International Journal of Hybrid Information Technology
Vol.8, No.11 (2015), pp.413-422
http://dx.doi.org/10.14257/ijhit.2015.8.11.37

Diagnosis of Ship Generator Optimized Neural Network Based on Multi-population Chaos Genetic Algorithm

Ming Yang and Wei-feng SHI

Logistics Engineering College, Shanghai Maritime University, Shanghai 201306, China
yangming_smu@163.com, wfshi@163.com

Abstract

In view of fault diagnosis of the ship generator , the paper proposes improved fault diagnosis method of ship generator ,which is Optimized Neural Network based on Multi-population Chaos Genetic Algorithm. The results prove that the method effectively solves low precision,slow constringency and local minimum of neural network and improves global search ability, optimizes the rate and precision of fault diagnosis. The method has a certain application prospect for the ship power system generator fault diagnosis.

Keywords: *Faults Diagnosis, Multi-population Genetic Algorithm, Chaos, Neural Network*

1. Introduction

By virtue of its advancement and high efficiency, the electrification and informatization of ship will become the inevitable tendency of ship development, which make 'All electric ship' become the important development direction of the ship power system [1]. With the ship generating sets and high power propulsive motor as marine power plant, the electric power system of ship consists of generating sets-power distribution and conversion- high power propulsive motor, which substitutes combustion motor. The system provides the electric power to ensure the reliability and security of the ship. Nevertheless, the ship electric power system is high order, strong coupled and nonlinear. Besides, the severe sea condition and working environment in the marine engine room can all trigger the parameters of ship generating sets to change and make the fault possibility increase sharply. Therefore, if we can detect early faults of ship power systems timely and adopt effective actions, we will evade the damage to ship machinery and even marine accident. At the same time, it can minimize the number of casualties, the financial loss and negative effect on the society.

2. Normal Faults in Ship Generator and Ways to Detect

2.1. Normal Faults in Ship Generator

Mechanical failure and electrical failure are two kinds of ship generator faults. At the same time, the generator can also be affected by the environment of marine engine room. There are mechanical, electromagnetic, acoustical and electrical signs and insulation system changes. From the mechanical aspect, the inevitable shake while sailing and intermittent operation of motor will make the winding loose and bearing worn. From the electrical aspect, unbalance of voltage or winding potential may lead the damage to insulating layer. From the environment aspect, heat and dirt make the motor overheated in a direct or indirect way. It's the important reason for accelerating the aging of insulating layer and undermining of insulativity.

ISSN: 1738-9968 IJHIT

Generally, the faults of ship generators include stator core fault, stator winding fault, rotor winding fault, bearing fault, air-gap eccentric fault, and so on.

(1) Stator core fault. If the vibration of the motor itself is kind of strong, after long period operation, the insulation between stator laminations will be damaged. When bearing is damaged, it's easy to generate friction between stator and rotor and damage the stator core.

(2) Stator winding fault. Aging,overheat,damp,vibration and abrasion can result in undermining the insulativity of motor,which may cause turn to turn short circuit or grounding.

(3) Rotor winding fault. Frequent starting or overload operating of a motor exert certain stress on the rotor.With the stress for a long time,rotor bar and end links will have mechanical fatigue,generating fracture and snap of welded joint.

(4) Bearing fault.Bearing is the supporting roller of motor. When inner bearing ring and rotor are running with a high speed,the bearing need to bear a certain load.It may easily lead to faults.

(5) Air-gap eccentric fault. When air-gap existed,air-gap permeance become nonuniform along the circumferential direction. Therefore,rotor harmonic component is emerged as well as the abnormal electromagnetic force wave,which affect stator and rotor.

2.2. The First Coordinate Transformation for Substructures

Methods of faults diagnosis of ship generators mainly result from the diagnosis of electric power system on the land, and with the combination of it, the methods adopt mathematical model, direct measurement, expert diagnosis, fault tree analysis and artificial neural network, *etc*. Fu Zhu [2] analyzed fault mechanism and then put forward a method to diagnose interturn short circuit,which is based on mathematical model; Jia Chen [3] adopted fault tree analysis to make a comprehensive assessment about all factors of ship power system fault; Chuanwen Lv [4] combined ant colony optimization with artificial neural network to diagnose and assess ship power system fault; Shaoyuan Li [5] achieve good results by applying data fusion technology in the fault diagnosis system in ship power station.

