Journal of Electronic Research and Application, 2023, Volume 7, Issue 1
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

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 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:

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

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:

$$X_{ij} = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \vdots & \vdots \\ X_{1n} & \cdots & X_{1n} \end{bmatrix} \quad (1)$$

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

$$L_{ij} = \sqrt{\left(y_i - y_j\right)^2 + \left(x_i - y_j\right)^2}$$

(2) Switch constraints

The switch constraints are represented by the equation below.

$$f_2 = \sum_{i=1}^{n} type_i C_{kai}$$

$type_i$ 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.

$$k\left(P_G\right) = \begin{cases} K_r\left(P_{G\min} - P_L\right) & P_G < P_{L\min} \\ K_r\left(P_{G\max} - P_L\right) & P_G > P_{L\max} \\ 0 & P_{L\min} \le P_G \le P_{L\max} \end{cases}$$

In the equation above, k represents the penalty factor. P_L, P_{Gmin}, P_{Gmax} 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:

$$f_3 = K_r\left(P_{G\max} - P_L\right)$$

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

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:

$$C = \left(c_{ij}\right)_{n*n} \in \{0, \infty\},$$

$$c_{ij} = \begin{cases} length, (i,j) \in A \\ 0, \qquad (i,j) \notin A \end{cases}$$

Based on the equation above, *length* is the length of the connection of the two paths.

The user reliability is calculated using the equation below:

$$p_i = \sum_{i=2}^{n}\sum_{j=1}^{n} w_i c_{ij} + \sum_{i=1}^{n} v_i type_i$$

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.

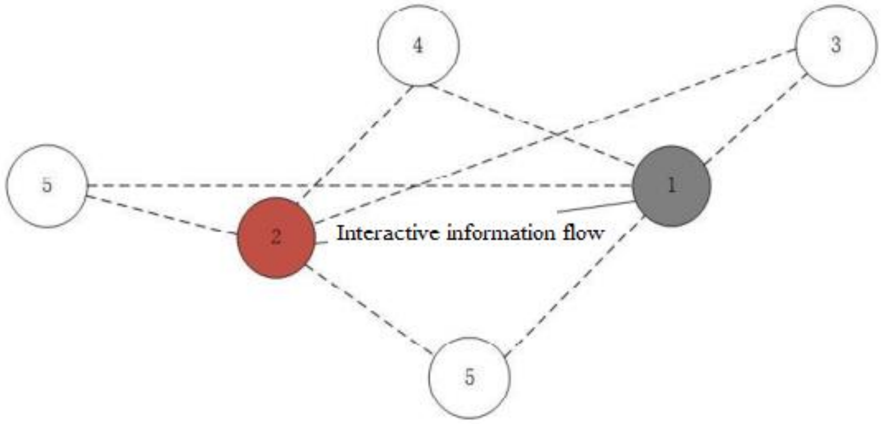

Figure 1. The establishment process of dual power distribution network

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, $t = t + 1$; z 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 1. Display of power supply types

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

5.2. User and reliability

Users and reliability are shown in **Table 2** below:

Table 2. User and reliability

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

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Serial number	Username	Coordinate x (km)	Coordinate y (km)	Demand (MW)	Reliability	Corresponding power supply
8	usr20	11	36	32	0.748143342	soc0
9	usr21	16	-24	15	0.732222874	soc0
10	usr27	72	-6	92	0.857575745	soc0
11	usr29	40	-35	34	0.752772364	soc0
12	usr31	86	5	66	0.912433831	soc0
13	usr32	24	-28	80	0.747053962	soc0
14	usr33	58	61	10	0.867919042	soc0
15	usr37	85	-94	21	0.669729178	soc0
16	usr40	80	-26	82	0.817351013	soc0
17	usr43	74	43	84	0.931688894	soc0
18	usr45	18	52	91	0.776659943	soc0
19	usr46	-1	-33	13	0.704053697	soc0
20	usr48	90	-31	10	0.79747634	soc0
21	usr50	97	-84	76	0.692558585	soc0
22	usr51	26	55	16	0.790026538	soc0
23	usr52	98	-74	14	0.708180735	soc0
24	usr53	10	39	67	0.748487667	soc0
25	usr56	21	-9	40	0.768599589	soc0
…	…	…				
…	…	…				

5.3. Bifurcation point results

The bifurcation point results are shown in **Table 3**.

Table 3. Bifurcation point results

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

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

5.4. Corresponding generated graph

The corresponding generated graph is shown in **Figure 2**.

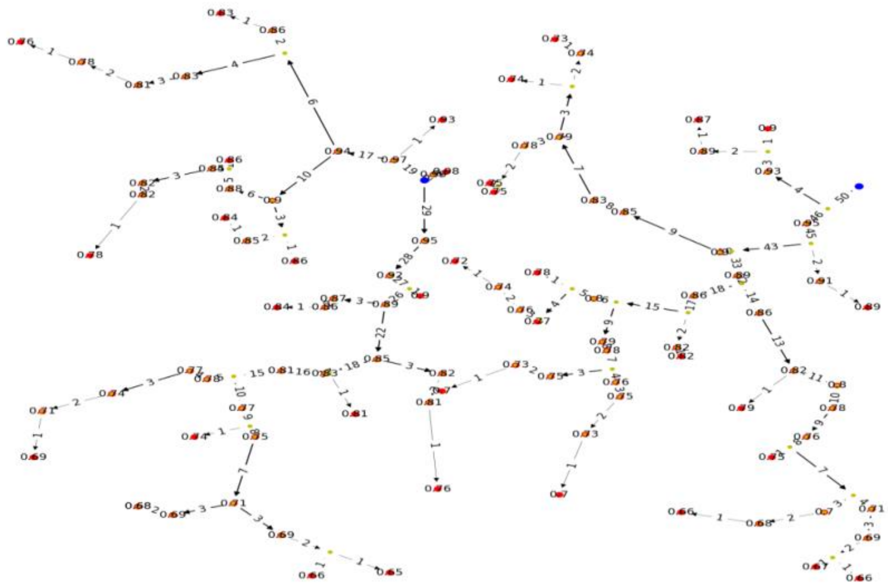

Figure 2. Corresponding generation graph

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
############connection line class, the attributes include the nodes of grid 1 and grid 2 connected to it
###########
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
####################
```

Disclosure statement

The author declares no conflict of interest.

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