The Research of Optimization in Electric Energy Transportation Based on Improved Imperialist Competitive Algorithm

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Abstract:-As a weak link in China's economic system, the construction of electric energy transportation system which including power transmission network becomes urgent affairs. This paper does a study on optimization of distribution network planning in electric energy transportation system, and proposes imperialist competitive algorithm which based on biological evolution, through the introduction of differential evolution strategy, it can effectively enhance the diversity of the population and retain outstanding individuals, thus can avoid falling into local optimum in the optimization process. A numeric example is employed to validate the effectiveness of the proposed model.
Key-Words: -Energy transportation system; Distribution network planning; Imperialist competitive algorithm (ICA); Differential evolution strategy (DE)

1 Introduction

Energy transportation system directly affects the sustainable development of the power industry, and its irrational structure is the key issue which currently affects the sustainable development of China's power industry. The adjustment and optimization of the electric energy transportation structure is greatly demanded from diverse perspectives such as energy security, environmental protection and resource carrying capacity. As the end part of the power system, distribution network directly faces to users, and plays a crucial role in guaranteeing supply capacity and power quality. Distribution network structure optimization is a non-linear integer programming problem with dynamic, multi-objective, uncertainty. There are two types of optimization methods in distribution network planning, namely the classical optimization methods and heuristic optimization methods.

There are some typical classical optimization methods, such as Shortest Path, Mix-integer Programming (MIP), Linear Programming, Nonlinear Programming, Network Flow Method and so on. Due to belonging to the large-scale combination of mathematical problems, network planning issues has a long time for calculating and occupies large computer memory, thus it is easy to cause "curse of dimensionality" problem when using typical classical optimization methods in the actual large-scale systems [1].

Compared to classical optimization methods, heuristic optimization methods combine planning efficiency with planning effectiveness and have prominent advantages. In particular, modern heuristic optimization methods are often able to give a satisfactory solution. There are some typical modern heuristic optimization methods, such as Genetic Algorithm (GA) [2], Simulated Annealing (SA) [3], Tabu Search (TS) [4], Ant colony optimization (ACO) [5] and so on. GA is an algorithm to mimic the biochemical process of evolution, it is continent to operate, what’s more, it has low requirement to data as well as multi-point optimization. Document 6 applies the combination of GA and fuzzy logic into the distribution network planning, it makes experimental result more accurate than standard GA. SA uses Metropolis acceptance criteria to avoid falling into local optima, thus asymptotic converge to the global optimum. As SA belongs to single point optimization, it usually combines with other methods. Document 7 applies SA-GA hybrid model into the distribution network planning in order to overcome the instability and local convergence problem of the standard GA algorithm. By recording historical data, TS can gain knowledge and use it to know the subsequent search direction thus can avoid local optima. Document 8 applies TS into solving optimization problems of the tie-line power distribution system. ACO is a multi-agent algorithm, its main features are the positive feedback, distributed computing, and constructive applying of greedy heuristic search. Document 9 applies the improved ACO algorithm into the distribution network optimization and the experimental results are satisfactory. These modern heuristic algorithms have two common defects, namely a long running time and the results easy to fall into local optimum.

To address the above mentioned problems, this paper employ a new global optimization algorithm, namely imperialist competitive algorithm (ICA), which is inspired by an imperialistic competition mechanism. The ICA was first introduced by Atashpaz-Gargari and Lucas[10] in order to solve continuous optimization problems. This algorithm not only is easy to implement, powerful and computationally efficient bu also has a few parameters to adjust. ICA has been applied in solving scheduling problem[11] , and classification problem[12] , etc. This paper applies differential evolution operator[13] into PCA to achieve the purpose of increasing the population diversity, and uses the hybrid model to solve the distribution network planning problems. The rest of this paper has the following structure: Section 2 introduces the distribution network planning optimization model. The Improved Imperialist Competitive Algorithm is introduced in section 3. Section 4 introduces a real example of distribution network planning and compares and analyzes the above model with other optimization models; and section 5 concludes and summarizes the whole paper.

