Intelligent Real-time Fault Restoration of the Large Shipboard Power System Based on Genetic Algorithm

Xiuxia Yang, Yi Zhang

China Yantai, ErMaLu, No.188, 301 group, China
264001

yangxiuxia@21cn.com

Abstract

The shipboard power system (SPS) supply energy to sophisticated systems for weapons, communications, navigation and operation. So when the system is damaged, the faults should be isolated and restored immediately to ensure the system survivability. Currently the genetic algorithm (GA) is successfully used to SPS fault restoration and the superiority over the other methods is proved, but the simple GA is difficult to achieve the real-time maximum restoration. This paper provides an improved genetic algorithm, which can fully use the system information and the evolution information, improve speed of convergence of genetic algorithm, and avoid premature convergence. RTDS fault restoration experiments show that the restoration algorithm based on the improved genetic algorithm can restore the fault in real time.

Keyword: real-time fault restoration, shipboard power system, improved genetic algorithm.

I. Introduction

The Shipboard Power System(SPS) supply energy to sophisticated systems for weapons, communications, navigation and operation. The reliability and survivability of SPS are critical, especially under battle conditions. With the appearance of electric propulsion and high energy weapon, the shipboard power system(SPS) will become main dynamic system from auxiliary system and the system capacitance will rise rapidly, which result in the topology structure more and more complex. The structure of SPS is moving from the tree form to ring and mesh configuration, electrification and automation are also improved in SPS, which bring forward higher demand on the security service.

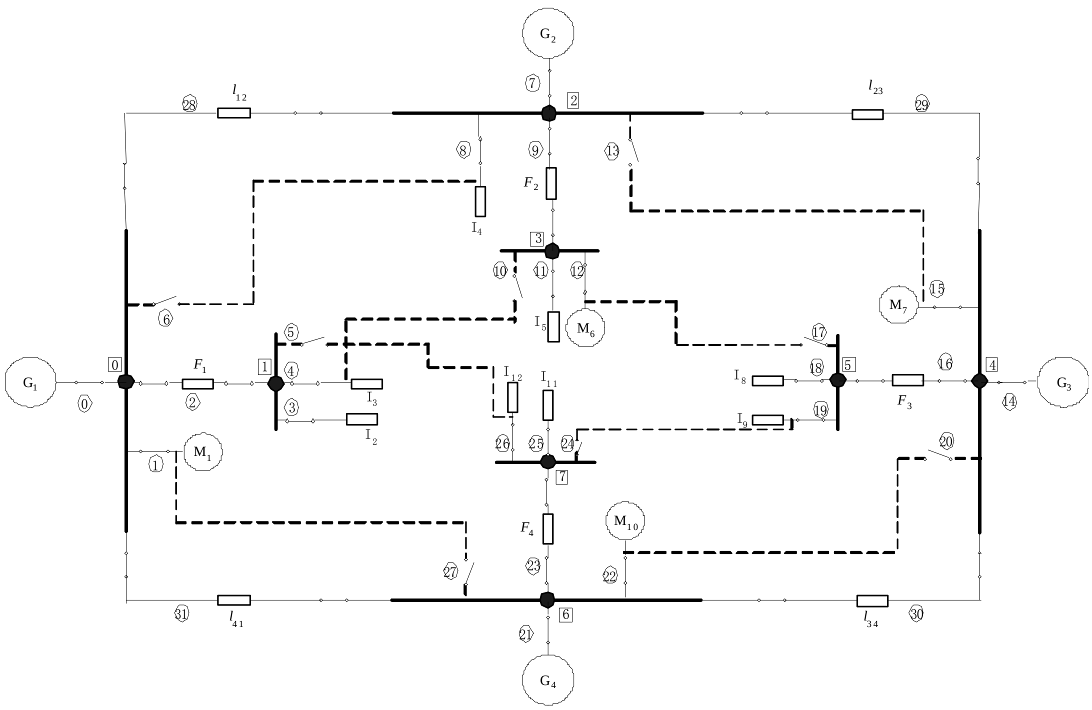
When damage occurs, the fault should be isolated immediately and there will be unfaulted sections that are left without supply. It is required to quickly restore supply to these unfaulted sections to increase the system survivability.