This paper combining multi-population genetic neural network with back propagation artificial neural network on fault diagnose of ship generators. Meanwhile, it introduces a method based on Genetic Algorithm to improve BD network's rate of convergence and tries to avoid the local minimum value. By multi-population genetic neural network, it can improve GA's search and optimization and restrain its premature problem [6, 7] and we anticipate a more effective application in this area.

3. Multi-population Chaos Genetic Neural Network

The multi-population chaos genetic neural network algorithm is a comprehensive algorithm. Firstly, it combines multi-population genetic algorithm and the chaos optimization algorithm. The global searching ability and convergence speed will be improved by making use of the ergodicity and recurrence of the chaotic genetic algorithm. At the same time, the premature convergence problem of the standard genetic algorithm has been improved by the chaos optimization algorithm. Secondly, it optimizes neural network by multi-population chaos genetic algorithm. The initial weights value and the threshold of neural network are optimized. The learning convergence speed of the neural network is effectively improved. So the multi-population chaos genetic neural network algorithm integrates a variety of intelligent algorithms and overcomes the defect of genetic algorithm and neural network.

3.1. Chaos Optimization Algorithm

Chaos is a universal phenomenon in nature. There is the characteristics of the chaos in randomness, convenience and regularity. The states can not be repeated in a certain range by its own rules [8]. The chaos is the motion state of randomness based on the deterministic equation. The chaotic state variables can be called 'chaotic variables'. The common model of the chaos is the one dimensional 'Logistic' map [9]. The mathematical model is $\beta^{(u+1)} = \mu\beta^{(u)}(1-\beta^{(u)})$ where i denotes the number of chaos variables, $i = 1, 2, 3, \ldots, r$,r is the length of individual chromosome; u is the population number, $\mu = 1, 2, 3, \ldots, m$,m is the population size; β is the chaos variable; μ is the Chaotic attractor, $\mu = 4$ here.

The randomicity, ergodicity, and sensitivity to initial conditions of chaotic algorithm is the most important superiority for function optimization.

3.2. Genetic Algorithm

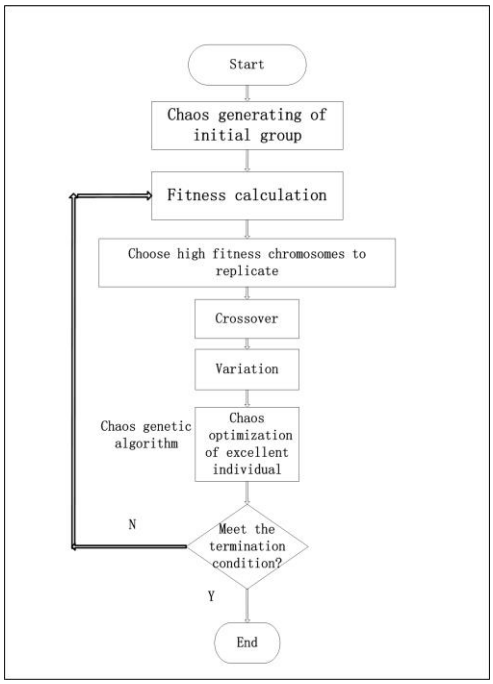

Figure 1. Process of the Chaos Genetic Algorithm

GA(Genetic algorithm) is a iterative, self-adaptive and probabilistic search method established on Natural Selection and genetic mechanism. It simulate the development law of biological evolution in nature to optimize objective [10, 11]. Because of its favorable robustness, extensive adaptability and fast global convergent, it can realize the optimal probability and the global optimal solution. The main genetic operation including coding, fitness calculation, selection, crossover and variation.

Code generally uses binary coding, in addition to floating-point encoding method, Gray code, symbol coding method, multi-parameter encoding methods. Fitness evaluation is to inspect individual fitness. However, GA's premature problem can not be overlooked, it mainly occurs in the population stops when a super long individual emerges, the irrational valuation of crossover probability and variation probability and too small population scale and so on.

The algorithm which Combines the chaos optimization algorithm and genetic algorithm can avoid falling into local minima. Two measures are adopted such as the

chaotic initial population generation and chaos optimization excellent individuals. The chaotic initial population generation will produce better results than random search's.

The chaos optimization excellent individuals will improve the accuracy of Solutions by fine-grained local search.

Process of the Chaos Genetic algorithm is shown in Figure 1.