2 Mathematical model of distribution network structure optimization

Network structure optimization is based on the existing network structure. Knowing the power data and load demand, network structure optimization assumes the time, place and capacity have been identified when the substation needs expansion or new construction, thus it can decided how many circuit of transmission lines should be erected in the future plan in order to make a minimum annual fee. The objective function is expressed as:

$$\min f\left(X\right)=K_1\sum_{i\in D_1}l_i a_i X_i+K_2\sum_{i\in D_2}l_i a_i + K_3\sum_{i\in D}l_i r_i\frac{p_i^2}{U_N^2} \quad (1)$$

Where D_1 represents for new circuits, D_2 represents for built circuits, D_3 represents for all new circuits; K_1 , K_2 , K_3 represent for weight coefficient; X_i represents for 0-1 variables; it means that $X_i=1$ represents for the construction of the circuit is yes, $X_i=0$ represents for the construction of the circuit is not; l_i represents for the length of the circuit; a_i represents for the investment of per unit length; r_i represents for the resistance per unit length of the conductor; p_i represents for the active power flowing through the circuit; U_N represents for the rated voltage of the circuit.

The objective function should satisfy the following constraints:

(1) Load point voltage constraints: $U_{i\min}\le U_i\le U_{i\max}$, where U_i represents for the node voltage; $U_{i\max}$ represents for the upper bound

value of the node voltage, and $U_{i\min}$ represents for the lower.

(2) Branch current constraints: $I_{hi} > I_i$. Among it, I_i represents for the branch current, I_{hi} represents for the ampacity of branch i.

(3) Capacity constraints: $p_i \le p_{i\max}$. Among it, p_i represents for the flowing capacity of branch i; $p_{i\max}$ represents for the maximum capacity allowed to flow through branch.

(4) Radiation Network Constraints: The distribution network must be a network of radiation, in order to ensure the normal operation of the grid. For processing constraints, this paper uses the popular penalty method [14]. The target function is converted into the following form:

$$\min F(X) = \begin{cases} f(X) + C_1 w_1 + C_2 w_2 \\ \quad + C_3 w_3 \quad Radiation\ Network \\ C_4 \qquad Non-radiation\ Network \end{cases} \tag{2}$$

Where $f(X)$ represents for the function (1); C_1, C_2, C_3 represent for the overload penalty coefficient; w_1 represents for the overload which does not meet the load node voltage constraints; w_2 represents for the overload which does not meet the branch load node voltage constraints; w_3 represents for the overload which does not meet the capacity constraints; C_4 represents for the radiation which does not meet the conditions for net penalty value; C_i $(i = 1,2,3,4)$ represents for the large positive.

3 Improved imperialist competitive algorithm

3.1 Basic imperialist competitive algorithm

Imperialist competitive algorithm is an evolutionary algorithm based on imperialist competitive mechanism, which was proposed by Atashpaz-Gargari and Lucas in 2007 [10]. It belongs to random optimization searching method of social enlightenment. The detail steps are as follows:

(1) Initialization of Empire

Country is the unit of imperialist competition, for an N dimensional optimization problem, country can be expressed as follows:

$$country = [v_1, v_2, \cdots, v_N] \tag{3}$$

Where v_i is the optimized variable, which can be seen as the social political nature of the country.

Powers of country are measured through the cost function:

$$\text{cost} = f(country) = f(v_1, v_2, \cdots, v_N) \tag{4}$$

Powers of country is inversely proportional to the value of cost function, which means that the bigger the power is, the smaller the values.

There are N_{pop} random countries, choosing N_{imp} countries with bigger power as imperialist countries, the rest N_{col} countries will be the colonies. Divide the colonies according to the power of imperialist countries. The quantity of each imperialist country is calculated as follows:

$$\begin{cases} C_n = c_n - \max_i \{c_i\} \\ p_n = \left| C_n \Big/ \sum_{i=1}^{N_{imp}} C_i \right| \\ N.C._n = round\{p_n \times N_{col}\} \end{cases} \tag{5}$$

Where c_n is the cost function value of imperialist countries n, C_n is its normalized cost, p_n is its normalized size of power, $N.C._n$ is original quantity of imperialist countries n. As a result, there are N_{imp} imperialist countries, which is shown in Fig1.

