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A Granular Ant Colony Algorithm for Power Distribution Network Planning*

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Abstract

Ant colony algorithm (ACA) is a new heuristic algorithm which has been proven a successful technique and applied to a number of combinatorial optimization problems. An Granular ACA algorithm based on scout characteristic is proposed for solving the stagnation behavior and premature convergence problem of the basic ACA algorithm on TSP. Proposesing a Granular computing adaptive ant pheromones mechanism base on researching on ant colony algorithm model, pheromones update and pheromones selection had been improved. Make up the traditional ant colony algorithm for the calculation of distribution network planning that is slow and easy to fall into local optimal solution. And improved the convergence of the optimal solution. The validity of the GACA has been verified using a testing function. In addition, a satisfactory optimum solution for a Power Distribution Network Planning that has 73 users has been obtained.

Keywords*: Granular Ant Colony Algorithm; Power Distribution Net woke Planning; Optimization; dynamic adaptive*

1. Introduction

Ant colony algorithm is a simulation based on the species evolution to solve complex optimization problem for heuristic. The idea of ant colony algorithm are simulated ants foraging behavior, That is, the use of a large number of ants in the search space in the random search, And use of information has always been to strengthen the search route, and guide other artificial ants search, At the same time, the introduction of the volatile pheromone mechanism. A new heuristic algorithm named ant colony algorithm (ACA) has been proposed through studying foraging behavior of real ants and applied to solving combinatorial optimization problems such as traveling salesman problem (TSP), assignment problem[1-2], and job-shop scheduling problem[3]. ACA has received increased interests from researchers quadratic assignment problem (QAP) and shop scheduling problem (JSP) solution to achieve good results.

ACA has received increased interests from researchers in recent years and a relatively large amount of successful applications are now available[4-9]. The MAX-MIN ant system (MMAS) and local search for TSP are proposed[4]. Reference[5] developed a computationally efficient vector optimizer using ACO algorithm for multi-objective designs. Reference [6] designed an ant algorithm for balanced job scheduling in grids.

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Reference [7] studied a formulation of ant algorithms for the water distribution system optimization. Reference [8] proposed an improved ACA optimization methodology for solving automatic bubble image segmentation.

In 1997, professor Zadeh is pointed out that granular computing is fuzzy Information granulation, rough set theory and interval computing superset of grain number Learn subset. Professor Yao Y Y more generally believe that granular computing is in To solve the problem in the process of using "size" of all the theory, method, Techniques and tools of "tag"[10-17].

Now ant colony algorithm has been optimized in the motor design, network distribution, function optimization and integrated circuit wiring in areas such as applied [18]. Forestry waste from electricity distribution network from the power station involved in each location, size to meet future demand for electricity in rural areas since, for each subject since the power station capacity at the same time, radial network structure, as well as reliability requirements, such as binding. Because of lot of variables and constraints involved, spontaneous power distribution network planning is a very complex combinatorial optimization problem[19-21].

In this paper, these issues of Granular ant colony algorithm and proposes a granular computing-modal adaptive ant colony pheromone search mechanisms, and their use achieved good results in the electricity distribution network optimization.

2. Ant Colony Algorithm and Granular Computing

2.1. Ant Colony Algorithm

The ant optimization algorithm is mainly composed of the switching rules and the repealing information element rule. As an example, We present the ant colony algorithm applied to the TSP (Traveling Salesman Problem) for illustrating the principle of ant colony algorithm. There is the assumption N cities, traveling salesman problem are looking for an optimal travel path of the shortest route. The TSP models the situation of a traveling sales man who is required to pass through a number of cities. The goal of the traveling sales man is to traverse these cities (visiting each city exactly once) so that the total traveling distance is minimal. Feasible solution of the traveling salesman problem is a non-repeat sequence of all the cities.[8] Assuming that only m ants Add to the given n cities: d_{ij} (i,j=1,2,…,n) where d_{ij} is distance between city i with city j. $b_i(t)$ where $b_i(t)$ is the number of ants is located in city i when it's t. m= $\sum_{i=1}^{n} b_i(t)$ .where $\tau_{ij}(t)$ is the information on residual that connect city i and city j at time t, The amount of information of Each line is equal on the initial time, Supposing $\tau_{ij}(0)$=C(C is a constant).A k ant choice next step institute direction according to the information content in the process.

