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The Key Research and Application in Grid Planning Using Improved Genetic Algorithm

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ABSTRACT

In order to guarantee the power grid operation under the premise of reliability and stability, acquire relative economic investment and operating cost, and adaptable to all kinds of change flexibly, this article improves the traditional generic algorithm by considering the various objective function and constraint condition. The improved algorithm can search and optimize according to mechanism for the survival of the fittest. It is especially suited for the optimization solution of integer variables. The application of the algorithm proposed to fifteen nodes system of a certain city and comparative experiments show that the algorithm has fast convergence speed and optimizing result. A comparative analysis of the optimizing project using improved generic algorithm and computational result using engineering computational method in practical grid planning yield the same results, this shows that the improved algorithm has better adaptability.

KEYWORDS

Adaptability, Generic Algorithm, Grid Planning, Objective Function, Survival Of The Fittest

INTRODUCTION

Grid planning can optimize network structure, determine the direction of investment, reduce network running cost and improve the efficiency of electricity transmission, distribution and using in the whole society, which has a considerable social and economic significance (Wang & Wang, 2015; Zhang & Yu, 2011). Based on current study, the focus of grid planning is to look for an optimized network structure from the whole, which includes genetic algorithm, immune algorithm, tabu search algorithm, particle swarm optimization, ant colony algorithm, simulated annealing algorithm etc. (Liang & Zhang, 1998; Jiang, 2006; Ge, Liu, & Yu, 2004; Chen & Chen, 2005; Huan & Huang, 2008; Wang, Zhang, Shu, & Wang, 2011). Genetic algorithm can process any form of objective function and restriction, which has strong universality, internal parallelism and stronger global searching ability. Roulette selection method is adopted to choose crossover parental bodies in conventional genetic algorithm, which cannot reflect individual competitiveness and realize the survival of the fittest of the genetic algorithm. Although traditional genetic algorithm can converge to globally optimal solution theoretically, it still has the problems of premature convergence, convergence to local optimal solution and low convergence speed in practical application (He, Zhu, & Luo, 2011; Wang, Gao, & Li, 2013).

The large-scale integration of renewable energy has radically changed the basic form and operational characteristics of power system. In order to ensure reliable operation of power system

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and promote capacity of renewable energy consumption, it is of great importance to evaluate the adaptability of power system to strong volatility and uncertainty of renewable energy at the initial stage of power system planning. The paper consider that the adaptability of power system is difficult to quantify, and it analyses the characteristics and actual operation sate of the high-penetration renewable energy system and proposes an index series of grid-structure and generator-capacity adaptability bases on operation safety, efficiency, stability and supply and demand coordination. On the basis of the adaptability indexes, a grid-source coordinated transmission multi-objective planning model is put forward. Finally, the simulation of Gaver-18 bus system shows the feasibility and effectiveness of the adaptability indexes and planning model (Fan, Li, & Liu, 2018).

The distributed generation spread rapidly, the study of the distributed network planning with distributed generation is also increasing. Based on model of micro-grid system, the study established the model of substation locating and sizing and network planning respectively. The foregoing multi-objective nonlinear models are solved by using the improved particle swarm algorithm. In addition, IEEE 50-node example is used to verify that the proposed model is in favor of improving the reliability and economy of the system. And it is good for structure of network (Yang, Zhou, & Xia, 2018).

The paper proposes a method of transmission network expansion planning based on improved quantum genetic algorithm (Zhou, Lin, & Wen, 2012). On the basis of the quantum genetic algorithm, the method proposed a strategy that the quantum chromosomes are directly compared with the current best solution to determine rotating angle of the rotating rate. This improved strategy is targeted and can effectively improve the convergence function of quantum genetic algorithm in the planning for transmission network.

In this paper, it is presented that the improved genetic algorithm is a new optimization for power network planning, which is different from the traditional genetic algorithm. It processes researching and optimizing which based on the principle of survival of the fittest and can consider different kinds of objective function and constraint conditions, especially suitable for optimization problems of integer type of variable. In mathematics, power network planning is belonging to a complicated multi-decision variable and multi-constrain condition optimized problem, whose character includes integer, nonlinear, multi-objective, dynamics and uncertainty, etc. This genetic algorithm, focusing on power network planning's characters, makes full advantages of easy coding technique and evolutionary mechanism to abstract planning problems into mathematical problems, which is easy to build mathematical models. Simultaneously, it can process integer variable and continuous variable, namely integer, nonlinear variable. Specific methods will be analyzed and detailed in this paper. This algorithm does not need decomposition processing to bulk power grid planning problems and let the network operates' calculating results consider into evaluation values, thus it avoids errors of decomposition or linear and improves significantly the accuracy of analyzing problems with genetic algorithm. This improved genetic algorithm can rapidly converge to the optimized results to accomplish evolution by simple operation.