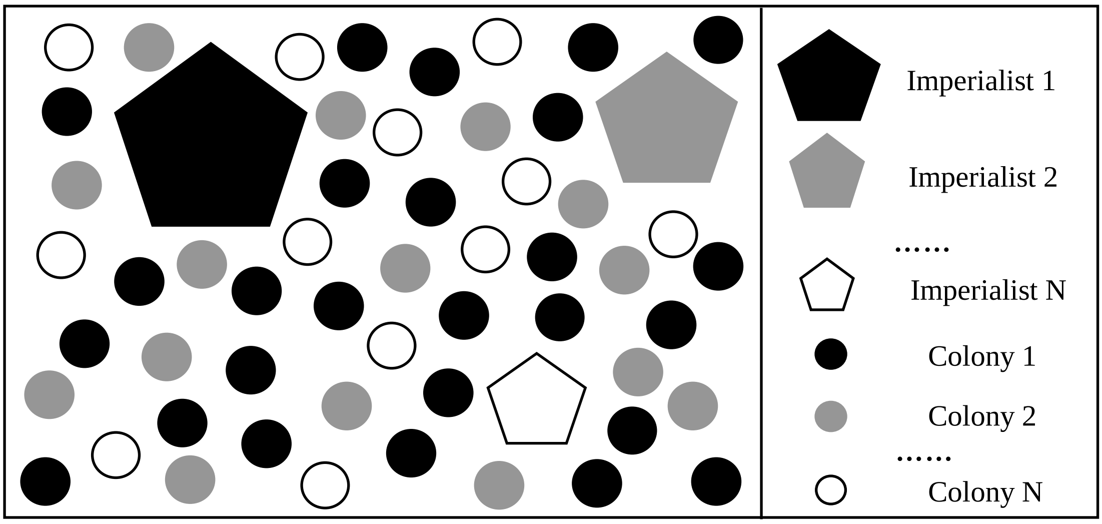

Fig 1. Generating the initial empires

(2) Assimilation operation

In order to expand, the empire tries to absorb their colonies as part of the empire. Colony moves to empire along the coordinate axis. As is shown in Fig 2. The distance that colony moves is defined as follows:

$$x \sim U(0, \beta \times d) \tag{6}$$

Where $\beta > 1$, d is the distance between Colonial Countries and imperialist countries.

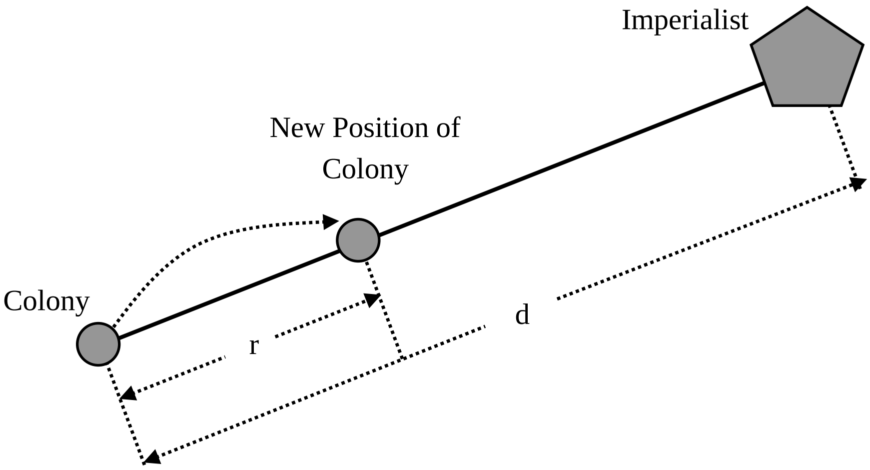

Fig 2. Moving colonies toward their relevant

At the same time, in order to enlarge searching range, add an offset direction θ, which is defined as follows and shown in Fig 3:

$$\theta \sim U(-\gamma, \gamma) \tag{7}$$

Where $0 < \gamma < \pi$ is used to adjust the moving direction of colonies .

