The Research of Path Planning for Transmission Network Based on Improved Ant Colony Algorithms

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Abstract. With the continuous expansion of power grid scale, reasonable transmission network planning is the basis of reliable, safe and economic operation of power system. The path planning for transmission network is a high-dimensional, large-scale and non-linear combinatorial optimization problem, which is difficult to solve by traditional mathematical optimization methods. The ant colony algorithm is a very intelligent bionic optimization algorithm, ant colony algorithm is applied to solve the transmission network planning problem in this paper. An improved ant colony algorithm is proposed, which uses it to search the pathes and reduces the coupling between parameters. On the premise of guaranteeing the convergence accuracy, the calculation speed of ant colony algorithm in the planning for transmission network is improved effectively. The results show that the improved ant colony algorithm in the paper has many advantages in computing time and can search the optimal transmission line path more efficiently.

1. Introduction
Due to various social factors, an urgent problem which the power companies should solve is the construction of high-voltage overhead power lines [1]. At the same time, the monitoring equipment of overhead high-voltage power line online plays a very important role in smart grid [2]. Current standards for field work only involve safe distances without definite paths, so the work usually relies on line maintenance experience to carry out, while 1000 kilovolt UHV transmission lines have high-voltage space electric field strength, so it is difficult to carry out about the real-time safe distance measurement. And it is difficult to complete detailed and comprehensive experimental models and lines due to the changes of real towers [3]. Aiming at the intelligent selection of HV overhead transmission lines, the researchers studied various factors and their quantitative methods of route selection, and built an intelligent route selection system based on the shortest path algorithm of GIS terrain and spatial analysis [4].

All decision-making issues in the power system involve many stakeholders and affect millions of consumers. Mathematical optimization relies heavily on achieving consistent, effective and optimal results. The modern power system is based on a rigorous and comprehensive optimization model and an effective problem-solving algorithm [5]. The genetic algorithm is used to design a reasonable detection path. On this basis, which are established about the objective function and the path planning mathematical model. The optimization scheme can find the optimal detection path [6].

Intelligent algorithms have achieved many results in recent years, and the Ant Colony Optimization algorithm is applicable to many engineering problems, such as Traveling Salesman Problem (TSP), Secondary Distribution Problem (QAP), and Robot Path Planning. The improved Ant Colony algorithm which is based on the meta-heuristic Ant Colony algorithm for solving the power line path problem has been widely used [7]. In actual power systems, the EED problem becomes more complicated due to
economic and emissions targets, valve point effects, conflicts between the prohibited operating areas of the generator set and the safety limits of the transmission network [8]. Ant Colony Optimization algorithm is an algorithm of meta-heuristic. The artificial ants in ACO are random solution construction processes that use (artificial) pheromone information adjusted by using ant-based search experience and possible usable information. The problem instance of interest constructs a candidate solution [9]. The Ant Colony Optimization algorithm can be used to find the shortest path to switch the load during an overload contingency while minimizing power loss and maintaining the radiality of the system [10].

the Ant Colony Optimization algorithm is improved for the static planning problem of the transmission network and the characteristics of the multi-stage planning problem in this paper. The Improved Ant Colony Optimization algorithm is applied to solve the static planning problem and multi-stage planning problem of the transmission network, and the example is verified.

2. Path optimization model

2.1. Instruction of Traditional Ant Colony Optimization Algorithm

Traditional Ant Colony Optimization Algorithm is a kind of optimization algorithm based on ant colony foraging behavior. The ant can leave a pheromone on the path through which the motion passes, and the presence and intensity of the pheromone during the movement, and thereby guide the movement direction of the pheromone to the direction of high pheromone intensity can be sensed. The individual ants achieve the purpose of searching food through the exchange of information. Therefore the collective behavior of ant colonies composed of a huge large number of ants shows a phenomenon about positive feedback: the more ants passing through a path, the greater the probability that the latter will choose the path.

Traditional Ant Colony Optimization Algorithm is a random search algorithm. The Ant Colony Optimization Algorithm like other simulated evolution algorithms is a random search algorithm that seeks the optimal solution through the evolution process of the group of candidate solutions. The process is consist of two basic stages: the adaptation phase and the collaboration phase. Each candidate solution in the adaptation phase continuously adjusts its structure according to the accumulated information; the candidate solutions in the cooperation phase communicate through information to expect a better performance solution. The algorithm not only utilizes the principle of positive feedback, but also accelerates the evolution process to a certain extent, and the information exchange and transmission between individuals is an essentially parallel algorithm, which is conducive to finding better solutions. A single individual tends to converge to a local optimum. Multiple individuals converge to a certain subset of the solution space through cooperation, which is conducive to further the solution space exploration for not fall into local optimum easily.

2.2. Mathematical model of transmission network planning

1) Static transmission network planning model: Based on the single-level annual load level and power generation plan, the existing grid and the candidate route are known, and the transmission network expansion scheme that satisfies the relevant constraint requirements and the optimal planning objectives is obtained. The model objective function is usually composed of investment costs, operating expenses, and power generation subsidies.