Up to now, only a handful of papers discuss the restoration problem for SPS. The heuristic-search approach [1] has been used. This method is very simple, but it can’t ensure to the restoration of the loads. In the method of network flow approach [2,3], the load priorities had not been taken into account. Knowledge-based expert system techniques[4] were also exploited to develop guidelines on restoration. The disadvantage of these techniques is the difficulty in representing large knowledge base and designing an efficient inference engine to systematically draw conclusions from a large volume of rule-based knowledge. Genetic Algorithm(GA)[5] and hybrid simulated annealing-generic algorithm(GASA)[6] are used to realize the global fault restoration, with the load priorities and the maximum restoration are considered, but GA has some inherent defects, for example, it is easy to cause premature convergence and fall into a local optimum, the system information and the evolution information can't be used fully, the anaphase often appear to be oscillatory, so the algorithm can't be guaranteed to converge to the global optimum. Unlike the utilities, the shipboard power system especially requires real time and global restoration.

In this paper, the GA is improved. The system information and the evolution information are added to genetic algorithm using annealing selection, which can speed up the convergence. In the meantime, the population diversity is kept by using energy-entropy selection. Combining the characteristics of the SPS, the detail method is also presented.

II. Mathematical Problem Formulation

The shipboard power system is consisted of several power stations, which is connected by electrical wire. The switchboard is connected to the generator of every plant, which supply power to power panels or directly to loads. For vital loads, two sources of power (normal and alternate) are provided from separate sources via transfers. A simplified figuration of shipboard power supply system is shown in Fig.1.



Note:'*G*' denoting 'generator'; '*F*' denoting 'feeder'; '*I*' denoting 'static load';

'*M*' denoting 'motor'; '*l*' denoting 'connected line'.

Fig.1 Simplified figuration of shipboard power supply system

A. *Objective Function*

The objective of SPS fault restoration is to determine which switch of the system needs shut and which needs open, to restore the vital load rapidly and has the least outage load, while maintaining switch number to a minimum.

All the loads on the shipboard can be classified into three grades according to its importance. The first and the second grade load is vital load. Consider the vital load service restoration, the objective function is:

$$\max(L_{g1}+L_{g2})=\sum_{i=1}^{k}x_i L_{g1i}+\sum_{j=1}^{t}x_j L_{g2j} \qquad (1)$$

Where $i=1,2,\cdots,k$; $j=1,2,\cdots,t$; L_{g1} represent the first grade loads, L_{g2} represent the second grade loads, x_i , x_j =1 or 0,which signify the loads power supply or not.

$$Min \quad F(Y,Z)=\sum_{i=1}^{m}(1-y_i)+\sum_{j=1}^{n}z_{Tj} \qquad (2)$$

$y_i=1 \;\; or \;\; 0, \;\; i=1,2,\cdots,m$, which represent the switch of the one road supply loads keep close or open up while reconfiguring. $z_{Tj}=1 \;\; or \;\; 0, \;\; j=1,2,\cdots,n$, which represent the transfers alternate supply or keep normal supply while reconfiguring.

B. *Constraints*

(1) Radial limits

For the two road supply loads, only one edge can close.

(2) Capacity Constrains

$$\sum_{i=1}^{m}x_{ij}S_i \le M_j \qquad (3)$$

$x_{ij}=0 \;\; or \;\; 1$ represents the edge's state (open or close) which connect the loads i and branch j or the branch i and the switchboard j . M_j represents the capacity of branch j . S_i is the consumption quantity of electricity of the branch.

From the equation (1)-(3), we can see that the service restoration problem is a typical nonlinear integer programming problem. Following section discuss the GA in a view to solve it.