Distribution network reconfiguration (DNR) is an important measure to optimize radial power distribution systems (RDS) and a key research on automatic operation. This study presents an optimization method that combines simultaneously the reliability and the efficiency of radial power distribution systems (RDS), minimizing active energy losses, through a process of network reconfigurations. The study is based on the failure analysis on network branches, with a special concern regarding the protection system response to faults and the service restoration procedures, during the emergency state. The method analyses the RDS considering in a first step, the absence of investment, and in a second step, the possibility of placing a limited number of new tie-switches in certain branches, according to the definitions made by a decision maker. The effectiveness of the proposed methodology is demonstrated that through the analysis of a 69 bus RDS and by comparison against other reported methodologies (Vitorinoa & Jorgeb, 2013).

THE MATHEMATICAL MODEL OF POWER NETWORK PLANNING

When power network model is set up with newly-built circuit as planning variable, simulative network need to use dc power flow equation. Objective function is set up as the minimum value of the combination of the annual investment of newly-built circuit and system operating cost, which includes integer constrain of every newly-built circuit and many constraint conditions when the system operate normally and under the 'N-1' accident.N-1 accident is a situation, which has special constrain conditions, shows in form (4) and form (5).The six mathematical expressions can be adopted to describe the mathematical model of city power network planning.

This model uses newly-built circuit as planning variable, while the economy only consider the building investment of the circuit. Form (1) can be used to calculate the annual fee with the minimum annual investment of newly-built circuit:

$$\min F = \left(k_1 + k_2\right) \sum_{j \in \Omega_j} c_j x_j + k_3 \sum_{j \in \Omega_2} r_j P_j^2 \tag{1}$$

In the form: F is the annual fee (ten thousands yuan); k_1 is the capital recovery factor; k_2 is engineering fixed operating rat; k_3 is annual transmission loses cost rate; c_j is the investment of expanding one newly-built circuit in sub-circuit j (ten thousand yuan); x_j is the loop number of newly-built circuit in sub-circuit j; r_j is the resistor of sub-circuit j; P_j is the active power of sub-circuit transmission under the normal condition (MW).

Form (2) is a matrix equation, showing how to calculate load power with phase angle of electrical susceptance and power grid node voltage under normal condition:

$$B\delta + P_G = P_L \tag{2}$$

In form B shows the power grid node electrical susceptance matrix under normal condition; δ is power grid node voltage phase angle column vector under normal condition; P_G is node input power column vector; P_L is node load power column vector.

Form (3) is the constrain condition of power network under normal condition:

$$\left|A\delta\right| \leq ZP_{\max} \tag{3}$$

A is node sub-circuit incidence matrix; Z is diagonal matrix consisting of electrical susceptance value in every sub-circuit in the network; $P_{\max}$ is the maximum transmission power column vector in power network without back circuit.

Form (4) is a matrix equation, using electrical susceptance after switching circuit off and power network node voltage phase angle to solve load power:

$$B_l \delta_l + P_G = P_L, l = 1, 2, \cdots N_L \tag{4}$$

B_l is node electrical susceptance matrix of power network circuit l after switching off; δ_l is node voltage phase angel column vector in power network circuit after switching off.

Form (5) is constrain condition under the condition of power network breakdown:

$$\left|A\delta_l\right| \le C_\varepsilon Z P_{\max},\ \ l = 1,2,\cdots,N_L \tag{5}$$

C_ε is the circuit allowing overload rate column vector under circumstance of 'N-1'; $P_{\max}$ is the line number of limiting values of sub-circuit j allowing newly-built circuit.

Because active loss of circuit is the quadratic function of circuit transmission power, objective function is non-linear. Under the normal power network condition, and the constrain conditions are form (2) and (3); under the 'N-1' accident condition, the constraint conditions are form (4) and (5), of which form (2) and (4) belong to non-linear constrain. So, this model is a non-linear mixed integer planning model which has both continuous variables and discrete variables.

THE DETEERMINATION OF FITNESS FUNCTION

The fitness function formulates the minimum value sums of the annual build investment and annual system investment of planning scheme. Meanwhile, it also formulates the objectives and requirements of city power network planning. On the other side, fitness functions value is an important basis for genetic algorithm which guiding the searching direction. In the condition, which guarantees the value is not negative, requires the optimized direction of objective function should corresponding to the increased direction of fitness function value. According to this principle can construct fitness function like form (7) and form (8):

$$F = \begin{cases} F_0 - f & f \le F_0 \\ 0 & f \succ F_0 \end{cases} \tag{7}$$

$$F = (k_1 + k_2)\sum_{j\in\Omega} c_j x_j + k_3 \sum_{j\in\Omega} r_j P_j^2 + \beta W \tag{8}$$

F is fitness function; f is objective function; is penalty coefficient; W is network overload energy(MW); F_0 is given large constant.