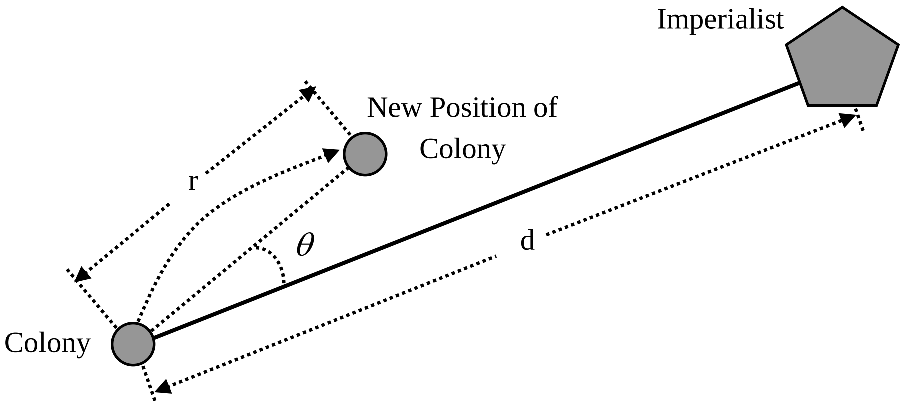

Fig 3. Moving colonies toward their relevant imperialist in a randomly deviated direction

When a colony moves to a new position, the cost function value of the colony could be smaller than that of imperialist country, in other word, when the power of colony is big enough, switch the position of colonial country and imperialist country, which means that the colonial county will become the imperialist country of that empire and the original imperialist country will become the colony, which is shown in Fig 4.

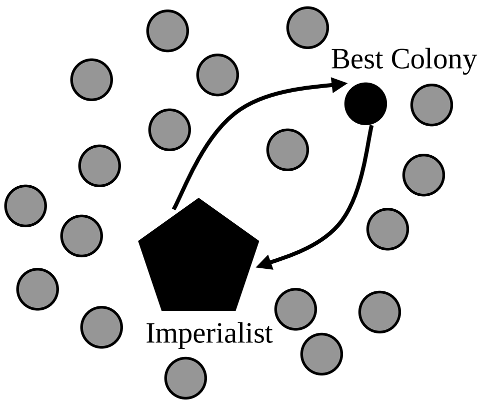

Fig 4. Exchange the positions of a colony and the imperialist

(3) Competitive operation

The imperial competition mechanism simulates the process that empire with bigger power conquers and controls colonies with smaller power in real society. The total power of an empire consists of its power and power of its colonies and its total cost value is as follows:

$$T.C._{n} = f\left(imp_n\right) + \xi \times \sum_{i=1}^{N.C._n} f\left(col_i\right) \Big/ N.C._{n} \tag{8}$$

Where imp_n is the imperialist country of empire n, $0 < \xi < 1$, the value of ξ decides how can a colonial country affects the whole empire power.

Choose the weakest colony in the weakest empire as the imperialist competitive object, the possibilities that other empires getting this colony are as follows:

$$\begin{cases} N.T.C._{n} = T.C._{n} - \max_i \{T.C._{i}\} \\ P_{P_n} = \left| N.T.C._{n} \Big/ \sum_{i=1}^{N_{imp}} N.T.C._{i} \right| \end{cases} \tag{9}$$

Where $N.T.C._{n}$ is the total normalized price of imperialist country n, P_{P_n} is the conquering possibility of every imperialist countries.

Considering the accident situations may occur, add a variable r_n, it is uniform distribution, as a result, the possibility of an imperialist country getting the colony is:

$$D_n = P_{p_n} - r_n \tag{10}$$

(4) Empire unity

Competition among empires makes the big empire even bigger by conquering other empire's colonies and the quantity of weak empire becomes smaller, which is shown in Fig 5. When the number becomes 0, the empire will disappear. At last, there will be only one empire with all the colonies. The optimal solution is founded.

