ISSN (Print): 2331-9062
ISSN (Online): 2331-9070

Research on method of total transfer capacity based on immune genetic algorithm

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Keywords: power system, immune genetic algorithm, total transfer capacity (TTC)

Abstract: In this paper the sum of the load active power incremental has been used for the objective function to create a mathematical model. The inequality constraints problems of generator group like power constraints and node voltage constraints, that are transformed to no-constraint conditions by introducing the penalty function. The optimization methods are programmed by MATLAB, and each module of the program are described; Basic process based on immune genetic algorithm to calculate the total transfer capacity (TTC) of power system is given. In order to verify the correctness of the model and algorithm proposed in this paper, IEEE-30-node system is taken as testing system. By the calculation of each line TTC of a grid line, the practicality of the proposed method has been achieved greatly.

Introduction

In recent years, the power generation capacity has been increasing at the rate of 10% per year in China. So the electrical shortage phenomena have been reduced largely. The total transfer capacity (TTC) problems have been solved by a large number of domestic and foreign experts and scholars with a variety of different ways. Disbranch distributing factor method was used for TTC as well as power transmission and generator outage distributing factor methods [1]. The nonlinear system and reactive power voltage were considered by continuation power flow method, which was superior to DC power flow [2]. The continuous quadratic programming method was adopted to figure out TTC [3]. The optimal power flow and the static voltage stability restraint were both requested for the computation [4]. The maximum economic benefit was joined into the calculating conditions [5]. The Newton's and the internal penalty function method are combined for the calculation of the probability of the available transfer capability [6]. In this paper, the immune genetic algorithm is applied to the solution of total transfer capacity of power system.

Model for total transfer capacity based on immune genetic algorithm

Equality constraints

$$\begin{cases} P_{Gi} - P_{Di} - V_i \sum_{j=1}^{n} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) = 0 \\ Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{n} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right) = 0 \end{cases} \tag{1}$$

where P_{Gi}, Q_{Gi} are the active and reactive power of the generator i. P_{Di} , Q_{Di} are the load active and reactive power of the node i. n is the total number of nodes. V_i, θ_i are the voltage amplitude and phase of the node i. $\theta_{ij} = \theta_i - \theta_j$, $G_{ij} + j\ B_{ij}$ are the corresponding elements of system nodal admittance matrix.

Inequality constraints. The voltage amplitude of each node must be maintained around the rated voltage. Thus the safe and steady operation of power system and power quality can be guaranteed. The constraint of power grid operation is composed of the active and reactive output constraints of generator. Here, the active power output of generator P_{Gi} and line capacity P_{ij} are selected as the control variables. And the node voltage V_i and reactive power output of generator Q_{Gi} are selected as the state variables [7-8].

The power constraints of generator sets:

$$\begin{cases} P_{Gi}^{*} \le P_{Gi} \le P_{Gi}^{\max} \\ Q_{Gi}^{*} \le Q_{Gi} \le Q_{Gi}^{\max} \end{cases},\quad i \in S_G \tag{2}$$

The constraint of node voltage:

$$V_i^{\min} \le V_i \le V_i^{\max}, i \in S_n \tag{3}$$

The constraint of line capacity:

$$P_{ij}^{\min} \le P_{ij} \le P_{ij}^{\max}, i, j \in S_n \tag{4}$$

where S_n is the muster of all the nodes. S_G is the muster of nodes in the power transmission zone. The subscripts $*$, *min* and *ma*x are respectively the per-unit value of basic power flow, the minimum and maximum of the variable.

Calculation for total transfer capacity based on immune genetic algorithm

The module for power flow. The P-Q decomposition was chosen as the key method for solving the TTC based on immune genetic algorithm in this paper. During the flow calculation, if the convergence can`t be caught within the set iterations, then the individual fitness value is taken as 0, that is equivalent to the objective function being taken as a very large value. When happened the pathological network, the P-Q decomposition method can`t converge, and the individual on behalf of that network can`t be a final solution [9-10].