2) the planning model of Multi-stage (dynamic) transmission network: The planning of Multi-stage transmission network is to divide the planning period into several load-level years and consider the transition between power grid planning schemes for each load level. There are also many different mathematical models, which can be divided into single-objective multi-stage transmission network mathematical models and multi-objective multi-stage transmission network mathematical models according to different planning purposes.

This paper mainly considers the line investment cost and the overload penalty fee. The requirements of the constraint condition are: When an overload occurs when a certain erection scheme runs normally,
the overload amount is converted into a fee through the penalty coefficient. The transmission network planning model selected in this paper is:

\[
\min W(x) = \sum_{i=1}^{n} C_i x_i + K P_0 \quad \text{Network Connection}
\]

\[
W_0 \quad \text{Network Disconnection}
\]

(1)

\[x\] represents a planning scheme, which is an n-dimensional vector representing the solution to the problem to be solved; \[x_i\] is an element of vector \(x\) (\(i = 1, 2, \ldots, n\)), and \(x_i = 1\) when the candidate line is selected. Conversely, \(x_i = 0\); \(C_i\) is the investment cost of the line construction, assuming that the investment cost is proportional to the length of the line; \(P_0\) is the total overload capacity when the “N-1” check is satisfied. This paper uses the DC power flow method to obtain the load flow; \(K\) represents the overload penalty coefficient, the value range is generally 50~100; \(W_0\) represents the penalty value when it is not connected.

### 2.3. Improved Ant Colony Optimization Algorithm search model for transmission line search

The improved Ant Colony Optimization Algorithm used in this paper makes some improvements to the pheromone management strategy based on the maximum-minimum ant system algorithm structure:

1) Initialize the pheromone value

All pheromone values in this algorithm are initialized to values at the beginning, which is:

\[
\tau_0 = \omega \cdot \tau_{max}
\]

(2)

\(\omega\) is a constant, which satisfies the condition \(0 < \omega \leq 1\). This means that the pheromone is initialized to the upper limit \(\tau_{max}\), when \(\omega\) is equal to 1.

2) Build a solution way

The main improvement of the Improved Ant Colony Optimization Algorithm in this paper is to simplify the pheromone model. The solution's build strategy still uses random scale rules.

\[
p_{ij}^{k}(t) = \begin{cases} \frac{\tau_{ij}(t)[n_{ij}]^p}{\sum_{e \in \mathcal{E}} \tau_{de}(t)[n_{de}]^p} & \text{if } j \in N_i^k \\ 0 & \text{otherwise} \end{cases}
\]

(3)

3) Update the pheromone

Only a single solution (iterative optimal solution) in the algorithm used to update the pheromone. But pheromones are limited to a fixed range, not change with changes in parameters. The range is still expressed as \([\tau_{min}, \tau_{max}]\), \(\tau_{min}\) and \(\tau_{max}\) are constants, which are not affected by changes in the value of the objective function. The amount of updating of the pheromone is also a constant related to \(\tau_{max}\). The pheromone is updated according to the following rules when all ants get the full path in iteration \(t\):

\[
\tau_{ij}(t + 1) = [(1 - \alpha) \tau_{ij}(t)] + \Delta \tau_{ij}^{best}(t) \tau_{min}^{max}
\]

(4)

\(\Delta \tau_{ij}^{best}(t)\) is the number of pheromones on the edge \((i, j)\) of the best ant. It can be defined as:

\[
\Delta \tau_{ij}^{best}(t) = \begin{cases} \alpha \tau_{max} & \text{if } (i,j) \in s_{best}^{max} \\ 0 & \text{otherwise} \end{cases}
\]

(5)

The pheromone satisfies the initialization condition, and the pheromone of each side does not exceed the upper bound of the pheromone. So it can be omitted that the judgment of whether the pheromone exceeds the upper limit in the Improved Ant Colony Optimization Algorithm.

In fact, the specific values of \(\tau_{min}\) and \(\tau_{max}\) do not affect the performance of the algorithm on the basis of satisfying certain conditions. \([\tau_{min}, \tau_{max}]\) can be taken as \([0.001, 0.999]\) in practice. Compared with the pheromone management strategy, the improved algorithm implements a simplified pheromone model in the maximum-minimum ant system algorithm, and sets the pheromone value interval to a constant, so that the pheromone update amount and initialization method are also improved ant colony algorithm. Make appropriate changes in it. The improved ant colony algorithm inherits the advantages of the max-min ant system algorithm, and some simplification strategies can also eliminate some problems in the max-min ant system algorithm.
2.4. Solving static transmission network planning based on Improved Ant Colony Optimization Algorithm

1) Each artificial ant searches for the plan each artificial ant performs multiple searches according to the mathematical model in formula (1), and each time a set of planning plans can be obtained, each planning plan has its fixed target. Function value.