$$p_{ij}^{k} = \begin{cases} \dfrac{\tau_{ij}^{\alpha}\eta_{ij}^{\beta}(t)}{\sum\limits_{s\in allowed_k}\tau_{ij}^{\alpha}\eta_{ij}^{\beta}(t)} & j \in allowed_k \\ 0 & \end{cases} \tag{1}$$

Where $P_{ij}^{(k)}(t)$ is the probability Ant k sets off town j from town i at time t and $allowed_k$={0,1,…,n-1}; $tabu_k$ is the ant k select the next step to allow the city. This is different from the real ant system, artificial ant system with memory function. $Tabu_k$ (k=1,2,…,m) $tabu_k$(k=1,2,…,m) is used to memory the city that the ant k has gone through. In order to avoid premature convergence to local optimal solution, the pheromone is evaporation, ρ is the coefficient for the residual pheromone.1-ρ is pheromone evaporation coefficient, the pheromone on each line adjust with (2) after Ants complete a circle at n moment.

$$\tau_{ij}(t+m) = \rho^{*}\tau_{ij}(t) + \Delta\tau_{ij} \quad (2)$$

$$\Delta\tau_{ij} = \sum_{k=1}^{m}\Delta\tau_{ij}^{k} \quad (3)$$

Where $\Delta\tau_{ij}^{k}$ is the amount of information Ant k left in on the path ij in this cycle; $\Delta\tau_{ij}$ is the amount of information all Ant left in on the path ij in this cycle.

$$\Delta\tau_{ij}^{k} = \begin{cases} \dfrac{Q}{L_k}, & \text{if the ant k traversed ij in this cycle} \\ 0 & \end{cases} \quad (4)$$

Where Q is a constant and L_k is the path length ant k traversed in this cycle, $\Delta\tau_{ij} = 0$ At the initial moment [3].

2.2. Granular Computing

Grain is the fundamental element of granular computing, it is in accordance with the indistinguishable Sex, similarity and function label together theory in the domain of the child Set, classes, cluster and elements.

Document [22] of the grain of the interaction of the different information is discussed Mechanism Level switch is refers to the problem of the solution can be in different grain layer Obtained, focuses on adjacent layer over the rapid reconstruction method, As shown in Figure 1.

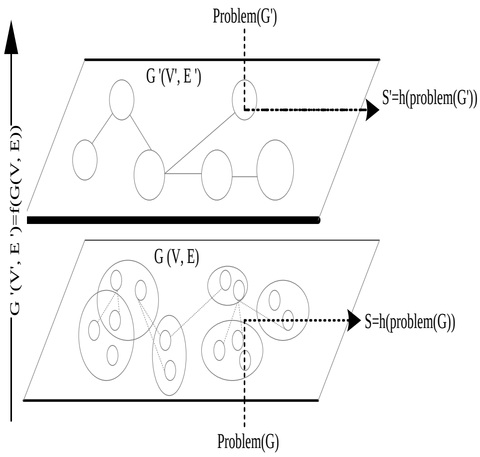

Figure 1. Based on the Rapid Solution of Solution of Granular Layer Switch Reconstruction Mechanism

In Figure 1, G (V,E) and G'(V',E') are two grain layer, f from G(V,E) to G(V,E') the mapping relationship, S and S' is the solution of solving process with function h() on topic problem in grain layer of G and G '. In the case of the problem and granular layer mapping known, solution of coarse grain layer G' in fact can be determined through S=h(Problem(G')[23].

