td>
<td>25</td>
<td>soc0</td>
</tr>
<tr>
<td>4</td>
<td>dot8</td>
<td>74</td>
<td>50</td>
<td>soc0</td>
</tr>
<tr>
<td>5</td>
<td>dot9</td>
<td>84.02689487</td>
<td>18.15403423</td>
<td>soc0</td>
</tr>
<tr>
<td>6</td>
<td>dot12</td>
<td>65.73838631</td>
<td>15.41075795</td>
<td>soc0</td>
</tr>
<tr>
<td>7</td>
<td>dot13</td>
<td>86</td>
<td>5</td>
<td>soc0</td>
</tr>
<tr>
<td>8</td>
<td>dot14</td>
<td>59</td>
<td>50</td>
<td>soc0</td>
</tr>
<tr>
<td>9</td>
<td>dot22</td>
<td>67</td>
<td>7</td>
<td>soc0</td>
</tr>
<tr>
<td>10</td>
<td>dot24</td>
<td>68.05670103</td>
<td>4.25257732</td>
<td>soc0</td>
</tr>
<tr>
<td>11</td>
<td>dot25</td>
<td>63</td>
<td>15</td>
<td>soc0</td>
</tr>
<tr>
<td>12</td>
<td>dot27</td>
<td>41</td>
<td>29</td>
<td>soc0</td>
</tr>
<tr>
<td>13</td>
<td>dot32</td>
<td>72</td>
<td>-6</td>
<td>soc0</td>
</tr>
<tr>
<td>14</td>
<td>dot35</td>
<td>80</td>
<td>-26</td>
<td>soc0</td>
</tr>
<tr>
<td>15</td>
<td>dot36</td>
<td>57</td>
<td>0</td>
<td>soc0</td>
</tr>
</tbody>
</table>
(Continued from previous page)

<table>
<thead>
<tr>
<th>Bifurcation point</th>
<th>Node</th>
<th>Coordinate x (km)</th>
<th>Coordinate y (km)</th>
<th>Corresponding power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>dot38</td>
<td>34</td>
<td>33</td>
<td>soc0</td>
</tr>
<tr>
<td>17</td>
<td>dot39</td>
<td>53</td>
<td>-18</td>
<td>soc0</td>
</tr>
<tr>
<td>18</td>
<td>dot40</td>
<td>55.70588235</td>
<td>-5.823529412</td>
<td>soc0</td>
</tr>
<tr>
<td>19</td>
<td>dot45</td>
<td>90</td>
<td>-31</td>
<td>soc0</td>
</tr>
<tr>
<td>20</td>
<td>dot46</td>
<td>26.02919708</td>
<td>54.91970803</td>
<td>soc0</td>
</tr>
<tr>
<td>21</td>
<td>47</td>
<td>26</td>
<td>55</td>
<td>soc0</td>
</tr>
<tr>
<td>22</td>
<td>48</td>
<td>34</td>
<td>-1</td>
<td>soc0</td>
</tr>
<tr>
<td>23</td>
<td>49</td>
<td>39.08235294</td>
<td>-2.129411765</td>
<td>soc0</td>
</tr>
<tr>
<td>24</td>
<td>51</td>
<td>36</td>
<td>-16</td>
<td>soc0</td>
</tr>
<tr>
<td>25</td>
<td>52</td>
<td>80</td>
<td>-26</td>
<td>soc0</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.4. Corresponding generated graph
The corresponding generated graph is shown in Figure 2.

![Figure 2. Corresponding generation graph](image)

5.5. Display of user reliability
The minimum cost to construct two single-supply networks from a dual power supply is 314307.721080619 thousand yuan. The user with the lowest reliability is usr70, with a reliability of 0.651492406202301. When evaluating user reliability, the evaluation index system of distribution grid planning should also be considered [16]. The evaluation index system constructed needs to complement each other with user reliability, and it should be evaluated from the macro level and the micro level. At the macro level, it is necessary to understand the advantages and disadvantages of the distribution network structure, especially whether the distribution network plan is consistent with the regional planning, or there will be certain conflicts. At the micro level, it is necessary to quantify these evaluation indicators: economic costs, social benefits, and safety indicators. Solutions should be provided to increase the reliability of weak distribution networks, so that the sustainable development of distribution networks can be promoted and a safe,
economical and environmentally friendly operation can be achieved [17-20].

6. Conclusion
In this paper, a dual-power distribution network model was established according to the user’s power supply demand. The feasibility of each user’s access to the power grid was proven through digital simulation experiments.

(1) Considering the current situation of our country’s contemporary distribution network, a method to simplify the planning of distribution network grid was given. (2) A distribution network plan was constructed by using the parallel ant colony optimization algorithm, with saving the overall costs as the main goal. In the process of planning, the working principle of parallel ant colony optimization algorithm and the characteristics of distribution network planning was fully considered, and the two were organically integrated to achieve the expected goal. (3) The artificial ants in the algorithm were compared with real ants, and the procedure and working principle of the ant colony algorithm were studied with the help of the TSP. The limitations of the ant colony algorithm were then analyzed, and improvement strategies were proposed. (4) Digital simulation was carried out with python, and the reliability of model establishment and algorithm improvement were proven.

Prospects: (1) The ant colony optimization algorithm has a good development prospect. The data selection is usually based on the results accumulated through experiments. The parameters of the algorithm still need to be modified before it can be used for other problems. (2) The grid planning of the distribution network is usually based on the existing grid planning, and the optimization scheme obtained is relatively ideal. In the planning process, where not only the distribution network itself is considered, but also many other social factors. In many cases, the planning work is wasted because of one factor in the planning process that is not well considered. Therefore, the actual situation of the distribution network should be fully studied before the planning to reduce the idealistic components of the plan and increase the realistic factors as much as possible. (3) The actual geographical location of the line and substation should also be considered while drafting the plan. In the process of collecting geographical information, the amount of data is large. Therefore, the data can be processed using Google Earth software, which can effectively reduce the workload.

7. Part of the code
#
# coding: utf-8

Created on Sat Sep 3 08:08:01 2022

import networkx as nx
import pylab as plt
import numpy as np
import random

class ComLink:
    def __init__(self, Name, dotInNet1, dotInNet2, linkLoad=0, linkCost=0, userCount=0):
        self.Name=Name
        self.dotInNet1 = dotInNet1
        self.dotInNet2 = dotInNet2
        self.linkLoad=0
self.linkCost=0
self. userCount = 0
self.type=1

###############################################################
node class (bifurcation point class)

###############################################################

class Dot:
def __init__ ( self, Name, X, Y, Need=0, userCount=0 ) :
    self.Name=Name
    self.X = X
    self.Y = Y
    self.Need = Need
    self.userCount = userCount
    self.toSourceCalced=False
    self.toUserCalced=False
    self.reliability=0
    self.source=None
    self.toSocList=[]
    self.comlink=None

The forward and reverse calculation method of node class, calculate the number of users and reliability

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Disclosure statement
The author declares no conflict of interest.

References


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