Against the existing GA's problem, we substitute multi-population genetic algorithm for the chaos genetic algorithm. The advantages of multi-population genetic algorithm including: it cites multi-population as well as processes optimizing search to achieve different searching aim; it uses immigration operator to make multi-population coevolve and gain the optimum solution; the major operations contain immigration operator selection, fitness calculation, function selection, crossover operator and artificial selection operator. Crossover probability and variation probability determine the global search and local search capacity of multi-population algorithm. By using different controls parameters, it makes multi-population coevolve and takes account of both global search and local search of the algorithm.

Process of multi-population genetic algorithm is shown in Figure 2.

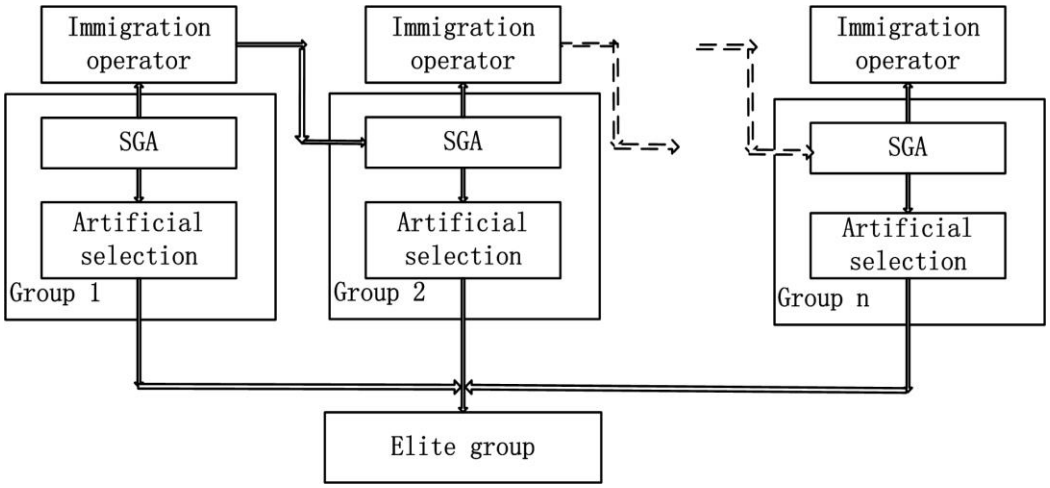

Figure 2. Process of Multi-population Genetic Algorithm

BP neural network algorithm is a learning algorithm adopts decline of error gradient as convergence condition [12] and possesses favorable parallel processing capability, self-learning ability and associative memory. Benefited from its capacities, the algorithm gain extensive application in fault diagnosis and prediction, but also easy to get into the problem of local minimum which limits its effect [13].

Combining multi population genetic algorithm and BP neural network algorithm, multi population genetic algorithm has good robustness and wide adaptability [14], fast convergence and realizing the characteristics of high probability of global optimal and global optimal solution, and the structure of BP network weights optimization study. In order to optimize the BP neural network to achieve the ideal effect.

4. Design of Multi-population Chaos Genetic Neural Network

The multi-population chaos genetic neural network mainly contains network structure establishment, weight and threshold value optimization by multi-population genetic algorithm, BP neural network training and prediction. The topological structure of BP neural network depends on the number of sample's I/O parameters. Accordingly, the number of parameters need to be optimized are determined as well as encoding length of population individual.

4.1. Network Creation and Population Initialization Code

Generally, three-layer network can solve pattern recognition well.

$$s_1 = 2i_1 + 1$$

In the equation, s_1 is hidden layer's number in neural network; i_1 is neuron number of input layer.

Let the output parameter be o_1,then weight value is

$$q_1 = i_1.s_1 + s_1.o_1$$

and threshold value is

$$f_1 = o_1 + s_1$$

so the number of parameters which need to be optimized by multi-population chaos genetic algorithm is

$$c_1 = q_1 + f_1$$

It randomly generates m initial populations:

$$W = (w_1, w_2 \ldots w_m)^T$$

m depends on the numbers of weight value and threshold value.

4.2. Chaotic Initial Population Generation

According to the follow formula, give the $\beta^{(u)}$ 3 different initial value and generate m chaotic variables in different trajectories such as

$$\left\{\beta_1^{(u)}, \beta_2^{(u)}, \ldots \beta_m^{(u)}\right\}$$

According to the formula 2,m chaotic variables are mapped to the value range of optimization variables,such as （i=1,2...m）

$$\beta_i^{(u+1)} = \mu\beta_i^{(u)}(1 - \beta_i^{(u)})$$

Any group of feasible solution will be Calculated by the degree of adaptation. The high fitness individuals group will be Selected as the initial population.