OBJECTIVE FUNCTION

Because it needs to consider the minimum annual fee of circuit build investment cost and operation cost as objective function to do network plan, shows in form (9):

$$\min NF = \frac{i(1+i)^n}{(1+i)^n - 1}\left[X + \sum_{t=0}^{n-1} \frac{A_t}{(1+i)^t}\right] \tag{9}$$

X is the whole circuit build investment cost in this model (without considering construction years), A is the number t-year of operation cost in the model. When set level year as objective, setting the service life of electrical equipment is 25 years and discount rate i is 0.1. In the economy service life, every year operation cost is equal, so form (9) changes to:

$$\min NF = 0.11X + 1.1A \tag{10}$$

Already built circuit only need to calculate annual operation cost, while newly-built circuit not only need to calculate annual operation cost, but also need to calculate invest capital. Invest capital can be shown as form (9), setting the length of circuit j is L_j, per unit length of package investment is α_j, so the amount X_j can be shown as:

$$X_j = \alpha_j L_j \tag{11}$$

The already known circuit annual cost is shown as form (12):

$$C_j = H_j L_j \alpha_j + \frac{C_0 \gamma_j L_j \tau}{U_N^2 \lambda_j^2} P_j^2 \tag{12}$$

H_j is the percentage of maintain, depreciation cost and so on in the investment; C_0 is the price of electrical energy loss; τ is the maximum loss time of load; γ_j is the resistor of unit wire length; P_j is active power flows pass the circuit; U_N is the nominal voltage of the circuit; λ_j^2 is the square of the load power coefficient.

Basing on the forms above, form (10) can be transformed into form (13):

$$\begin{aligned} \min NF &= \sum_{j\in D1} \theta_J \left(0.11 + 1.1H_j\right) L_j \alpha_j + \sum_{j\in D2} 1.1 H_j L_j \alpha_j + \sum_{j\in D3} \frac{1.1 C_0 \tau \gamma_j L_j}{U_N^2 \lambda_j^2} P \\ &= K_1 \sum_{j\in D1} \theta_j L_j \alpha_j + K_2 \sum_{j\in D2} L_j \alpha_j + k_3 \sum_{j\in D3} \gamma_j L_j P_j^2 \end{aligned} \tag{13}$$

D_1, D_2, D_3 is the sum of newly-built, already had whole circuit; K_1, K_2, K_3 is constants; θ_j is coefficient.

After considering the constrain conditions, the model of argumentation function of minimum objective function of building cost and operation cost can be shown as form (14):

$$F = NF + C_g \sum R_p \tag{14}$$

In the form *NF* is the annual cost of the project, C_g is penalty coefficient, R_p is the constrain condition of the project.

CONSTRAIN CONDITION

Constrain conditions only consider power flow, circuit transmission capacity overload and voltage constrain condition. After setting objective function, route selection j is chosen to consider the constrain conditions below:

- Power flow constrain

$$B_t P_t = D_t \quad \left(t = 1,2,\ldots T\right) \tag{15}$$

B_t is node active injection and circuit flow active incidence matrix in time period *t*; P_t is the circuit flow active power in time period *t*; is node injection active power in time period *t*.

- Capacity constrain

$$P_{lk} \leq P_{lk,\max} \tag{16}$$

$P_{lk,\max}$ is the power flow limiting value of sub-circuit k, $k \in D_3$.

- Voltage drop constrain

$$V_{i,\min} \leq V_i \leq V_{i,\max} \tag{17}$$

$V_{i,\max}, V_{i,\min}, V_i$ are the voltage of upper, lower limit and normal operation, respectively. N_b is the number of node.

RELATIONSHIP BETWEEN OBJECTIVE FUNCTION AND CONSTRAIN CONDITION

The determination of the objective function is determined according to the various demand of the power grid planning this article from the perspective of economy(Zhao & Geng, 2011; Bao & Yin, 2002; Ye & Shan, 2000), so the objective function with investment cost and operation cost of the minimum as the target to determine, the objective function formula as shown in form (9), in the actual power grid planning, the operation of the power grid under different conditions of constraints, so we need to set constrain conditions according to the actual operation situation, delimit the constraint region, the constraint conditions for actual power grid operation in the limited area, based on the basic of the basic requirements of power grid planning, consider only flow, capacity and voltage conditions, such as form (15), (16) and (17), Based on the above considerations, the final power grid planning not only meets the actual operating conditions of the power grid, but also has the lowest operating cost, so as to truly realize the optimization of power grid planning from all aspects (Zheng & Yang, 2014; Zhao & Geng, 2011; Wang, 2003).

IMPROVED GENETIC ALGORITHM OF SOLUTION PROCESS IN POWER NETWORK PLANNING

Improved genetic algorithm must be equipped with conditions:

- define reasonable fitness function;
- set up effective objective function;
- correspond to relevant constrain condition.

