Application of Multi-agent and Genetic Algorithm in Network Reconfiguration of Ship Power System

Zheng Wang[1,2], Li Xia[1], Yongji Wang[2]

[1]College of Electrical and Information Engineering, Naval University of Engineering,
Wuhan, 430033, P.R. China

[2]Department of Control Science and Engineering, Huazhong University of Science and Technology,
Wuhan, 430074, P.R. China, phone: 86-13886038762
marchy618@163.com

Abstract—**Network reconfiguration of ship power system may be abstracted as a typical non-linear discrete optimization problem featuring multi-target and multi-constraint. According to the characteristics of ship power system, simplified network model and reconfiguration mathematical model of ship power system are established. A multi-agent and genetic algorithm is presented. The results of simulation show that multi-agent and genetic algorithm can reconfigure shipboard power system efficiently.**

Index Terms—**Multi-agent and genetic algorithm (MAGA), network reconfiguration, ship power system (SPS).**

I. INTRODUCTION

With the development of industrialization, the generation capacity and scale of ship power system (SPS) are keeping on enlarging, the way of the system works and its protection become more complex. It is important to reconfigure the system as fast as possible when faults occur. Because of many differences between the ship and the land power system, the network reconfiguration of land power system which bases on how to lower the network loss of system does not work well on the ship. Network reconfiguration of SPS is to be researched.

Network reconfiguration of SPS is a non-linear combinatorial optimization problem. Sanjeev K used improved algorithm to reconfigure, but it cannot restore the loads as much as possible [1]; Nagata T used multi-agent technique to reconfigure, but it also cannot make the result most optimal [2].

Based on analyzing many methods in existence and according to the characteristics of SPS, a multi-agent and genetic algorithm (MAGA) is presented to solve the SPS network reconfiguration problem. Theoretical analysis and simulation results show that: MAGA can reconfigure the network of SPS better.

II. SIMPLIFIED NETWORK MODEL AND RECONFIGURATION MATHEMATICAL MODEL OF SPS

A. Simplified Network Model

Large SPS is usually made up of several power stations, every station is composed by several generators. A ring or ladder power system is built by loop switches among buses and main switchboards, the loads get power from buses or distribution switchboards. Important loads can get power through normal routes or alternative ones by automatic or manual switches. The loads can be graded into three ranks, of which Rank 1 and Rank 2 loads usually have two power supply routes, the normal one and the alternative.

The research of this paper is based on the typical three-power-station ladder shipboard power system, its simplified network model is given in Fig. 1.
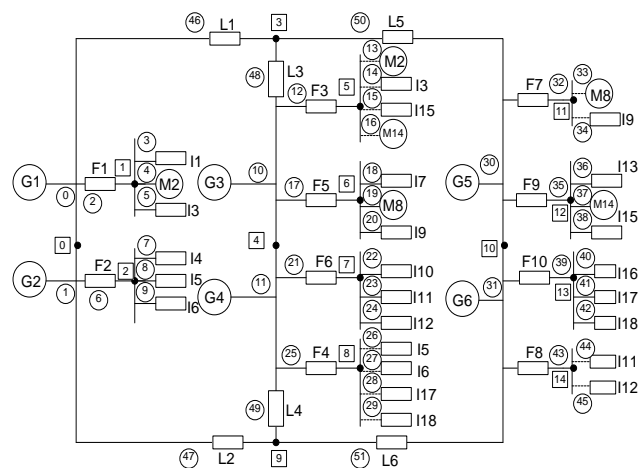

Fig. 1. Ladder ship power system.

The system is made up of 6 generators G, 18 loads (including static loads I and motors M), 10 feeders F and 6 jumper wires L. The switchboards and jumper wires divide the whole system into three power stations. The alternative routes of important loads are connected by dashed lines.

According to the graph theory, in Fig. 1 the electrical devices connection wires are abstracted to be branches, while the connection points between the devices to be nodes. So

there are totally 15 nodes and 51 branches in the whole system.

B. Network Reconfiguration Mathematical Model

SPS requires the maximum load restore and supply power for important loads (Rank 1 and Rank 2) in priority after network reconfiguration, and make the operation times of switches as few as possible. So the object function can be expressed as following

$$\max F(X) = \sum_{i=1}^{n_1} \lambda_1 L_{g1i} + \sum_{i=1}^{n_2} \lambda_2 L_{g2i} + \sum_{i=1}^{n_3} \lambda_3 L_{g3i} - \eta S_x, \qquad (1)$$

where L_{g1i}, L_{g2i}, $L_{g3}i$ are the 3 grade loads, n_1, n_2、n_3 are the total number of each grade loads, λ_1、λ_2、λ_3 are the weight coefficients of each grade loads, S_x is the total operation times of switches, η is the punitive weight coefficient. We can get the maximum important load restore and the least operation times of switches by choosing the proper weight coefficients. For example, λ_1=1 for Rank 1 loads, λ_2=0.1 for Rank 2 loads, λ_3=0.01 for Rank 3 load.