4.3. Fitness Calculation

Substitute the initialized weight value and threshold value into BP neural network, and use training samples of the network at first, then use test sample to test the network, we can get test error:

$$e = \sum \left| o_{sc} - o_{sj} \right|,$$

the calculation of fitness function is

$$f = 1 / e ,$$

O_{sc} is the network output values inputted in test sample. O_{sj} is the network's actual output values.f is fitness.

4.4. Selection

We use fitness proportion method to select. The possibility of genetic effect on next generation depends on the probability of every individual's fitness function value. The possibility of next generation is selected is

$$P_s = f_i / \sum_{i=1}^{p} f_i, i = 1, 2, 3 \ldots, p$$

4.5. Crossover

Crossover operation is the most important operation in GA. we can obtain a new generation by it. The new individuals can combine elder generation's characters. Crossover embodies the idea of information exchange [15]. We can determine the position of selected individual through arithmetic crossover by crossover probability Pc,such as

$$\begin{cases} X_1' = X_1 + (1-c)X_2 \\ X_2' = X_2 + (1-c)X_1 \end{cases}$$

In the equation: c is a random number between 0 and1.

4.6. Variation

Variation is a measure randomly changes a string's value in string structure with a certain probability. Operate variation by probability Pm:

$$\begin{cases} x_{ij}' = x_{ij} + (x_{ij} - x_{max}) * r * (1 - g / G_{max}), & r \geq 0.5 \\ x_{ij}' = x_{ij} + (x_{min} - x_{ij}) * r * (1 - g / G_{max}) & r < 0.5 \end{cases}$$

In the equation: X_{max} is maximum of chromosome;X_{min} is minimum of chromosome; g is the number of current generation; $G_{max}$is the number of maximum generation, r is a random number between 0 and 1.

4.7. Chaos Optimization of Excellent Individuals

In order to further optimize the individual quality, guide the evolution of the population rapidly, we can select some individual with high degree fitness after genetic operations,then do some tiny chaos perturbation.Along with the search process, we can adjust the adaptive disturbance amplitude. According to[7], take the following operation.

$$\delta_k' = (1-\alpha)\delta^* + \alpha\delta_k$$

In the equation: δ^* is the vector that the current optimal values are mapped in the area between 0 and 1. we can call δ^* Optimal Chaotic vectores. δ_k is the chaotic vector after k Iteration. δ_k' is the Superposition of the Chaotic vector. α is iterative control coefficient.

$$\alpha = 1 - \left|\frac{k-1}{k}\right|^m$$

m is a positive integer and will be set according to the requirements.

4.8. Multi-population Genetic Algorithm

In order to solve GA's premature problem. we adopt multi-population genetic algorithm to make whole evolutionary process change along with population scale. This method can effectively improve GA's global convergence ability [6] .

Following is the process:

(1) Let i=0, random initial population is P(0),population scale is N;

(2) Decide whether the population is eligible. If eligible, output the optimal individual's objective function; if not, turn to (3).

(3) Process selection, crossover and variation, and generate intermediate population P'(i) with the same scale of P(i).

(4) Decide whether the current population meets the requirements of expanding the population scale. If true, introduce P'(i) randomly, and expand its scale until it meets setting requirement, then get next generation P(k+1),and back to (2);if not, turn to (5).

(5) Eliminate bad individuals to shrink P'(i)'s population scale and get P(k+1),back to(2).

4.9. Fusion

We use multi-population genetic algorithm to optimize BP neural network's initialized weight value and threshold value, and then, process training and learning through BP neural network. It can not only overcome the problem of local minimum, but also take full advantage of neural network's non-linear approach capability, realize advantageous complementarities, avoid their own defects and have better result.