3. Granular Adaptive Ant Colony Algorithm

Previous studies have shown that ant colony algorithm has a strong ability to find a better solution, It is not only because the use of the positive feedback principle, to a certain extent on the process of speeding up the optimization, and is a nature of a parallel algorithm, carried out between individual mutual collaboration and exchange of information transmission, is conducive to a better solution was found. But this algorithm is time-consuming than other intelligent optimization algorithms, the complexity of the algorithm can reflect this[15]; The algorithm is prone to stagnation, that is, the search to a certain extent, all individuals found that the solution is exactly the same solution cannot further the search space is not conducive to a better solution was found[16].

In this paper, the mathematical model of the algorithm has been improved in three ways.

First, single Pheromone cannot satisfy the practical application of a variety of constraint problem question. It is clear that only selecting one of pheromones as the definition of the optimal solution would be a hindrance to the rapid generated in the number of constraints. Because of the above, changing the practical application of a variety of practical constraints properly into a "pheromone". A variety of "pheromone" Update in accordance with the actual constraints. This mechanism can not only accelerate the speed of optimization, but also reduce risk of local optimal solution. Yao Y Y designed the measurement of granular in Reference[24].

$$\mathrm{GM}(\pi)=\sum_{i=1}^{m}\frac{|X_i|}{|U|}\log|X_i| \tag{5}$$

Where $\pi=\{\mathrm{X}_1, \mathrm{X}_2,\cdots, \mathrm{X}_m\}$ is a partition of the domain U, X_i is a subset of the set of U. When each grain is the single point set, GM(π)=0; When the whole universe is a grain, GM(π)=log|U|. The optimal solution is obtained as pheromones.

Second，the ant colony algorithm uses feedback mechanism to reinforce the good solution and is prone to stagnation into local optimal solution. In this way, both the probability and the random of search are increased and improve traffic density. After some interactions, the distribution of pheromone adjust dynamically According to the case of solution by type (6). Increase the pheromone of the route and update the pheromone if the solution has improved, reduced on the contrary. Increase the pheromone of the route and update the pheromone if the solution has improved, reduced on the contrary.

The pheromones adjust as follows by this method:

Each pheromone will be adjusted in after a loop in accordance with the ratio of area and the wiring. Amended equation (2) to:

$$\tau_{ij}(t+m)=(1-\rho)\tau_{ij}(t)+\Delta\tau_{ij} \tag{6}$$

Where：ρ is self-defined parameters based on the actual that reflects the extent of such a volatile pheromone;

$\Delta\tau_{ij}=\sum_{k=1}^{n}\Delta\tau_{ij}^{k}$ Where $\Delta\tau_{ij}^{k}$ is the amount of information that the ant k left in the path ij on this cycle, $\Delta\tau_{ij}$ is the total amount of information remain in the path ij on This loop：

$$\Delta\tau_{ij}=\begin{cases}\frac{\mathrm{S}}{\mathrm{L}_K}*\mathrm{d}_{ij}, & \text{if the path}_{ij}\text{ is the current shortest}\\ 0, & \text{other}\end{cases} \tag{7}$$

Where L_k is the path length ant k traversed in this cycle; S is the area the m ants go by; d_{ij} is the distance from i to j.

4. Distribution Network Optimization

4.1. Model of Distribution Network

Distribution network planning objective is to extend the fixed costs of distribution network energy losses associated with the minimum cost, at the same time meet the power plant capacity, Paragraph feeder capacity, Voltage landing, Radial network structure, as well as constraints such as reliability constraints[25]. Because of The characteristics of biomass power, using the mathematical objective function model of the distribution network that Calculated by the direct-current equation:

$$\min Y = \sum_{i=1}^{N_L} A_i \times L_i \times Z_i + Pe \times U \tag{8}$$

Where A_i is the comprehensive cost of New lines of unit i, Li is The length of the new line, Z_i is the State of the line I, Pe is The penalty coefficient of the network has excess load, U is the load, N_L is the total line built newly[26-27].