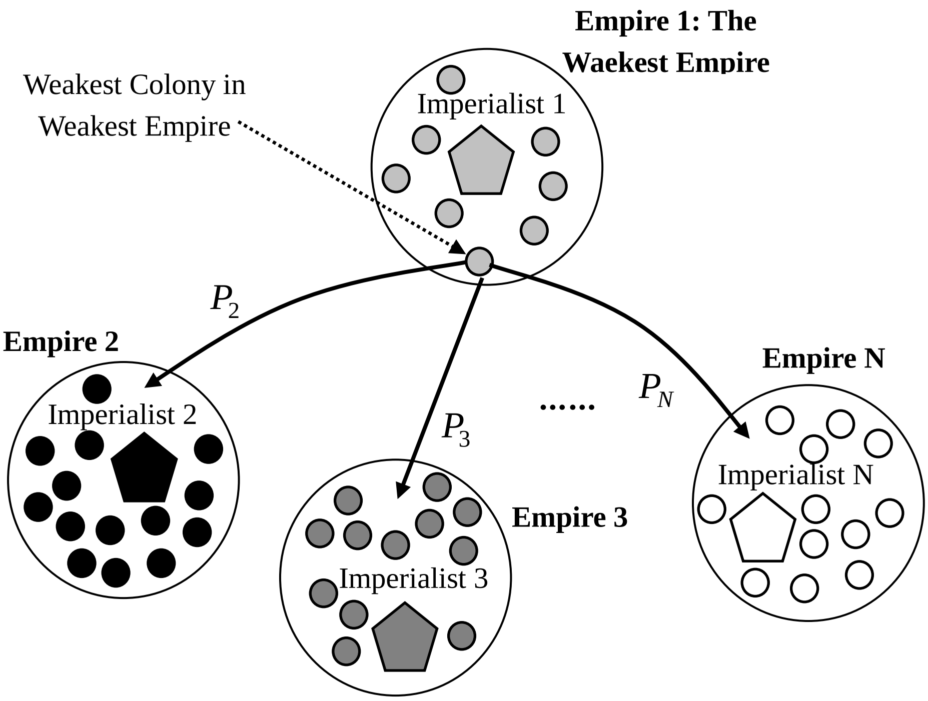

Fig 5. Imperialistic competition

3.2 Improvements for ICA based on differential evolution

In traditional ICA, imperialist competitive operation shows the information interaction between empires, however, imperialist competition just returns the weakest colony to the strongest empire,differential evolution and this process has small influence on empire power. Lack of information interaction between empires can be shown only after many times. As a result, this paper used differential evolution theory and uses a differential evolution arithmetic operator [13,14].

Add the following operations between the Assimilation operation and competitive operation:

(1) Every colony has a possibility of MR to finish differential mutation according to Eq.(11):

$$C = Col_{r3} + F\left(Col_{r1} - Col_{r2}\right) \quad (11)$$

Where Col_{r1} , Col_{r2} , Col_{r3} are three random colonies, $F \in [0,2]$ is scaling factor.

(2) Do differential crossover to every dimension according to Eq.(12):

$$D_i = \begin{cases} C_i , if\ rand < CR \\ Col_i , otherwise \end{cases} \quad (12)$$

Where $CR \in [0,1]$ is the crossover factor, $rand$ is random number in $[0,1]$.

(3) Use greed strategy, when power of the new colony D is bigger than original colony, when $f(D) < f(Col)$, changing the position of colony.

In this paper, improvements for imperialist competitive algorithm based on differential evolution is short for DE-ICA.

3.3 Improved ICA applied in distribution network planning optimization

Based on the above algorithm improvements, apply them to the distribution network planning optimization, and the detail processes are as follows:

(1) Initialization of imperialist competitive algorithm parameter. Parameters in imperialist competitive algorithm contains: number of countries N_{pop} , number of imperialist countries N_{imp} , assimilatory coefficient β , offset direction γ and colony affection coefficient ξ .