Basing on this can improve the genetic algorithm (Asakura, Genji, & Yura, 2013; Binato, Pereira, & Granville, 2001; Li, Zhang, & Yan, 2011). First, generating randomly N×n samples; then dividing them into N subgroups, each subgroup contains n samples and operating each genetic algorithm independently to every subgroup. It would be better for these N genetic algorithms to have significant differences in set feature, which can produce more kinds of good models for future high-level genetic algorithm. The choices of crossover probability P_c and mutation probability P_m in the parameters of genetic algorithm is the key to affecting behaviors and characteristics of it, which can influence the astringency of algorithm directly. The bigger P_c is, the higher speed of producing new unit. However, the probability of breaking genetic pattern would be higher if P_c is too large, causing highly-adapted unit result broken soon. But if P_c is too small, the searching procedure would be slow and always stand still (Huang, Liu, & Wang, 2018; Zhang & Hu, 2011; Orfanos, Geogilakis, & Hatziargyriou, 2013). For mutation probability P_m, if P_m is too small, it would not be easy to produce new unit. If P_m is too big, then the genetic algorithm would become random search algorithm. Improved procedure must have some methods, aiming at the problem of describing power network planning as a non-linear mix integer planning (Rouhani, Hosseini, & Raofat, 2014; Lu, Huang, & Shan, 2017; Vitorinoa & Jorgeb, 2013). The detailed methods are described below:

- Original data are formed input, the data include line parameter, network topology, power output and load of each node. Genetic algorithm also need many parameters, such as the number of population N_{YC}, crossover probability P_c, mutation probability P_m, parameter k_1, k_2, the biggest iteration $T_{\max}$ and convergence criterion ξ, etc.
- Choosing binary coding to code chromosome and form into chromosome colony (Zhou & Xu, 2011; Gu, Mccalley, & Ni, 2012; Shi, Wang, & Wu, 2017; Cheng, Li, & Wang, 2017). The length of chromosome is the number of selective newly-built circuit, each chromosome represents a scheme. Then natural ordering each selective newly-built circuit according to the number of both ends node in the circuit, basing on the order can choose each selective newly-built circuit as the gene on chromosome. Using binary coding to show every gene, when gen is 0, it means the selective newly-built circuit is not chosen to join the network; When gene is 1, it means the relevant selective newly-built circuit is chosen to join this network (Bi, Yang, & Wang, 2010; Liu, Zhao, & Su, 2008).
- Before calculating DC power flow and fitness function in city power network, every chromosome should be processed connectivity test and 'N-1' accident check.
- Executing genetic manipulation. Doing select and interlace operations to every chromosome in this generation.
- Executing mutation operation. Coupled mutation should be doing in the city network planning.
- 10%-15% of the number of this chromosome colony. Those reserved fine varieties are chosen the gene with biggest values of fitness function from parent population, and these fine varieties will inherit to next generation directly, then it becomes a new generation of chromosome after random choose, interlace and mutation operations.
- Constringent judgments. Judging whether constringing or not can base on given biggest number of genetic generation, also can base on the frequency of occurrence of optimal scheme. At the same time, convergence criterion can also be judged according to range of variation in fitness function average values of adjacent two generations. If convergence, doing operation (8) directly; if not, convergence then turning to (3).
- Output the calculation result of genetic algorithm in programming and network optimization. Output the chromosome of several groups with calculated the biggest values of fitness function, restoring into the realistic planning scheme of city power network planning. And output the

annual investment of final scheme and operating cost and other economy indexes (Wang, 2012; Ding & Xu, 2007).

The flowchart of random topological tree type of searching generates the group of original solutions is described as Figure 1.

In Figure 1, n is the number of chromosome, d is the number of node, $\alpha_j(j = 1 - n)$ is the j original chromosome generated, whose every dimension gene represents the number of stringing in the corresponding corridor. The working step of the whole flow chart is decomposed as below:

- initialize the lines waited to be selected, which is $j = 0$
- judge if j is bigger than n. If so, then end the procedure; if not, then go to next step.
- Initialize the chromosome α_j and node searching sign $F(i)$ to zero.
- randomly search a start node $F(k) = 1$
- record the set of planning lines waited to be selected as C_n, and run the initialization.
- get all the signs among the beginning and the end and find out the corridor whose search sign has only one zero, then put it into C_n.
- randomly select an expanding route in C_n; judge the selected corridor, if C_n is zero, then repeat step 2; if not, then go to next step.
- reset the search sign of those nodes whose search sign is zero in the either ends of selected corridor nodes as 1; repeat the searching process until all the corridor set C_n waited to be selected that can be found is null set.