The goal of the path evaluation model is to find an improvement space of each path in optimal solution. The improvement space is calculated according to the following formula

$$\min Y = \sum_{i=1}^{N_L} A_i \times S_{ij} \times Z_i + PE_k \times U, \begin{cases} S_{ij} = \frac{1}{m+n}\left(\sum_{s=1}^{n} w_{is} \left| d_{is} - d_{ij} \right|^{r} + \sum_{r=1}^{m} w_{is} \left| d_{is} - d_{ij} \right|^{r} \right) \\ PE_k = \sum_{k=1}^{n} \tau_{ij}, (k \in ANTS) \end{cases} \tag{9}$$

where dis is the length of arc(i, s), n is the corresponding station number, d_{jr} is the length of arc(j, r), m is the corresponding station number, w_{is} is the weight of arc(i, s), w_{jr} is the weight of arc(j, r). w_{is} and w_{jr} are decided by rank sum, and r is the adjustment parameter. We can control the differences of path evaluation through setting a different value to r.

4.2. Graining Pheromone is Determined

As the network optimization program is aimed at ensuring electricity to the load centers safely and reliable, Using of the fitness function of the circuit evaluation that distribution network construction and running costs to a minimum, for each line to be elected state optimal trend of distribution. This model's movement request is refers to regarding the movement way which assigns does not present the load, the efficiency temporarily only has taken into account line's construction investment expenses, namely belongs has the restraint minimum question, obtains the distribution network plan optimized sufficiency function is:

$$T_{best} = \sum_{j=1}^{N_L} N_j, (j = 1, 2, \cdots, n) \tag{10}$$

Suppose T is a collection of all the candidates of the slip, each slip is 1 or 0, which is selected or not selected. Where N is a collection of all the new load nodes for the planning period. The state of the candidate slip in T corresponding changes would occurred, when some of the nodes in N changed [7-17].Using granular "pheromone" In this paper, m is the number of ants, two kinds of pheromone is The power plant capacity and radial network structure; make the initial density a very of $\tau(0)$ and $\eta(0)$ small positive number, where their coefficients constrained α =1, β =1.The algorithm describe as Figure 2:

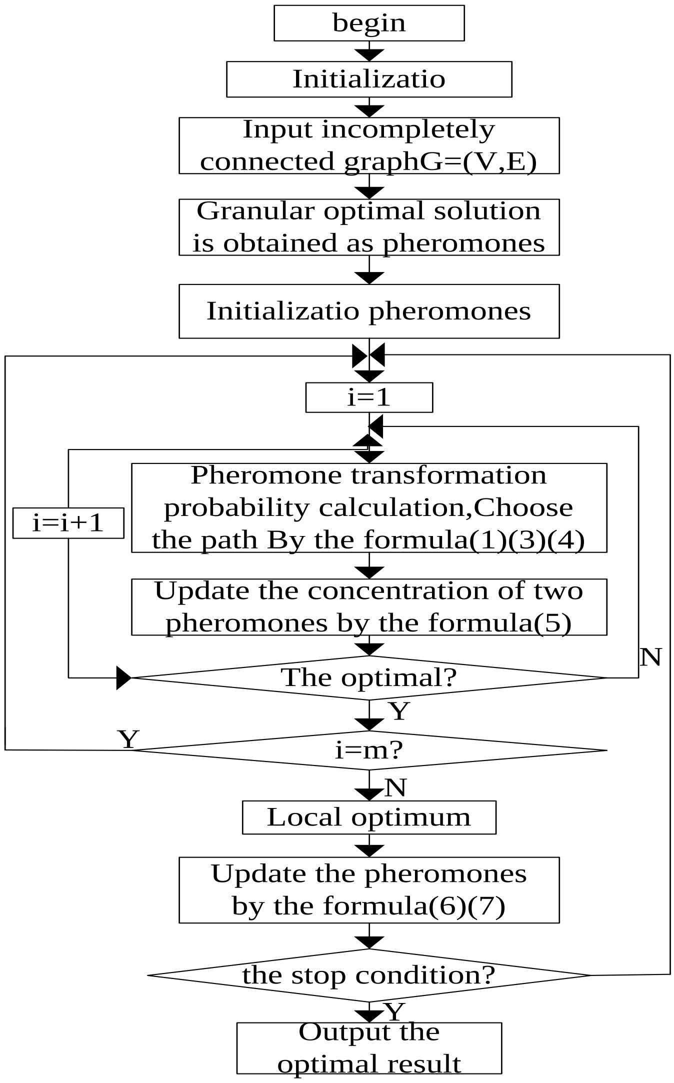

Figure 2. The Unoptimizative Distribution Network

Case Analysis

To optimize the distribution network that has 73 user and 15 small-scale self-generation power station (as shown in Table 1 and Table 2). Where points 0-72 is all users and small-scale self-generation power station are 1-4, 11-15, 31-33, 46-48. The solid line is the feeder to be built at the actual situation, The dotted line are the possible feeder to be built. The total cost of construction is 107.95A if A is a unit of the cost of construction. To optimize the power network using the basic ant colony algorithm and the improved ant colony algorithm the programming respectively. Algorithm select parameters of international standards $C_0=1, C_1=1, \alpha=1, \beta=1, \rho=0.8, Q= 2\times106, m=50$. The Solid lines are the feeder lines that must be set up and the point line is the feeder lines that have been optimized in Figure 3.

Table 1. Performance Indicators of Self-Generation Power Station

Sation_id	Capacity (MVA)	Load(W)	Planning status	Restricting conditions
1	3*20	4975.66	Y	Load;load rate;length...
2	3*50	5674.15	Y	Load;load rate;length...
...	...	...	...	...
46	3*30	1983.46	N	Load;load rate;length...
47	3*40	5042.19	Y	Load;load rate;length...

Table 2. The Demand of Node

Node_id	Planning status	Load(W)	Sation_id	Restricting conditions
5	N	1066.499	null	Load;load rate;length
6	Y	2764.229	15,11,10	Load;load rate;length
7	Y	1529.485	15,11,10	Load;load rate;length
8	Y	4409.619	15,11,10	Load;load rate;length
...	...	...	...	...
70	Y	1324.690	1,2	Load;load rate;length
71	N	499.000	null	Load;load rate;length
72	Y	5421.115	1	Load;load rate;length

The network basic has been optimized using Ant colony algorithm (as shown in Figure 4). The distribution network have three sub-nets in the improved planning: one is the power stations 1-4 and 11-15, one is 31-33 and other is 46-48 then all the stations control all of users.

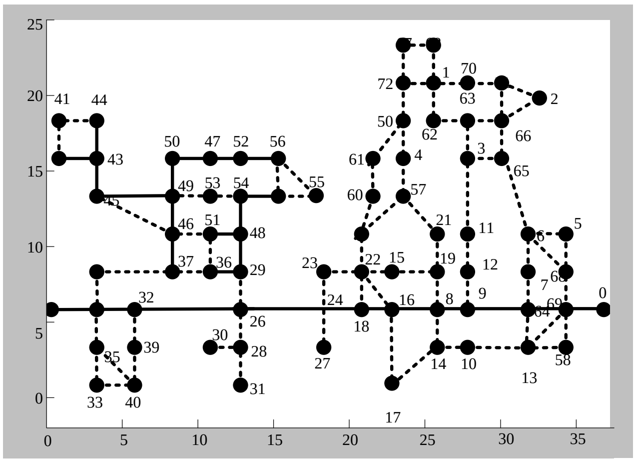

Figure 3. The Unoptimizative Distribution Network

Compare with two algorithms (as shown in Figure 4 and Figure 5), the GACA can fits the basic needs of the user's and can reduce the length of subnet while saving the cost of planning. The costs of the distribution network planning are 87.94% of the costs of the original planning, and optimization efficiency increased slightly. Above all, the granular ant colony algorithm has good optimization capabilities, the result is more satisfactory from Table 3.