III. Improved Genetic Algorithm and Its Application in Fault Restoration

For the good robust, flexibility and generalization, genetic algorithm is used in many fields to search the global optimum, but it always falls into a local optimal solution and the local search ability is bad, the system information also can't be fully used, so it can't satisfy the SPS fault restoration real time demand. To solve this problem, the improved GA is given:

Step 1 Encode and initialization

According to the characteristic of SPS, 0, 1, 2 coding is provided where 0 denotes that loads lose power, 1 and 2 express that loads are supplied by normal and standby roads respectively. The gene value of load with only one power supply road is 0 or 1, while the gene value of load with standby road can be 0, 1 or 2. Under normal condition, electric power is supplied zonally, directly or indirectly, where power stations are connected in a complicated structure, such as loop, trapezoid and so on. At each power station, there is a main switchboard, which connects with loads directly or supplies power to loads via zonal switchboards. Below main switchboard level, the power network is connected in radiate structure. Each important load is supplied power in two roads by transfer: one for normal condition, the other for standby. These characteristics can act as heuristic information when solving problems and the population can be initialized by heuristic searching according to these information and faults information.

Step 2 Selection

The annealing fitness selection with the best individual kept can ensure that GA reaches optimization after several generations. But, for the problems requiring real time, the expected value can not be gained if annealing speed is not slow enough. In this article, the energy-entropy selection[7] is added to SPS fault restoration, which can keep the population diversity when evolving to optimization, the selection probability $P(x_i)$ of individual x_i is

$$P(x_i) = e^{-(E(x_i)+\beta f(x_i))} / \sum_{i=1}^{N} e^{-(E(x_i)+\beta f(x_i))} \qquad (4)$$

Where, $E(x_i)$ is energy-entropy of individual x_i, β is a coefficient.
By adding the energy-entropy selection, all of energy state can be sampled at equal probability and the heredity of individuals with high fitness is ensured as well.

Step 3 Heuristic Search

The characteristics of shipboard power system can also act as heuristic information in the involution. If the aim can be achieved by modifying the local loads, the power supply resumes at maximum speed, instead of entire search.

In genetic operation, the locus of individuals can be selected in the probability of P_v, then all of the loads with the same feeder are operated on the principle of inducing the number of operated switches and uninstalled loads. The important load should be supplied power in standby road if its normal road is damaged and some nonvital loads should be uninstalled if capacity is not enough. By this way, most loads can obtain local optimum power.

Because there is lots of useful information to evolution in the optimized individual, this kind of individuals are produced with the probability of p_u in next generation. Tests have proved that this method can greatly speed up evolution.

Step 4 Judge if the population falls into local optimum
If the best fitness keeps constant in D generations, keep the best individual and generate other individuals randomly.

Step 5 Crossover and mutation

Perform the crossover with probability p_a and mutation with probability p_b. Perform local heuristic search with probability P_v. If the result is better than original, then keep the operation, else keep it with probability P_c.

The above operation can fully utilize the information in system and evolution process, speed up computation, inherit the individuals which have low fitness and high energy-entropy on the base of reserving optimized individuals and keep the population diversity.

IV. RTDS Realtime Fault Restoration Experiment

In RTDS real time simulation environment, the ring-configuration shipboard power system shown in Fig.1 is built.

RTDS simulates the faults arise in the system. Through the in-out signal collection system, the fault signal is outputted, analyzed and sent to the fault restoration program. The fault restoration control signal is inputted to RTDS also through the in-out signal collection system to test the real time and the reliability of the fault restoration algorithm. The test principle is shown in Fig.2.

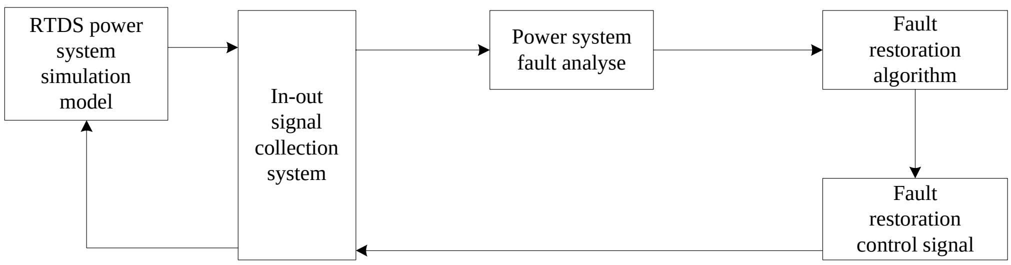
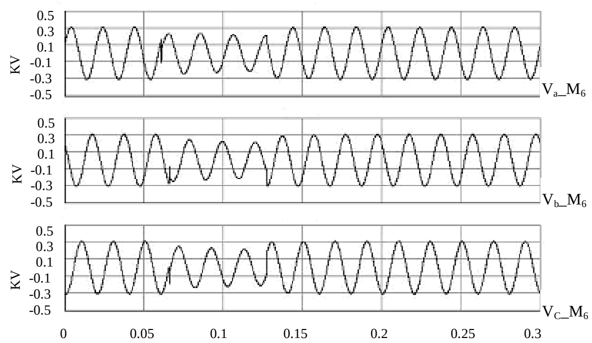