Here for the P-Q decomposition mathematical equations.

Iterative correction equations are:

$$\begin{bmatrix} \Delta P_1/V_1 \\ \vdots \\ \Delta P_n/V_n \end{bmatrix} = \begin{bmatrix} B_{11} & \cdots & B_{1n} \\ \vdots & & \vdots \\ B_{n1} & \cdots & B_{nn} \end{bmatrix} \begin{bmatrix} V_1\Delta\theta_1 \\ \vdots \\ V_n\Delta\theta_n \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} \Delta Q_1/V_1 \\ \vdots \\ \Delta Q_m/V_m \end{bmatrix} = \begin{bmatrix} B_{11} & \cdots & B_{1m} \\ \vdots & & \vdots \\ B_{m1} & \cdots & B_{mm} \end{bmatrix} \begin{bmatrix} V_1 \\ \vdots \\ V_m \end{bmatrix} \tag{6}$$

The above equation can be abbreviated as:

$$\Delta P/V = -B^{'}V\Delta\theta \tag{7}$$

$$\Delta Q/V = -B^{''}\Delta V \tag{8}$$

where $B^{'}$ and $B^{''}$ are symmetric real matrix, which are remained unchanged in the iterative process.

The equations for every node ΔP_i , ΔQ_i are:

$$\Delta P_i = P_i - V_i \sum_{j=1}^{n} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) \tag{9}$$

$$\Delta Q_i = Q_i - V_i \sum_{j=1}^{n} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right) \tag{10}$$

1. Enter the original data. The input data are nodes and branches in the design of this program.
2. Form the admittance matrix. The nodes are processed by optimized sorting and the indexed list of sparse storage of non-diagonal elements for the admittance matrix is constructed. Therefore, the coefficient matrix has been obtained and came to the admittance matrix.
3. Form the factor table. It comes from the triangular factorization of B' and B''.
4. Set the initial voltage. PV and PQ nodes need to set the initial voltage.
5. Determine whether to meet the convergence condition. $|\Delta P/V \le \varepsilon|$ and $|\Delta Q/V \le \varepsilon|$ are both the judgments in this paper.

The basic flow of algorithm. The TTC calculation procedures based on immune genetic algorithm are as follow:

1. Input the initial data

The input data main include generator parameters, load parameters, lines, etc.al. In this paper, the data need to verify are basic node data, the upper and lower limits of node voltages, actual operating data of generator and the allowed output limits of generator.

2. Calculate the basic power flow

The basic power flow has been solved according to the original data, while each branch node variable under the basic flow is obtained. Thus, the line active and reactive power, each node voltage amplitude and phase angle can be verified.

3. Generate the initial antibodies

If it`s the primary response, then all the initial antibodies are. If not, then half the initial antibodies are generated randomly in the solution space, the others are from the memory unit.

4. Calculate the antibody fitness

The objective function is taken as the fitness function in the paper, so the affinity values of antibody are drawn by the calculation results of the power flow. Since this objective function is used for seeking the maximum problem, so the approximation of antibodies and optimal solution is proportional to the value of the objective function.

5. Genetic operation

In accordance with the proposed genetic algorithm, the following are went on: cloning, crossover and mutation.

6. Determine whether the antibody diversity meet the requirements

By calculating the affinity A and information entropy H we can determine whether the diversity of antibodies meets the requirements. If met then proceed to step 7, if not return to step 5.

7. Update based on the aggregate fitness

The antibodies fitness and concentration are evaluated comprehensively by calculating the aggregate fitness. The antibodies of excellent fitness also can suppress much high concentrations of antibodies.

8. Update the memory cell

The antibodies are arranged according to the size of fitness value, where the lower fitness antibodies in the memory set are replaced by the top antibodies. Such memory cells always contain the higher fitness antibodies. But their solution distribution is relatively good and increase the convergence speed greatly.