(2) The power network X_i which needed to be planned could be regarded as one dimension v of individual countries while a planning scheme $Y_i = [X_1, X_2, \cdots, X_n]$ containing n lines to be planning could be seen as an individual country with the dimension n. Adopt binary code for individual

countries Y_i which indicated that the line was to be constructed when $X_i = 1$ and not when $X_i = 0$.

(3) Using DE-ICA model to optimize the distribution network planning, so as to get the optimal solution of distribution network planning. The specific process of the model is shown in the Fig 6.

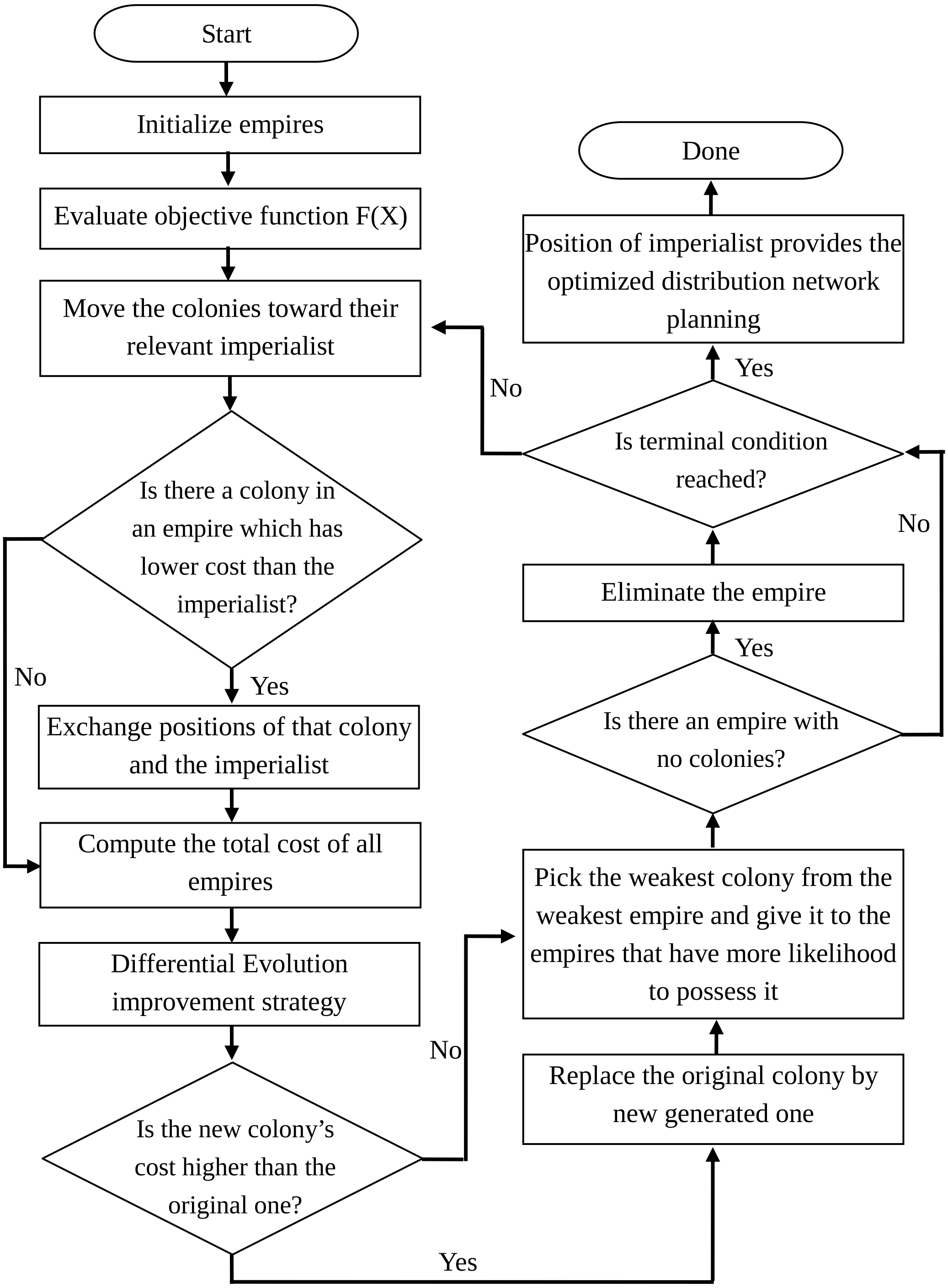

Fig 6. The flowchart of DE-ICA model

4 A specific example and results analysis

Take the 110kv high-voltage power distribution system as an example [15], which has five power points (220kv substation) and 19 load points (110kv substation). The relative position of power supplies and load points is shown in Fig 7. In the figure, the square stands for power point and the circle for load point, while the solid line represents an existing line and the dotted as the line to be selected. The corresponding load power is shown in Table 1.

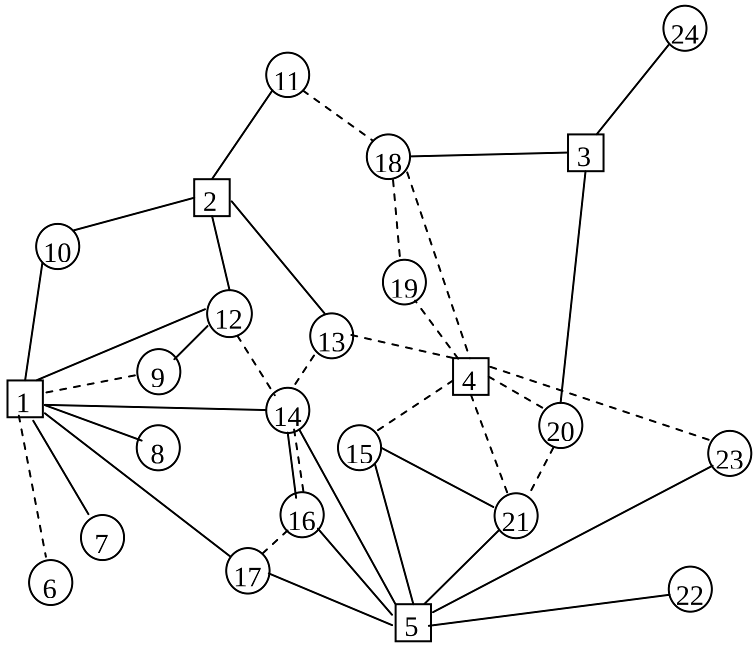