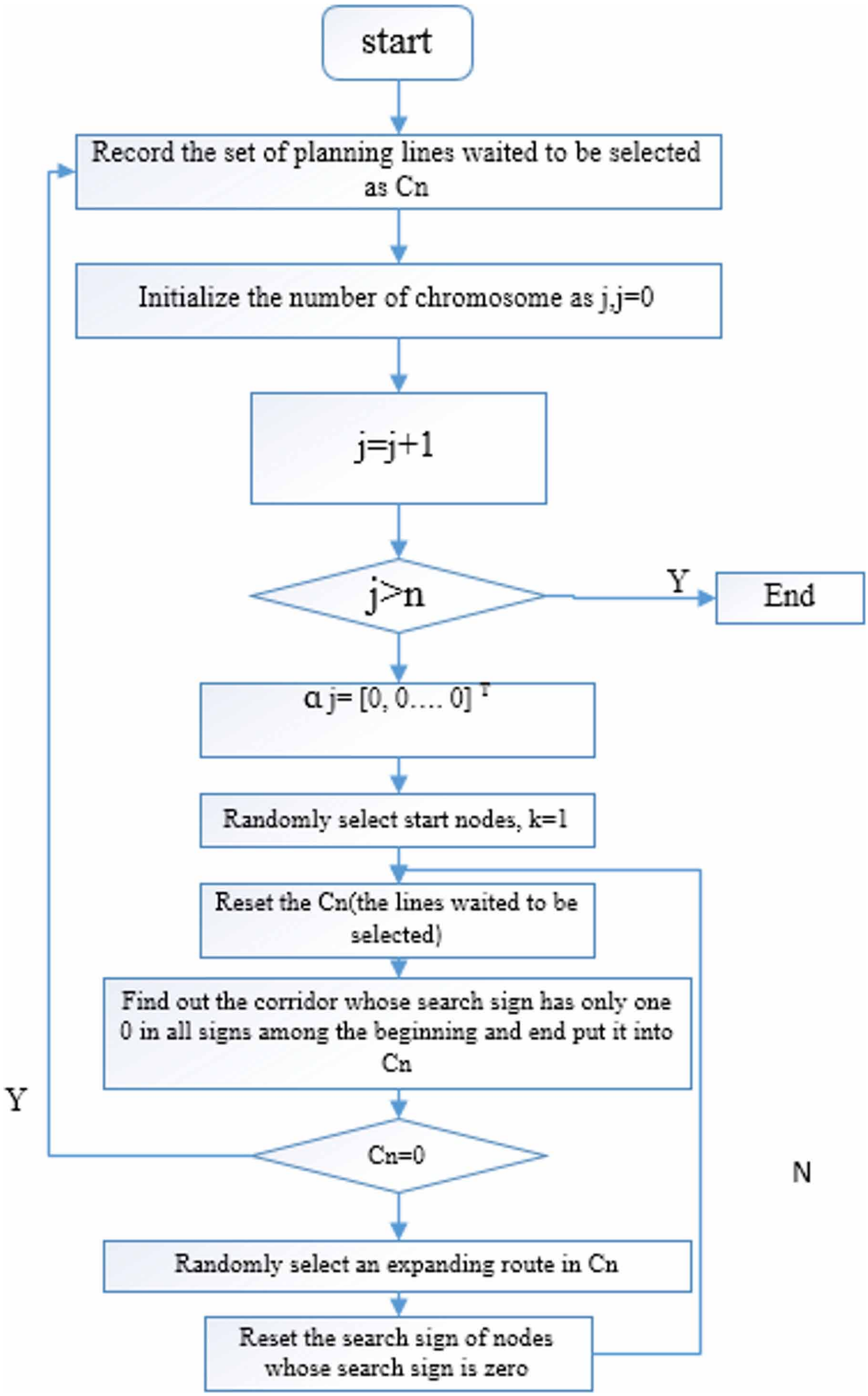
The improved genetic algorithm, whose crossover probability and mutation probability can automatically change with fitness, in this paper is pointing at the disadvantages of this genetic algorithm. This method can choose the optimal crossover probability and mutation probability of a certain solution. The self-adapted genetic algorithm can not only maintain the diversity of groups, but also ensure convergence of genetic algorithm. The self-adaption should include two level of self-adaptions. One is the self-adapted adjustment of crossover probability and mutation probability, the other is the self-adapted adjustment of cross and mutant operator. From the perspective of the whole evolution procedure of group, the sum of crossover probability and mutation probability should proceed self-adapted change based on the extent of group diversity. It will rise accordingly when the group diversity declines and has the trend to stick in locally optimal solution. It will drops when group diverge in solution space and group diversity is higher, but it is among the different individuality in a certain group (Zeng, Liu, & Li, 2015; Wu, Sun, & Qiao, 2017; Liu, Chen, & Liu, 2015; Fang, Yang, & Ma, 2013). The improved genetic algorithm has the following significant characters compared with traditional basic genetic algorithm:

- It has strong self-adjust function, which can increase the ability of local searching.
- It has immune memory function, which can increase searching speed, avoid vibration and ensure converging to the globally optimal solution quickly.
- It has the diversity maintaining function of antibody, which can improve the globally searching ability, avoid immature convergence and reach the best answer.

CASE ANALYSIS

In order to testify whether the improved genetic algorithm can get the optimized power network planning expand map through multiple calculation based on satisfying N-1 safety, the paper will use

Figure 1. The searching flowchart of random topology tree



the power network in X county, Fuzhou City, Jiangxi Province, as test case. Figure 2 represents the network nodes and routes waited to be selected based on the actual power network geographic connection. The system has 11 nodes, 9 routes now, and it the future it will grow to 15 nodes. In this case, there are 18 corridors existing newly-added routes, which means the length of chromosome is 18. Set the region of chromosome $n = 100$, crossover probability $P_c = 0.5$, mutation probability $P_m = 0.5$, threshold value $C_0 = 1.3 \times 10^5$. It is assumed that the construction expense per unit length is the same in different routes, then the expense can be replaced by the length of routes in the calculation (Lu & Huang, 2010; Yang, Zhao, & Yang, 2004; Ding, Wang, & Zhang, 2016; Shu, Sun, & Si, 2002).