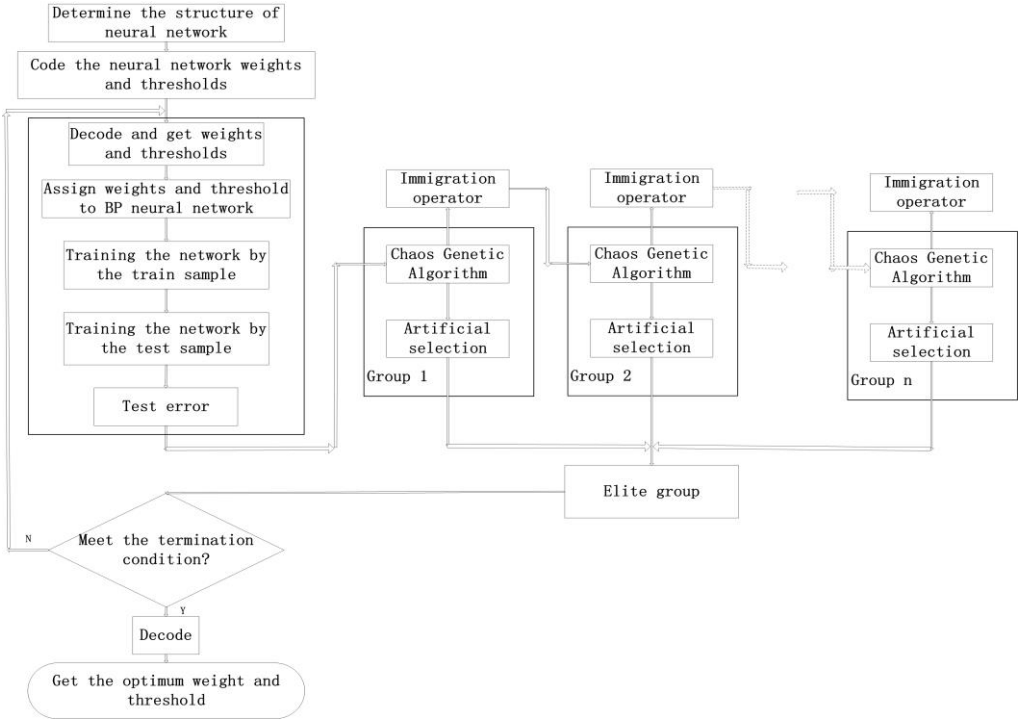

Figure 3. Is the Process of Multi-population Genetic Chaos Algorithm

5. Examples of Fault Diagnosis of Ship Generators

Let ship generators fault be the objects of study, we use multi-population genetic algorithm to diagnose them. Input 5 fault features sample level [16]------normal, stator fault, bearing fault, rotor fault, air gap eccentricity's character frequency band in their vibration frequency spectrum. Normalize the related signals as the input of network.

Operating in different working conditions, we gather 90 groups sample data in 5 classic condition and divide each sort of sample into 18 groups. After the normalization, select 85 groups of them as network's training sample,5 groups as test sample.

A sample have 5 input parameters and 5 output parameters (Yi,i=1,2,…,5).In this multi-population neural network, BD neural network.' s structure is 5-11-5.It means there are 5 nodes on input layer,11 nodes on hidden layer, and 5 nodes on output layer. There are totally 110 weight values and 16 threshold values. Therefore, the number of optimal parameters is 126. In the network, hidden layer neuron's transfer function is tansig( ), and output layer neuron's transfer function is logsig( ).

Through the training of data, actual output of network's diagnostic samples is shown in sheet 1. Test sample's simulation error is 0.1786. Use multi-population genetic neural network to train the data ,The training number is 1000,training objective is 0.01, learning rate is 0.01,population number is 10,generation gap is 0.95,and refer diagnostic result in

sheet 2. The optimum result of simulation error is 0.0845. Use multi-population chaos genetic neural network to train the data, The optimum result of simulation error is 0.0354. Refer diagnostic result in sheet 3.

Sheet 1. Actual Output of Neural Network's Diagnostic Samples

Order	Y1	Y2	Y3	Y4	Y5	Expected outputs	Conclusion
1	0.9517	0.0226	0.0214	0.0362	0.0788	1，0，0，0，0	**normal**
2	0.068	0.9656	0.0269	0.0375	0.0576	0，1，0，0，0	**stator fault**
3	0.0609	0.0242	0.9751	0.0475	0.0627	0，0，1，0，0	**rotor fault**
4	0.0754	0.0311	0.0267	0.9852	0.0381	0，0，0，1，0	**bearing fault**
5	0.0793	0.0493	0.0678	0.0357	0.9838	0，0，0，0，1	**air-gap eccentric**

Sheet 2. Actual Output of Multi-population Neural Network's Diagnostic Samples

Order	Y1	Y2	Y3	Y4	Y5	Expected outputs	Conclusion
1	0.9612	0.0224	0.0178	0.0217	0.0411	1，0，0，0，0	**normal**
2	0.011	0.9872	0.0238	0.024	0.0334	0，1，0，0，0	**stator fault**
3	0.0307	0.0206	0.9815	0.0255	0.0341	0，0，1，0，0	**rotor fault**
4	0.0137	0.0177	0.0195	0.9757	0.0221	0，0，0，1，0	**bearing fault**
5	0.0435	0.031	0.03575	0.0237	0.985	0，0，0，0，1	**air-gap eccentric**