Fig 7. Original distribution network structure

Table 1. The coordinates and state of load points

Number	Abscissa/ m	Ordinate/ m	The node load/kv
1	3700	8663	Source
2	6925	14892	Source
3	13198	15590	Source
4	11834	11236	Source
5	11242	3997	Source
6	3969	6776	50
7	5260	7819	94.5
8	5762	8602	150
9	5631	10744	120
10	3810	12988	81.5
11	8283	16412	150
12	7202	11638	63
13	9490	12118	100
14	8788	10224	120
15	10782	9389	113
16	8730	7655	80
17	7919	7325	100
18	11029	15468	150
19	11317	13409	100
20	12983	10526	63
21	12488	7939	150
22	14002	4421	150
23	15944	9648	80
24	14827	16983	150

The parameters of DE-ICA model are set in Table 2.

Table 2. DE-ICA model parameters settings

Parameters	β	γ	ξ	F	CR
Value	2	$\pi/4$	0.1	0.6	0.9

In the DE-ICA model, the two parameters, the number of countries N_{pop} and empires N_{imp}, could have a great impact on the pros and cons of solutions and the search time with different settings. Therefore, the above two parameters were assigned multiple sets of different values to do a test in this paper. In order to reduce the uncertainty of the test, each data set was repeated 10 times to test, then took the average. The test results are shown in Table 3.