9. Determine whether the termination condition is satisfied

Firstly, the optimal solution should be searched within the limits of certain genetic generation. If the solutions searched is still optimal after many iterations, then jump out of the evolution. If the optimal solution changes, then the continue search work should be requested until meeting the constant optimal solution after many iterations. Secondly, if the optimal solution hasn`t be found after the maximum iterations, then the current suboptimal solution should be output.

Case study

The verification system is IEEE -30 node system. The system has 6 generators and 41 lines. It can be divided into 3 zones, as follows Fig. 1.

The Bender decomposition, traditional genetic algorithm and immune genetic algorithm are used to calculate the TTC between every zones. The final result is taken from the average value of each thirtieth separately. The results are shown in Table 1:

Shown in Table 1, the calculation results of traditional genetic and immune genetic algorithm based on the group optimization search is superior to those of Bender decomposition used alone. The traditional genetic algorithm is easy to fall into local optimal solution, while the result of immune genetic algorithm is more accurate than genetic algorithm. We can also get from Table 2, the computing time on immune genetic algorithm takes much shorter.

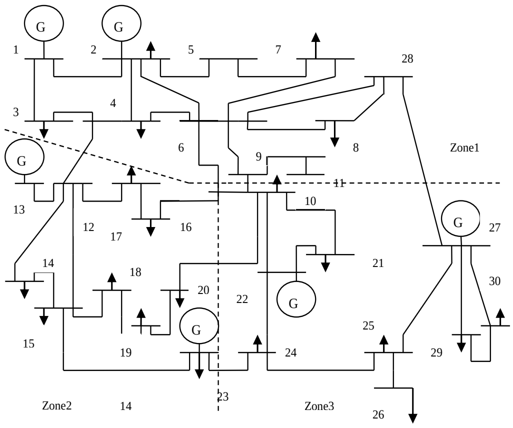

Fig. 1 IEEE-30-node system

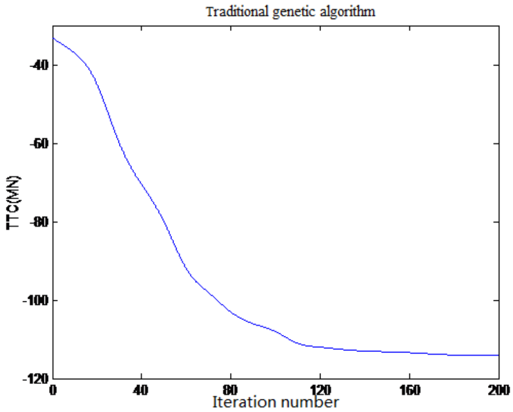

Fig.2 TTC convergence curve of genetic algorithm

Table 1 total transfer capacity calculations

zone	TTC /MW		
	Genetic algorithm	Immune genetic algorithm	Bender decomposition
1-2	113.67	116.98	111.32
2-1	55.58	59.38	35.15
1-3	106.44	110.54	108.31
3-1	90.33	97.02	58.03
2-3	46.09	49.03	37.2
3-2	80.59	85.23	58.34

Table 2 Zone 1 Zone 2 to the TTC and computing time averages

Algorithm	The average of TTC /MW	Computing time /s
Immune algorithm	82.06	498.55
Immune genetic algorithm	86.36	70.10

As shown in Figure 2, when the traditional genetic algorithm is considering, the curve of generations from 110 to 125, 129 to 148, 145 to 155 and 155 to 173 are showing a similar level of situation. Therefore, after a considerable number of iterations, the traditional genetic algorithm can be avoided into local optimal value and obtained the global optimal value. However, due to the slow calculating speed of traditional genetic algorithm, the curve slope in the initial search is very small. The TTC in the first 20 generations can reach 45 (MW). And it can`t reach 100 (MW) until passing 90 generations.

When we are going to calculate the transfer data, in order to improving the accuracy and speed of calculation process further, the immune genetic algorithm has been proposed by author for TTC. Based on the combination of immune theory and genetic algorithm, the population are initialized by immune theory and the capacity of conquering the limit value is superior to general algorithm. The curve in Fig. 3 is a better convergence curve of the modified genetic algorithm. We can find the improved initial population algorithm achieves the desired effect by the positions of initial points.