The change curve of maximum fitness and average fitness of the chromosome region in iterative process. From the change curve of average fitness, it can be seen that the improved algorithm curve change gently, which means the improved algorithm has strong self-adjustment function, and its searching ability also improves. From the change curve of maximum fitness, it can be seen that the improve curve does not vibrate and converges quickly, which means that the improved algorithm can accelerate converging speed, avoid vibration and ensure converging to the globally optimal solution soon (Du & Dong, 2018; Chen, Huang, & Ye, 2017; Liu, Yu, & Wang, 2018; Zhang, Hu, & Zhou, 2016). It can be found from the result that the constant rise of maximum adapted function value in the iteration process is due to the reason that it remains the best breed. Figures 3 and 4 show the change curve of average and maximal fitness.

It can be found, from the curve of convergence process in Figure 5, that the calculation process has strong vibration before the genetic algorithm is improved. And because of the vibration, it would take a long time to get the optimal, and the result may deviate from the actual value. The improved genetic algorithm can stop vibrating quickly, converge fast and reach a result similar to the actual value very soon. The improved genetic algorithm can converge to optimal quickly, while traditional genetic algorithm will cause vibration during calculation and finally reach locally optimal solution. Its curve of convergence process is shown in Figure 5.

Figure 2. The diagram of network path with eleven nodes

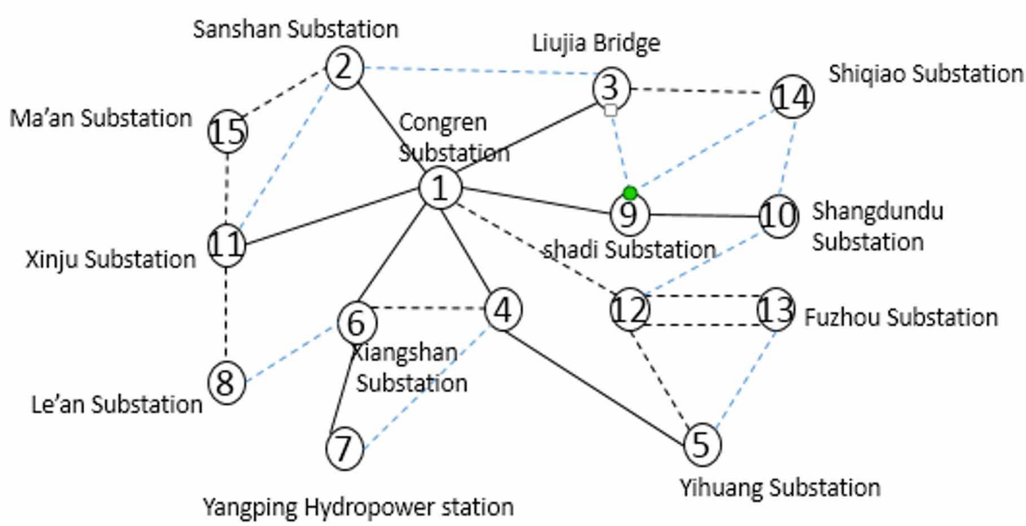
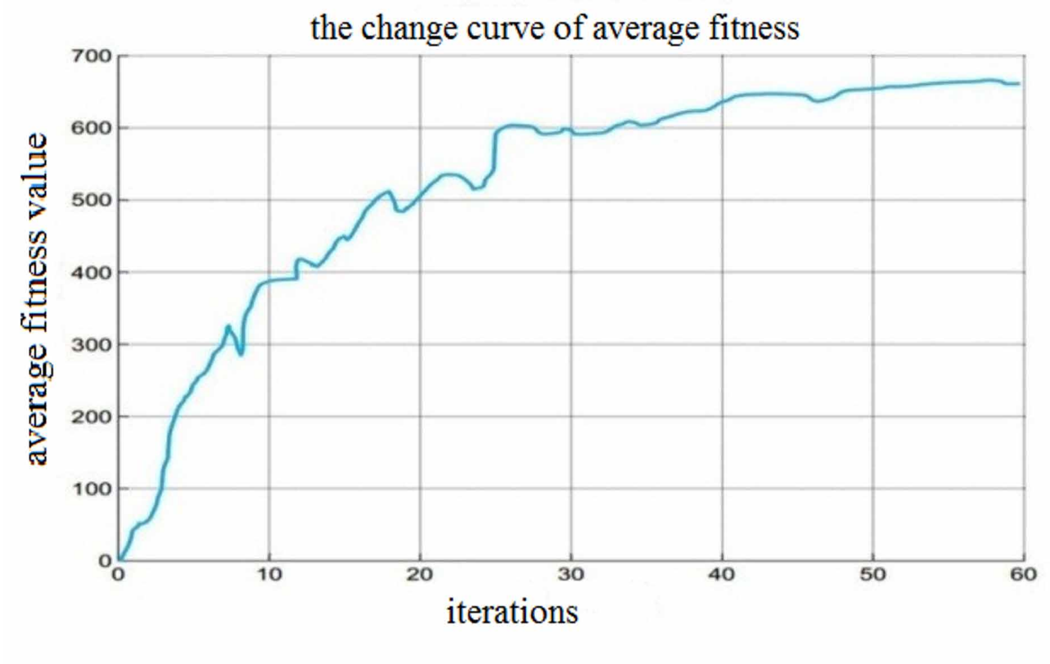