Table 3. The result of different parameters settings

N_{pop}	N_{imp}	Optimal solution /10^4	Iterations	Computing time/s
50	5	4.1365	14	5.73
	10	4.1854	10	5.25
	20	4.2015	7	5.12
100	5	4.1135	29	7.96
	10	4.1318	24	7.74
	20	4.1736	16	7.22
200	5	4.1365	47	11.03
	10	4.1273	35	10.85
	20	4.1354	28	10.33

As can be seen from Table 3, the model's iterations and running time increase along with the increase of the number of countries. When the number of countries remains unchanged, the number of empires has an inverse proportion relationship with iterations and running time. Crucially, different proportion of the values of two parameters affects the model whether it can achieve the global optimal solution. When the numerical ratio is 20:1, the optimization result is satisfactory, for example, the two groups of test results: $[100,5]$ and $[200,10]$. But it don't mean that the number of countries is more, the optimization effect is better. The optimization result with $N_{pop} = 100$, $N_{imp} = 5$ is better than that with $N_{pop} = 200$, $N_{imp} = 10$. Consequently, this paper seted the parameters $[N_{pop}, N_{imp}]$ as $[100, 5]$. Calculated by DE-ICA model, the optimization scheme of this distribution network structure optimization is to construct eight lines in total including 1-16, 4-15, 4-19, 4-20, 11-18, 16-17, 18-19, 20-21. And the optimized distribution network planning is shown in Fig 8.

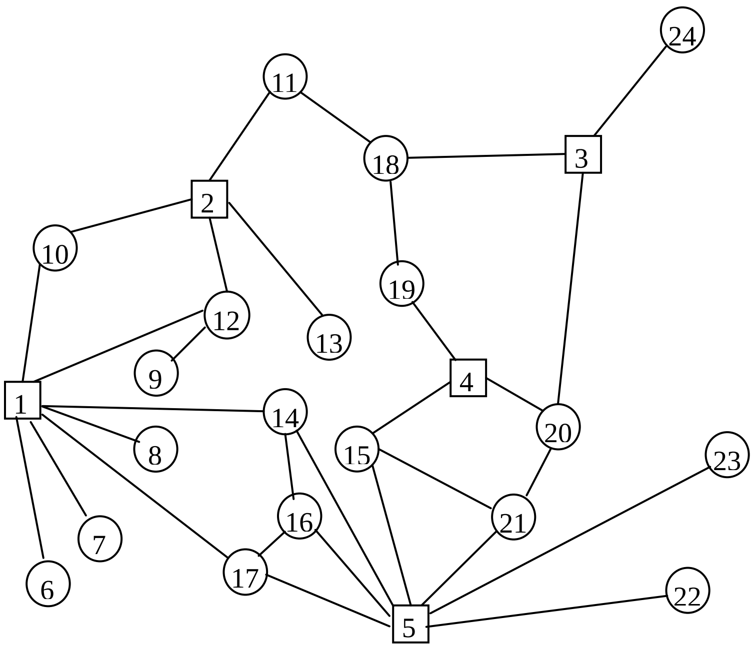

Fig 8. Optimized distribution network structure

For further analysis, this paper adopted standard ICA, SA and TS to optimize the above distribution network planning, then compared the optimization results with DE-ICA model, as shown in Table 4.

Table 4. The comparison result of algorithms

Algorithm	Iterations	Optimal solution/10^4	Computing time/s
DE-ICA	29	4.1135	7.96
ICA	45	4.1189	10.67
SA	-	4.5259	45.12

TS	-	4.2947	23.14

Seen from the Table 4, the proposed model is superior to the other models in the optimization results, the number of iterations and running time.

5 Conclusion

Distribution network optimization, which is a multi-target, multi-stage, discrete and nonlinear mixed integer-programming problem, and is also an important work in energy transportation planning content. In this paper, imperialist competitive algorithm is applied on this critical issue. Meanwhile, in order to ameliorate disadvantages of ICA such as premature convergence and low accuracy, the improved ICA algorithm is proposed based on biological evolution. In addition, colonial reform operator might make the strong colony lose resulting in the decrease of optimization accuracy. So, in the light of this deficiency, differential evolution operator is introduced which can enhance population diversity with retaining the excellent individual by utilizing information interaction between the colonies to create new colonies. And the effectiveness of this hybrid algorithm is verified by the results of distribution network structure optimization example.

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