The network reconfiguration of SPS should be constrained as following:
1) The connectivity constraints and radiate limit of the system. There is only one close normal or alternative route of power supply for the important load which can be restored;
2) The limit of system capacity. It indicates that when the load to be restored connects with the bus, branches or generators should not overload. If it happens, unload should be considered.

III. MULTI-AGENT AND GENETIC ALGORITHM (MAGA)

A. Application of Multi-agent in Network Reconfiguration of SPS

Considering of regional autonomy of multi-agent [3], the set of non-switch devices controlled by switch devices on the same regional feeder can be regarded as one agent. Therefore, the SPS network may be divided into some separate power supply agents.
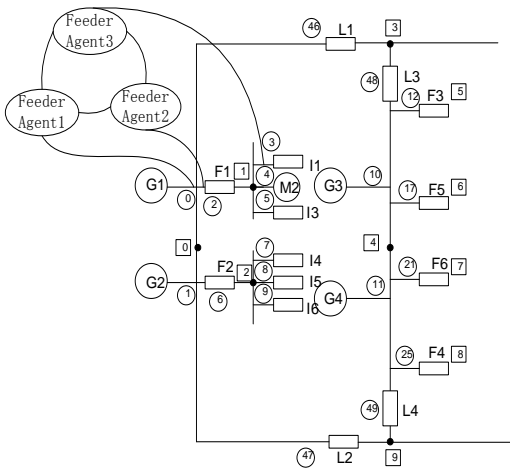

Fig. 2. Regional feeder multi-agent network model of SPS.

The SPS network shown in Fig. 1 can be divided into several feeder units. Each one is abstracted as a regional feeder agent. A regional feeder multi-agent network model is proposed, shown in Fig. 2.

The regional feeder agents are intelligent, they can judge and make decision autonomous. According to the operation condition of SPS, the regional feeder agents can communicate with adjacent agents so as to guarantee stable operation of SPS.

B. MAGA

Genetic algorithm (GA) is an iterative adaptive random searching method based on natural gene selection mechanism, it has better robust and search ability. Discrete states of switches and circuits are expressed as a series of binary codes to calculate and process easily [4].

Different from traditional GA, MAGA is based on improved feedback theory. The improved feedback evolves GA in specific direction in sample selection, gene covering position, crossover, mutation, and so on. MAGA makes regional feeder agents as individual codes, 0 and 1 represent states of power supply, 0 for no power, 1 for power supply. Based on agents' autonomy and activity, individuals in MAGA can communicate with others about genetic information. Especially in the process of crossover, mutation and optimal searching, regional feeder agent can change the individual codes in the smaller extension according to the object function, so as to change the network topology in the smaller extension and supply power in the optimal way.

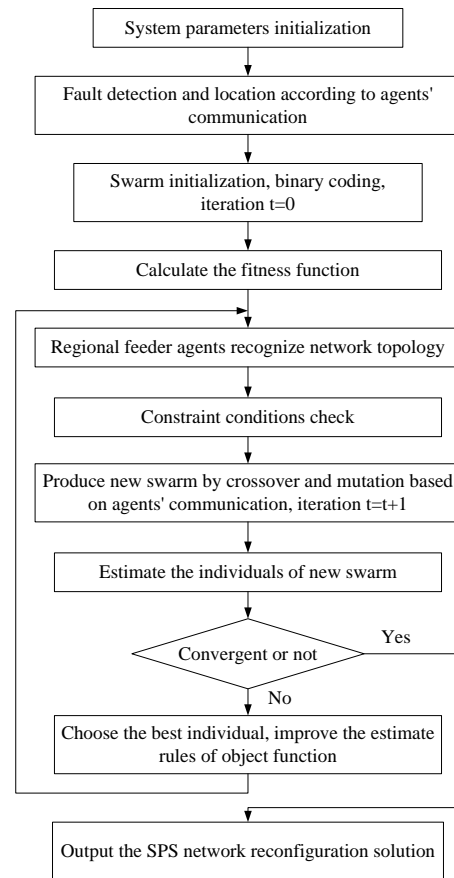The flow chart of SPS network reconfiguration based on MAGA is shown in Fig. 3.

Fig. 3. The flow chart of SPS network reconfiguration based on MAGA.

In the algorithm, formula (2), (3), (4) are to calculate individual selection probability, crossover probability, mutation probability.