Figure 3. The change curve of average fitness



Because of the reservation of best breed (Liu, Cai, & Zhang, 2015), the maximum fitness function value keeps increasing in the iteration process. The average fitness level of group also shows a rising trend, but it declines partially, and the reason is that genetic algorithm may produce some poor packages when it expands its solution room. These packages will evolve or eliminate quickly during the genetic process. The optimized scheme vibrated, after applying the improved genetic algorithm program into the system, deletes 9 routes waited to be selected and remains 9 routes waited to be selected. These routes and the original routes are combined to form the new power network in x county, Fuzhou City. It is shown in Figure 6.

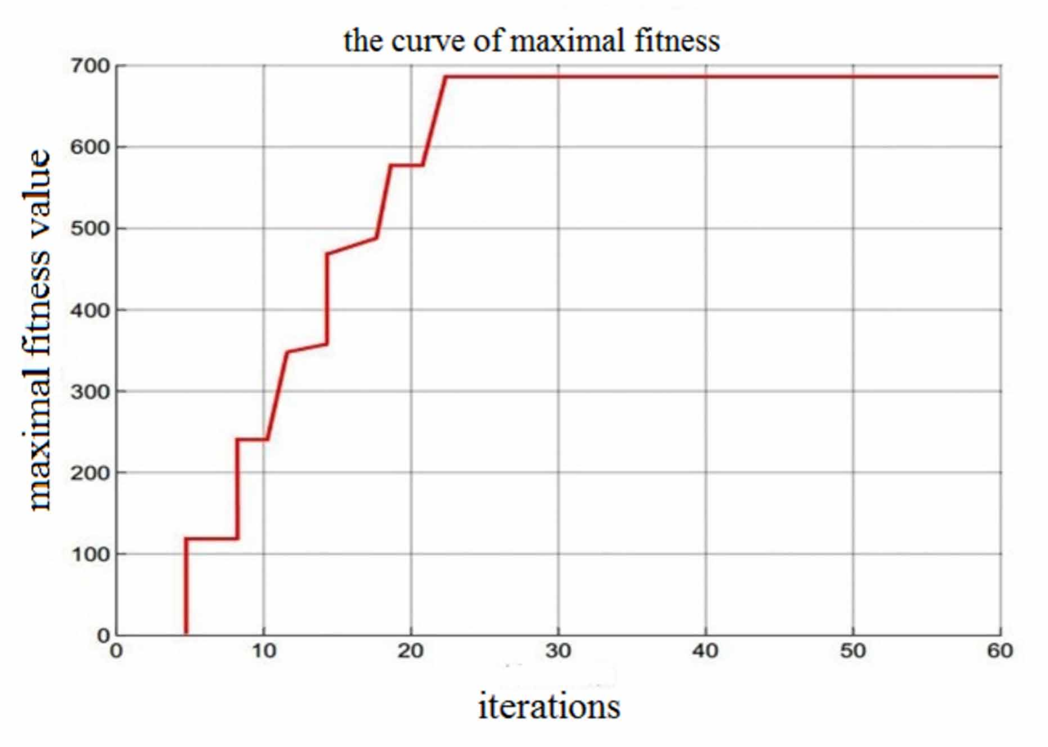
From the eventual network structure calculation, the optimized scheme is the same with the result from engineering reduction method, also known as gradually-decreasing method, used in the actual power network planning. The method can not only reach the optimal of planning theoretically, but also be applied in the actual power network planning.

CONCLUSION

This paper proposes a new genetic algorithm by considering the various objective function and constraint condition, which can search and optimize according to mechanism for the survival of the fittest. and then, the study case operates an experiment by using the improved genetic algorithm, the result shows that the new algorithm has faster convergence speed and optimalizing result. Finally, the new genetic algorithm can adapt to practical grid planning yield well, because comparative analysis of the optimalizing project using improved generic algorithm and computational result using engineering computational method in practical grid planning yield the same result, this give the information that the improved algorithm has better adaptability.

Genetic algorithm is an artificial intelligence method and also structured algorithm, especially suiting for optimization solution of integer variable, which is a new approach to solve the problem of

Figure 4. The change curve of maximal fitness



optimizing power transmission network. Basing on city power network planning model of improved genetic algorithm, it not only considers satisfying the demand of power load and safe operation constrain conditions, but also considers 'N-1' accident detection, which makes the planning scheme more reasonable. Using improved genetic algorithm to solve the problem of optimizing power transmission network can solve the problem of only reaching locally optimal solution instead of globally optimal solution. Through practical plan verification, improved genetic algorithm is used to plan power network in this paper, and the compiled program is feasible and has better effect.