Fig.2 RTDS fault restoration test principle diagram

Supposing that the generator G_2 and the connected line l_{12} 、 l_{23} have broken off, to restore the power supply to important loads, the system must be optimized entirely. On the following, the fault will be restored in three methods: heuristic genetic algorithm (HGA), annealing genetic algorithm (AGA) and improved genetic algorithm (IGA) brought forward in this article.

In the simulation test, let population number *N*=200, maximum evolving generations *G*=300, crossover rate p_a =0.85, mutate rate p_b =0.01, the reserving probability of the best individual P_u =0.05 and the probability of heuristic search P_v =0.2. The bad individuals kept probability P_c =0.5. The generations of regenerate the population *D*=20. Each method runs for 50 times randomly and the restoration result is: L_4, L_6 alternate restoration supply, L_5 lost supply. The restoration courses of motor load L_6 are shown in Fig.3~ Fig.8.



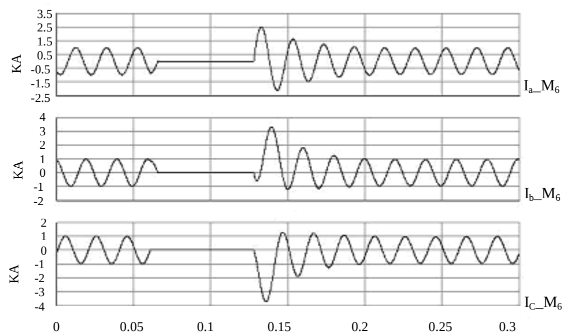


Fig.3 Voltage on load L_6 using HGA restoration **Fig.4 Current on load L_6 using HGA restoration**