Sheet 3. Actual Output of Chaos Multi-population Neural Network's Diagnostic Samples

Order	Y1	Y2	Y3	Y4	Y5	Expected outputs	Conclusion
1	0.9912	0.0022	0.0141	0.0092	0.0035	1，0，0，0，0	**normal**
2	0.0141	0.9962	0.0088	0.0045	0.0092	0，1，0，0，0	**stator fault**
3	0.0006	0.017	0.9735	0.0035	0.0056	0，0，1，0，0	**rotor fault**
4	0.0121	0.0024	0.0064	0.9885	0.0022	0，0，0，1，0	**bearing fault**
5	0.0078	0.0148	0.0097	0.0158	0.9913	0，0，0，0，1	**air-gap eccentric**

From the result and error of the simulation, the diagnosis based on multi-population chaos genetic neural network is more close to the expected result and the output of fault point is more close to 1, while other output value are more close to 0.From the error of simulation, multi-population chaos genetic neural network's training times are less then multi-population genetic algorithm's or neural network algorithm's. At the meantime, The former error of simulation is smaller than the latter generation's. Therefore,it is shown that training accuracy of the multi-population chaos genetic neural network is higher and relative rate of convergence is faster . The simulation error and optimum simulation error of the neural network, Multi-population genetic algorithm and Multi-population chaos genetic algorithm are shown in Figure 4-6. the comparison of error evolution in three kinds algorithm is shown in Figure 7

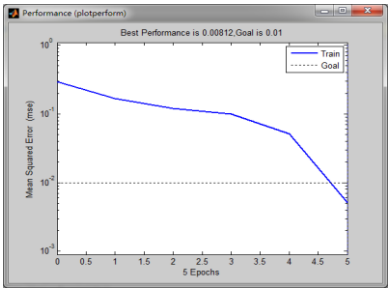

Figure 4. Neural Network's Simulation Error

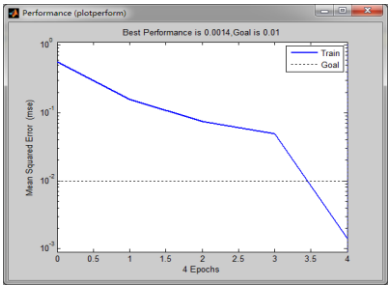

Figure 5. Multi-population Neural Network's Simulation Error

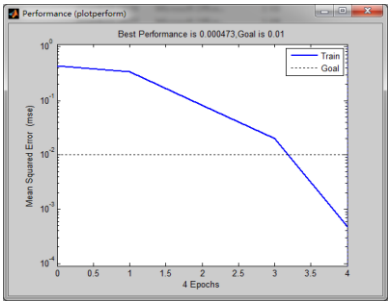

Figure 6. Multi-population Chaos Genetic Neural Network Simulation Error

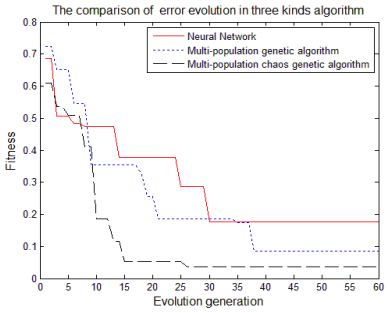

Figure 7. The Comparison of Error Evolution in Three Kinds Algorithm

This paper proposes a new algorithm that optimizes weights and threshold of neural network in the way of multi-population chaos genetic algorithm and applies the new algorithm for the fault diagnosis of ship generators. Through the comparison, we can see this method can improve fault diagnosis accuracy, overcome BP neural network' local convergence problem, and have high reference value to the effect of fault diagnosis of ship generators.

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Authors

Ming Yang, was born in Zhejiang Province,China ,in October ,1982.He received M. S. from Shanghai Maritime University in 2008. He has been in Shanghai Maritime University in 2004, where he is currently a lecturer in Logistics Engineering College. His rearch area is the condition monitoring and fault diagnosis of electric machines.

Wei-feng Shi, was born in Zhejiang Province,China ,in June ,1963.He received ph. D. from Shanghai Maritime University in 2005.He is currently a professor in Logistics Engineering College,in Shanghai Maritime University. His major research interest lies in the area of electric power system and automation, power electronics and power transmission.