The artificial ant starts at any point in the feasible domain, and after N steps, the entire planning grid is formed. In each step, after a branch, a value is randomly selected according to the state transition probability in the feasible domain. The number of lines expanded in the branch, as in the first step, the artificial ants will choose one value for the actual number of expansion lines. Finally, the new planning grid will be formed, and the fitness of the mathematical model will be determined by the objective function and constraints to determine whether the results of this search meet the planning objectives.

2) Solving transmission network planning with ant colony algorithm

After completing the above process, each artificial ant performs a local update of the pheromone according to formula (4), thereby enhancing the path pheromone value of the selected path in this iteration; after all artificial ants complete the above process, the pheromone global update is performed on the optimal path in the iterative process according to formula (5), enhancing the pheromone value on the optimal path, so that the entire population can be advanced in the direction favoring the objective function. The path is searched according to the search process segmentation until the given convergence condition is met, and the final planning scheme is obtained.

3. Example simulation

The mathematical model of static transmission network planning studied in this paper is the model of formula (1), that is, the cost of the candidate line in the example is proportional to the length of the line, assuming that the unit expansion cost of each line is the same, and the proportional coefficient is set to 1. The pheromone volatilization coefficient in the improved Ant Colony Optimization Algorithm $\rho = 0.004$, the path selection expectation important coefficient $\beta = 5$, and the pheromone threshold lower coefficient $\omega = 0.001$.

3.1. Case Analysis

In this paper, the Ant Colony Optimization Algorithm and the improved Ant Colony Optimization Algorithm program are run for the 18-node system, and the transmission network planning scheme is the same, the optimal result is 1654. The added line is: n1-2=1, n4-16=1, n5-12=1, n7-13=1, n6-14=2, n7-8=1, n9-10=1, n14-15=1, n16-17=2, n17-17=1; The convergence characteristic curve after the 18-node system is planned is shown in Figure 1.

![Figure 1 Planning Convergence Characteristics of the System Based on Ant Colony Optimization Algorithm](image)

3.2. the two different algorithms effect comparison

Based on the contradiction between convergence accuracy and computational speed, the Ant Colony Optimization Algorithm in this paper is improved. The traditional Ant Colony Optimization Algorithm
and the improved Ant Colony Optimization Algorithm are used for the Garver 6, 18-node system and IEEE 24 transmission network planning results respectively. The group algorithm and the improved Ant Colony Optimization Algorithm performed 100 simulations on the above three examples, and the obtained results are shown in Table 1.

Table 1: Comparison of Traditional Ant Colony Optimization Algorithm and the improved Ant Colony Optimization Algorithm

| System       | Traditional Ant Colony Optimization Algorithms | improved Ant Colony Optimization Algorithm |
|--------------|-----------------------------------------------|------------------------------------------|
|              | Best investment plan/$ | Solving time/s | The probability of finding the optimal solution /% | Best investment plan/$ | Solving time/s | The probability of finding the optimal solution /% |
| Garver 6     | 210 | 36-45 | 91 | 210 | 17-21 | 85 |
| 18-node system | 1654 | 110-118 | 86 | 1654 | 35-43 | 81 |
| IEEE 24      | 421 | 265-283 | 81 | 421 | 112-126 | 76 |

4. Conclusion

Being a kind of simulated evolutionary algorithm, the Ant Colony Optimization Algorithm is an efficient internal heuristic method, which is often used to solve the combinatorial optimization problems. However, the Ant Colony Optimization Algorithms involves many parameters, and there is strong coupling between each parameter, which leads to the inverse of the convergence accuracy and calculation speed. In this section, the constant pheromone upper and lower limits are used to reduce the coupling between the parameters in the improved Ant Colony Optimization Algorithms. Under the premise of ensuring convergence accuracy, the calculation time for obtaining the optimal solution is reduced. Finally, by comparing the improved ant colony algorithm in the Garver 6, 18-node system and IEEE 24 three classic examples, the static transmission network planning is compared with the traditional Ant Colony Optimization Algorithms in solving the time and searching for the optimal probability. It shows its advantage of fast calculation speed.

Under the premise of accurate load forecasting, the paper studies the application of improved Ant Colony Optimization Algorithm in the transmission network expansion planning way based on the operational characteristics of power industry and the theoretical basis of power system planning. The ant colony algorithm has made certain developments in the transmission network expansion planning of power system. Based on the contradiction between convergence precision and calculation speed, Ant Colony Optimization Algorithm is improve in this paper by using constant pheromone boundary and information mainly. The updating amount and initialization of the prime are also set to constants, and the calculation speed of the Ant Colony Optimization Algorithm in the transmission network planning is effectively improved under the premise of ensuring convergence accuracy. The sum of the new line investment cost in the planning model of the static transmission network and the penalty cost of the line load overload is taken as the objective function, and three examples are used to study the case. The simulation experiment is used to compare the Ant Colony Optimization Algorithm and the improved Ant Colony Optimization Algorithm. Convergence accuracy and calculation speed of group algorithm in transmission network planning. The calculation results of the three examples show that the improved Ant Colony Optimization Algorithm greatly improves the calculation speed under the premise of ensuring convergence accuracy.

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