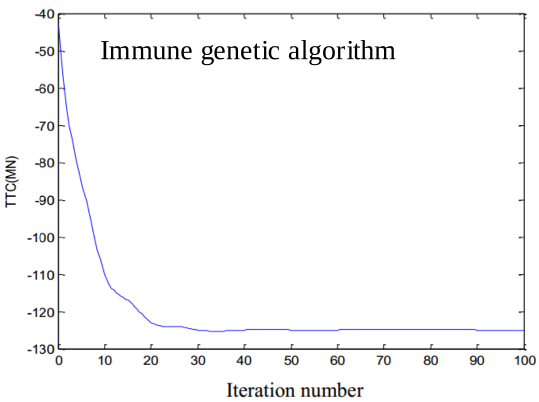

Fig.3 TTC convergence curve of immune genetic algorithm

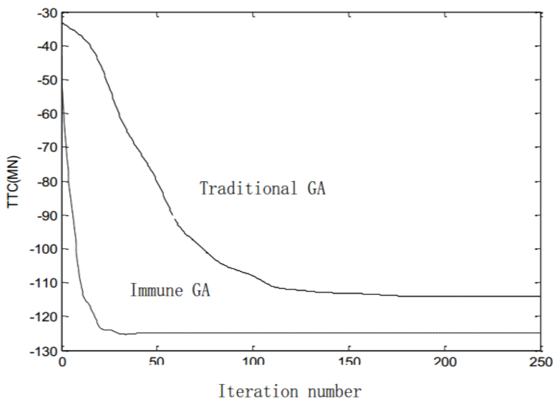

Fig.4 Convergence curve comparison chart of two algorithms

The immune genetic algorithm has characteristics of learning, memory, and adaptive capacity, so the population quality can be optimized significantly and the convergence speed is also improved. As shown in Fig. 4, the convergence speed of immune genetic algorithm has been faster than the traditional algorithm since the beginning of the process. By comparing the two curves can be found the immune algorithm has stronger ability to overcome the local minima.

As shown in Figure 2, the convergence curve of the traditional genetic algorithm from 110 to 125, 129 to 148, 145 to 155 and 155 to 173 are showing slight downward trend, which is similar to level situation. As a result, the search stagnation come out on the four stages of 15, 19, 10 and 18 generations. The rapidity and practicability based on the traditional genetic algorithm are affected greatly. However, the immune genetic algorithm has the stronger search capacity and more rapid convergence speed. The convergence curve of immune genetic algorithm appears continual small-scale fluctuations in the first 12 generations to the 35th. After several generations can the curve still escape from local optima and quickly move to the area close to the optimal solution, so that the immune genetic algorithm has very strong ability to overcome local minima. It does not appear the phenomenon of long-term search stagnation. In a sum, compared with traditional genetic algorithm, the immune genetic algorithm has the advantages of more accurate calculations, shorter iterations and good prospects in the application of the total transfer capacity.

5 Conclusion

In this paper, the total transfer capacity state of the power system has been introduced, which contains the TTC theory and its basic calculating methods. The genetic algorithm and immune genetic algorithm are both adopted and compared to calculate the TTC about IEEE-30-node system and a practical power grid. Overall, the following conclusions we can get:

1. The objective function is the maximum load increment and the penalty function is used for the state variables from constraint to non-constraint. So a mathematical model of the total transfer capacity has been established. Meanwhile, the immune genetic algorithm is applied to TTC.

2. The total transfer capacity issue is an important factor on the security and economic operation of the power system. Comparing with the general algorithm for TTC, lots of existed problems can be solved by the immune genetic algorithm excellently, such as long computing time, poor accuracy and so on. The application of immune genetic algorithm has developed a broad space for the total transfer capacity.

Acknowledgments

This work was supported by the Natural Science Foundation of Heilongjiang Province (E201260).

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