Figure 5. The curve of convergence process

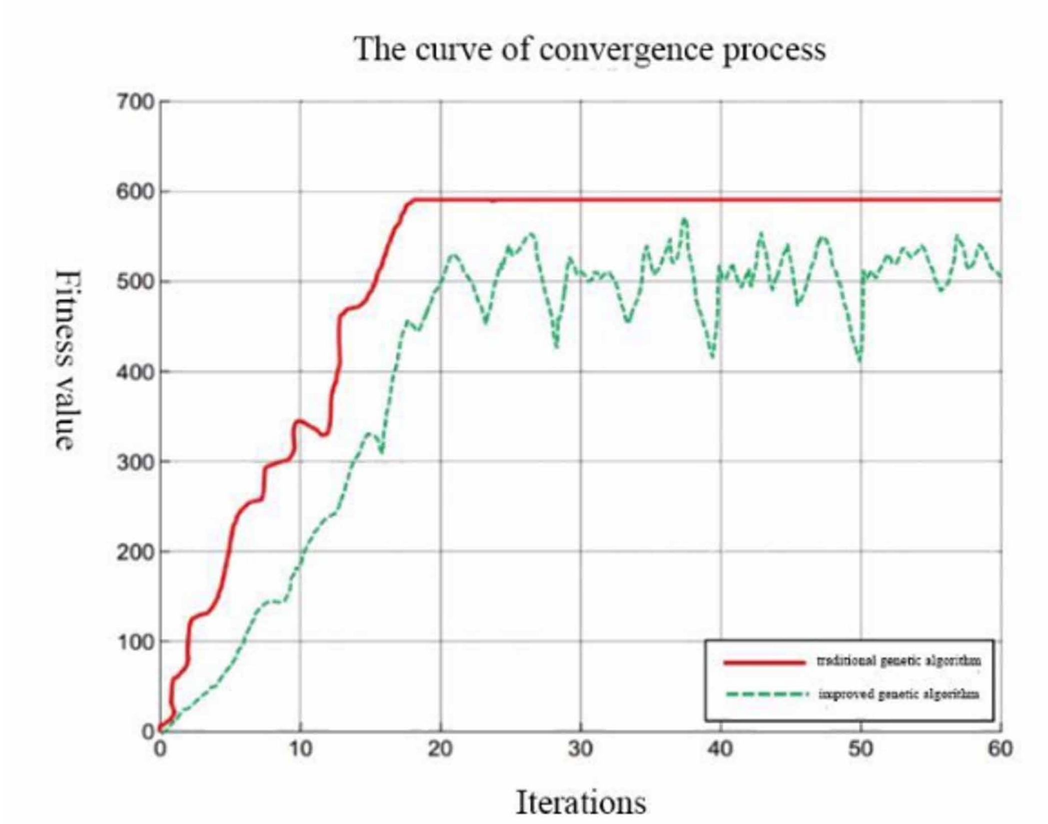
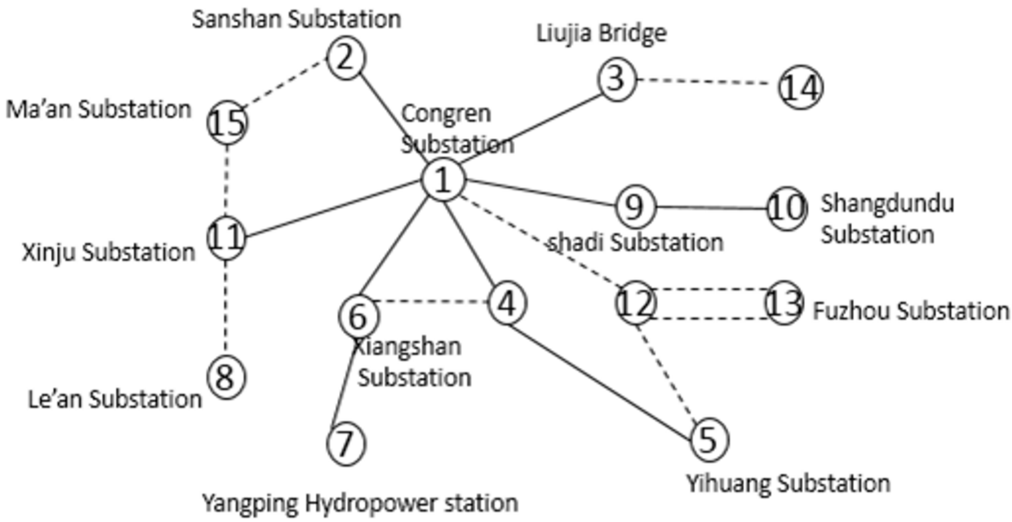


Figure 6. The planning map of fifteen nodes system under the improved genetic algorithm



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