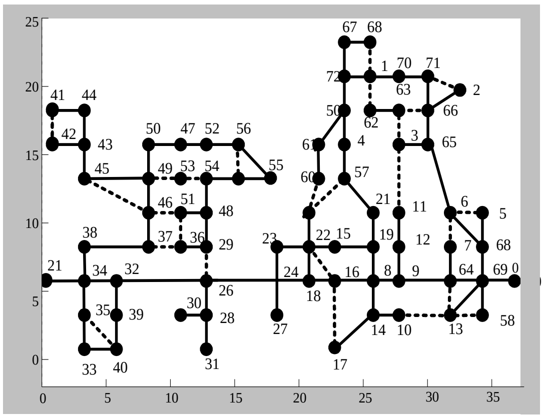

Figure 4. The Optimizative Distribution Network Using ACA

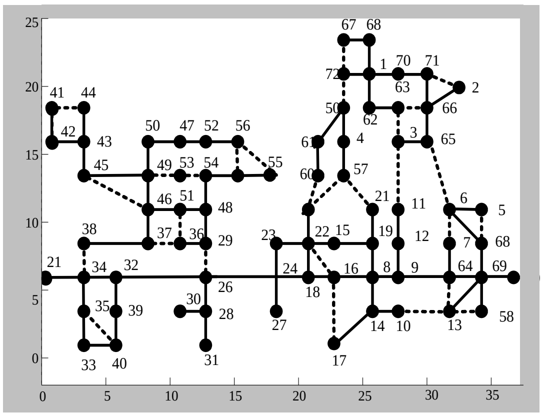

Figure 5. The Optimization using the GACA

Table 3. The Optimization Using the Gaca

Algorithm	The Total Cost of Construction	The Reduced Feeder	The Cost of Reduction	Efficiency of Optimization
The Base ACA	83.31A	15	15.57A	84.25%
GACA	74.142A	21	21.35	87.94%

Respectively, It are given that statistical results of the iterative process of two kinds of ant colony algorithm in Figure 6. Obviously, the number of the Optimal solution has reduced much in the basic ant colony algorithm before 100 iterations, Because less the density of pheromone accumulation does not give full play to the positive feedback mechanism of algorithm; The optimal solution of process decline rapidly, when the number of iterations is between 100 and 600;Optimal solution of the process decline flat, when the number of iterations is between 600 and 1000; The optimal solution of the process does not change more than 800 times. Granular Ant colony algorithm to the process of the evolution curve of the optimal solution. It can be seen that the number of iterations of Granular Ant colony algorithm less than that of the basic ant colony algorithm is about 50 times averagely. The algorithm based on ant colony algorithm for distribution network planning is stable, and the speed has improved.

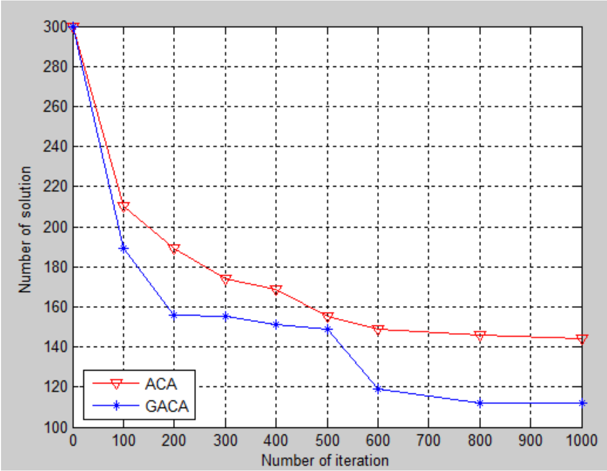

Figure 6. The Iterative Process of Two Kinds of Algorithm

5. Conclusion

In this work ACO algorithms are originally introduced to solve the optimized design of the distribution network, the results show that the algorithm is satisfied with search results. Compared with the traditional algorithm, The GACA are currently among the state-of-the-art methods for solving discrete optimization problems and improving the Time-consuming of the algorithm up to a certain extent; with other intelligent optimization algorithms, the improved ant colony algorithm for optimal design of distribution network and provides a new effective method. But the ant colony algorithm precocious and stagnation-prone situation, also need to be further improved; this can be mixed with other algorithms to improve it.

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