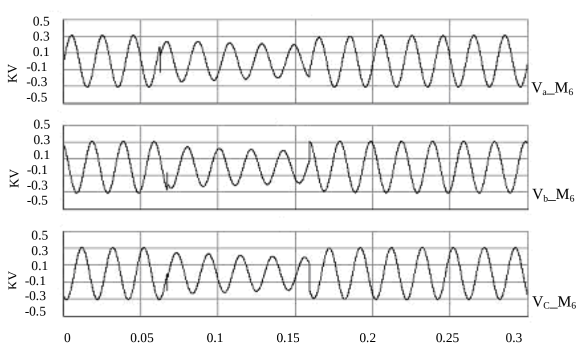


Fig.5 Voltage on load L_6 using AGA restoration

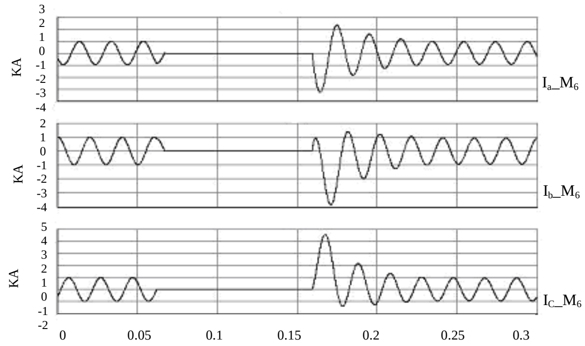


Fig.6 Current on load L_6 using AGA restoration

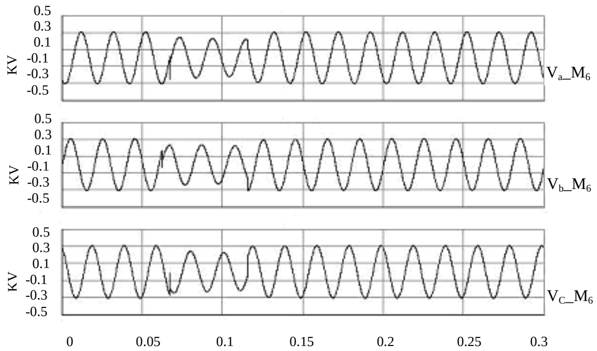


Fig.7 Voltage on load L_6 using IGA restoration

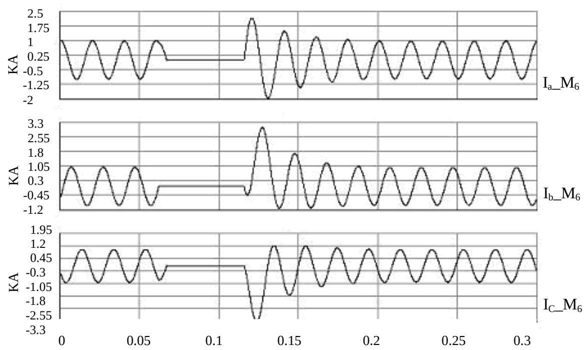


Fig.8 Current on load L_6 using IGA restoration

From the experiment, the conclusion can be drawn: For the IGA can explore the solution space sufficiently and heuristic search can use system information, its restoration time is the shortest, the vital loads can be restored after 56ms, the motor load rotate speed drops little, in Fig.3, the voltage period become to 0.0206S from the original 0.02S, the lowest voltage is 210V, which dropped 32.1%, the peak current after restoration is 3.24KA, which can reach normal value in two periods, the restoration algorithm based on IGA can satisfy the demand.

V. Conclusion

The improved genetic algorithm (IGA) uses annealing selection of energy-entropy and fitness, so it can explore the useful information of current population to keep the population diversity and avoid local optimization. By making use of system information sufficiently and adding heuristic search, IGA greatly increases the speed of solving problems. IGA has been applied to the restoration of shipboard power system and experiment results show that it can satisfy the SPS real time fault restoration demand, which is better than other general GA.

References

[1] K.L.Bulter, N.D.R.Sarma, “General reconfiguration methodology for AC radial shipboard power systems”, in *IEEE 2000 Power Engineering Society Winter Meeting*, New York, 2000, pp.1226 –1230.

[2] W.P. Luan, M.R.lrving and J.S.Daniel, “Genetic algorithm for supply restoration and optimal load shedding in power system distribution networks”, In *IEE Proc.-Gener.Transm.Distrib.*, vol. 149,no.2, 2002, pp.145-151.

[3] K.L.Bulter, N.D.R.Sarma and V.R.Prasad, "A new method of network reconfiguration for service restoration in shipboard power systems", in *Proc. 1999 IEEE Power Engineering Society Transmission and Distribution Conf*, 1999, pp.658-662.

[4] Sanjeev K.Srivastava,Karen L.Butler-Purry, N.D.R.Sarma, "Shipboard power restored for active duty", in *IEEE Computer Applications in Power*, vol. 15,no.3, 2002, pp.16-23.

[5] Yang Xiuxia, Zhang Xiaofeng, Zhang Yi, Cheng Yingchun, "The study of network reconfiguration of the shipboard power system based on heuristic genetic algorithm", in *Proceedings of the CSEE*, vol. 23,no.10, 2003, pp.42-46.

[6] Yang Xiuxia, Zhang Xiaofeng, Zhang Yi, et al, "The study of Nnetwork reconfiguration on the shipboard ring-configuration power supply system", in *IMECE'2003*, 2003, pp.58-63.

[7] Zhang Yi, Yang Xiuxia, "A fast genetic algorithm based on energy-entropy", in *System Engineering-theory &Practice*, vol. 25,no.2, 2005, pp.123-128.

Xiuxia Yang received the M.Sc. degrees in control theory and application in 2000 and the Ph.D. degree in power system automation in 2005. She is currently a lecturer in the field of control Engineering. Her research focus on the areas of computer and intelligent systems applications in power, power distribution automation, automatic control technologies and application.

Yi Zhang received the M.Sc. degrees in control theory and application in 2000. He is currently a lecturer in the field of control Engineering. His primary interests are virtual reality, fault detection and identification, automatic control technologies and application.