Individual selection probability

$$P_s(x_i) = \alpha \frac{f(x_i)}{\sum_{i=1}^{N} f(x_i)} + (1-\alpha)\frac{1}{N} e^{\frac{s_i}{\beta}}. \tag{2}$$

Crossover probability:

$$P_r = \begin{cases} P_{r\max} * 2^{-\frac{t}{Gen}}, & if\ (P_{r\max} * 2^{-\frac{t}{Gen}} > P_{r\min}), \\ P_{r\min} & otherwise. \end{cases} \tag{3}$$

Mutation probability:

$$P_u = \begin{cases} \exp(-\frac{f_{\max}-f}{f})\frac{1}{1+t/Gen}P_{u\max}, \\ if\ (\exp(-\frac{f_{\max}-f}{f})\frac{1}{1+t/Gen}P_{u\max} > P_{u\min}), \\ P_{u\min}, \quad otherwise, \end{cases} \tag{4}$$

where α, β are constant adjustive factors, $0 \le \alpha \le 1, 0 \le \beta \le 1$; x_i is the individual; $f(x_i)$ is the object function; s_i is the concentration of individuals; $f_{\max}$ is the maximum fitness value; f is the fitness value of mutative individual; t is the iterative generation; $P_{r\max}$, $P_{r\min}$ are the maximum and minimum crossover probability; $P_{u\max}$, $P_{u\min}$ are the maximum and minimum mutation probability; Gen is the maximum iterative times.

IV. SIMULATION RESULTS

For the SPS network model in Fig. 1, according to the different complexity degrees of faults, there are two cases to reconfigure using MAGA.

In the simulation, the number of individuals is 150, the maximum iterative generation is 200, the initial value of crossover probability is 0.8 (the maximum is 0.9, the minimum is 0.7), the initial value of mutation probability is 0.1 (the maximum is 0.1, the minimum is 0.07).

The individual codes after initialization are:
1111111111110000111111111110000111001111111111001111
1

A. Example 1

Assuming a fault occurs in regional feeder agent 9, the individual codes with fault are:
1111111110111000011111111110000111001111111111001111
1

MAGA is used to carry out network reconfiguration, simulation results are as following:
1) Regional feeder agent 27: the initial value is 0, the ultimate value is 1.
2) Fitness value is 5.63265, switch operation times (SOT) is 1.

The changes of fitness and SOT are shown in Fig. 4.

Simulation results show that regional feeder agent 9 communicates with adjacent agent when fault occurs, and choose the alternative route (regional feeder agent 27) to supply power. MAGA gets the best fitness value 5.63265 from the 50th iteration, but only until the 82nd iteration it gets

the minimum SOT: 1. So we get the best network reconfiguration solution from the 82nd iteration.
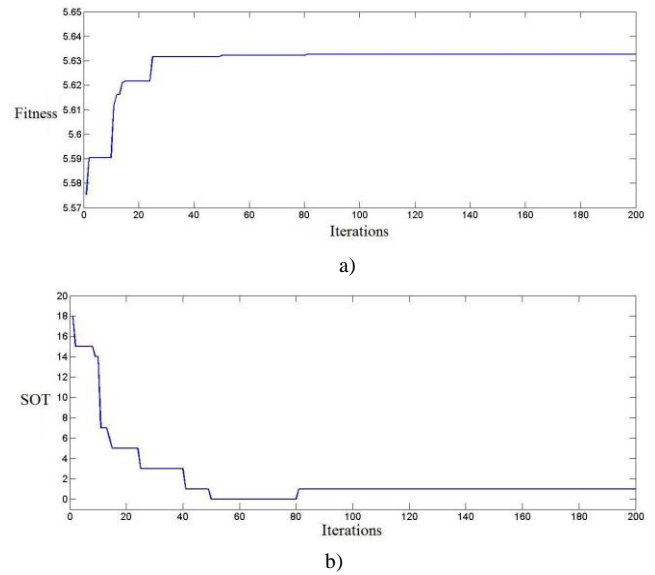

a)

b)

Fig. 4. The changes of fitness and SOT of example 1.

B. Example 2

Assuming faults occur in regional feeder agent 11, 20, 21, 24, 49, the individual codes with faults are:
1111111111101000011100110100001110011111111100111 0
1

MAGA is used to carry out network reconfiguration, simulation results are as following:
1) Regional feeder agent 34: the initial value is 0, the ultimate value is 1. Regional feeder agent 44: the initial value is 0, the ultimate value is 1. Regional feeder agent 45: the initial value is 0, the ultimate value is 1.
2) Fitness value is 5.61035, SOT is 3.

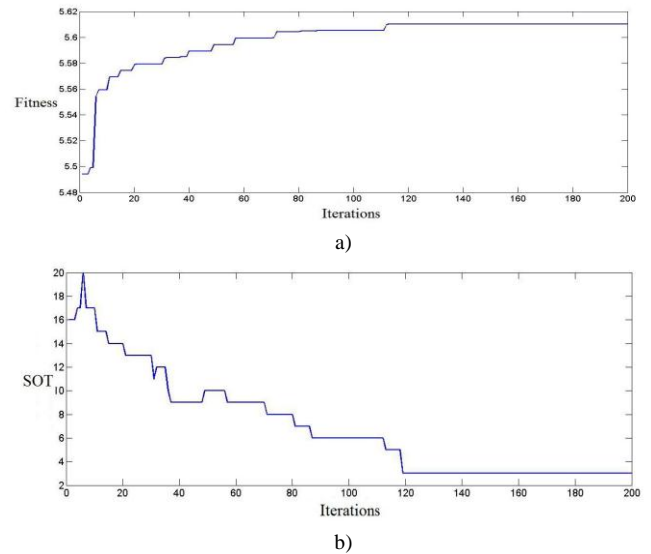The changes of fitness and SOT are shown in Fig. 5.

a)

b)

Fig. 5. The changes of fitness and SOT of example 2.

When faults occur, the regional feeder agents with fault communicate with adjacent agents. The adjacent agents would firstly estimate self-capacity. If all the constraint conditions are satisfied, they would supply power to the fault agents by alternative routes. MAGA gets the best fitness value

5.61035 from the 116th iteration, but only until the 119th iteration it gets the minimum SOT: 3. So we get the best network reconfiguration solution from the 119th iteration.

C. Comparison with Traditional GA

In order to verify the validity of MAGA, the simulation results of two examples are compared with traditional GA, shown in Table I and II:

Table I and II show that the application of multi-agent could significantly enhance the effect of intelligent network reconfiguration. It can accelerate convergence and optimization of intelligent algorithm. In example 1, multi-agent speed up convergence and optimization of traditional GA. In example 2, based on the information exchange between agents, MAGA change the network topology in the minimum extension to reconfigure. It gets a better reconfiguration solution.

TABLE I. SIMULATION RESULTS OF EXAMPLE 1 COMPARED WITH TRADITIONAL GA.

Algorithm Type	Optimal Network Reconfiguration Solution	Fitness			SOT			Best Iteration
		MAX	MIN	AVG	MAX	MIN	AVG	
Traditional GA	I6 is power supplied by the alternative route 27	5.63265	5.50843	5.58625	18	1	5.5	115
MAGA	I6 is power supplied by the alternative route 27	5.63265	5.50843	5.62283	18	0	3.9	82

TABLE II. SIMULATION RESULTS OF EXAMPLE 2 COMPARED WITH TRADITIONAL GA.

Algorithm Type	Optimal Network Reconfiguration Solution	Fitness			SOT			Best Iteration
		MAX	MIN	AVG	MAX	MIN	AVG	
Traditional GA	I9, I11, I12 are power supplied by the alternative routes 34, 44, 45. I15 is power supplied by the alternative route 15. I10 is unloading.	5.60255	5.50699	5.54698	13	7	8.6	146
MAGA	I9, I11, I12 are power supplied by the alternative routes 34, 44, 45.	5.61035	5.55469	5.59243	11	3	5.5	119

V. CONCLUSIONS

The simplified network model and reconfiguration mathematical model of SPS are established. GA and multi-agent technology are analyzed. Regional feeder agents are defined. Combining with multi-agent and GA, MAGA is presented. In this algorithm, regional feeder agents communicate with adjacent agents to accomplish SPS network reconfiguration. Simulation and comparison results show that MAGA can reconfigure SPS network faster and better.

REFERENCES

[1] K. Sanjeev, K. L. B. Srivastava, N. D. R. Sarma, "Shipboard power restored for active duty", *IEEE Computer Applications in Power,* vol. 15, pp. 16–23, 2002. [Online]. Available: http://dx.doi.org/10.1109/MCAP.2002.1018818

[2] T. Nagata, H. A. Sasaki, "Multi-Agent Approach to Power System Restoration", *IEEE Transactions on power systems,* vol. 15, pp. 457–462, 2002. [Online]. Available: http://dx.doi.org/10.1109/TPWRS.2002.1007918

[3] K. Rajesh, S. Devendra, K. Anupam, "A new hybrid multi-agent-based particle swarm optimization technique", *Int. J. of Bio-Inspired Computation,* vol. 1, no. 4, pp. 259–269, 2009. [Online]. Available: http://dx.doi.org/10.1504/IJBIC.2009.024724

[4] X. Yang, X. Zhang, Y. Zhang, "Immune genetic algorithm in the restoration of power supply application", *Chinese Society for Electrical Engineering,* vol. 24, no. 9, pp. 80–86, 2004.