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Intelligent fault self-healing of marine regional distribution power system based on SA-MPGA algorithm

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Abstract

The method of active control and fault prevention for intelligent self-healing of fault in marine regional distribution power system is studied. Simulated annealing multi-population genetic algorithm (SA-MPGA) adopts multi-population genetic algorithm and incorporates the mechanism of annealing algorithm, which can ensure that the algorithm will not fall into local optimum in fault self-healing calculation. In the later stage of the algorithm, the advantages of local search of genetic algorithm can be brought into play, so that the final result can converge to the interval of the optimal solution, and the optimal self-healing scheme of fault can be found. Simpowersystem fault simulation in matlab of regional distribution power system of ships shows that the improved algorithm avoids premature convergence, can speed up fault self-healing of recovering voltage frequency fluctuation greatly, and can prevent serious voltage frequency oscillation of ship power system caused by pulse load.

Keywords

Ship regional power distribution system; SA-MPGA algorithm; Fault self-healing; Pulse load.

1. Introduction

The harsh navigation environment of ships in the ocean leads to the load of propellers in water changing greatly, which brings great challenges to the safe and reliable operation of regional distribution power system of ships. In order to prevent the ship failure from threatening the safety of personnel and ships, and to ensure that important loads such as ship main power and pulse load do not lose power at the critical moment, the ship power system needs to quickly reconfigure the system [1] in case of failure or weapon attack, abandon the unimportant loads, and at the same time provide a decision-making scheme for restoring the power supply of the important loads to the maximum extent. Therefore, it is necessary to design an optimized intelligent algorithm for ship intelligent fault self-healing, and calculate the optimal self-healing scheme after the fault occurs.

In recent years, intelligent algorithms have been widely used in solving ship problems. Document [2] applies genetic algorithm to the motion control of large engineering ships. Document [3] introduces a distribution network fault location method based on immune binary particle swarm optimization algorithm. Document [4] combines particle swarm optimization algorithm with simulated annealing algorithm to avoid the defects of single algorithm. However, as far as the traditional genetic algorithm is concerned, it still has some defects. For example, individuals are only selected according to fitness, and there is no connection between the choices of each individual, which is easy to fall into local extremum, slow in convergence and easy to precocious.

In order to solve the limitation that the traditional genetic algorithm can't guarantee to converge to the global optimal solution with the maximum probability, this paper puts forward

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the mechanism that SA-MPGA introduces simulated annealing algorithm to jump out of the current solution with a certain probability, and breaks through the framework of single population evolution of traditional genetic algorithm, and introduces multiple populations for optimal search [5], effectively avoiding the phenomenon of local convergence and premature convergence. The SA-MPGA algorithm is used to calculate and analyze the fault recovery and reconstruction strategy of the ship regional distribution power system. Finally, the system fault recovery is tested by the simpowersystem platform simulation experiment of Matlab. The results show that the SA-MPGA algorithm accelerates the fault recovery and reconstruction speed of the ship regional distribution power system, and its comprehensive performance is obviously better than the traditional genetic algorithm.

2. Fault recovery and reconstruction of marine regional distribution system

2.1. Problem description of fault recovery and reconfiguration

The ship's power system adopts 6.6kv medium voltage power system with rated power of 60Hz, and the ship is equipped with four generator sets. The frequency change of the power system is closely related to the generator speed, which has a great influence on the normal operation of the power system. In view of the faults that occur when the ship is running on the sea, the load in the fault area should be cut off and isolated in time to prevent the faults from spreading to the whole system. Then the whole ship system network needs to be reconstructed by changing the combination of switch states, so as to optimize the power flow distribution in the system. The marine regional distribution power system is a complex nonlinear system, which is powered by a combination of various power supply modes. The whole marine power system is divided into various regions with complex and diverse connection structures. Therefore, the fault recovery and reconstruction of the marine regional distribution power system is a nonlinear, multi-constrained and discontinuous combinatorial optimization problem [6]. Fig. 1 shows the structure of regional distribution power system for ships.

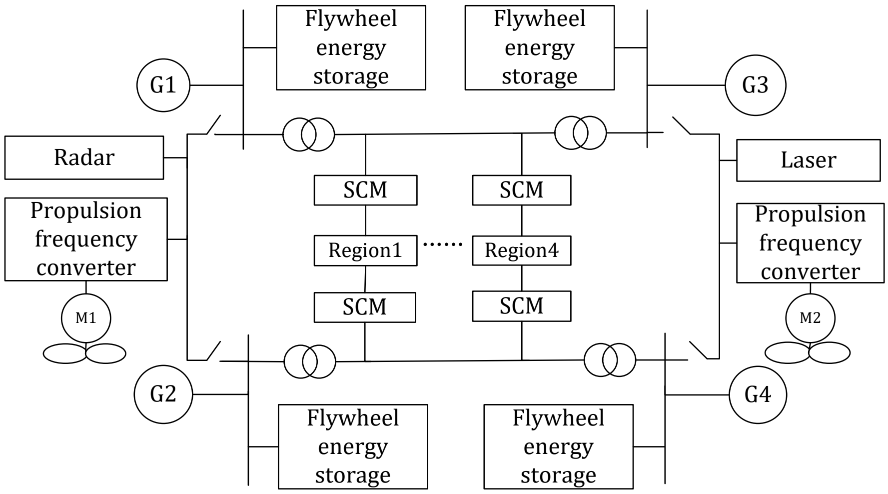

Figure 1: Structure diagram of ship regional distribution power system

2.2. Constraint equation of node power of ship regional distribution system

In the process of reconfiguration of regional distribution power system of ships, it is necessary to meet the constraints of power, current and voltage.

1) generator power constraint

$$P_i = U_i \sum_{j\in N} U_j\left(G_{ij}cos\theta_{ij} + B_{ij}sin\theta_{ij}\right) = 0 \tag{1}$$

$$Q_i = U_i \sum_{j\in N} U_j\left(G_{ij}sin\theta_{ij} + B_{ij}cos\theta_{ij}\right) = 0 \tag{2}$$

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In which, P_i、Q_i、and U_i are the injected active power, reactive power and voltage at node I, respectively; G_{ij}、B_{ij}、and θ_{ij} are the conductance, susceptance and phase angle difference between nodes respectively.

2) Inequality constraint

$$U_i^{min} \leq U_i \leq U_i^{max} \tag{3}$$

$$Q_i^{min} \leq Q_i \leq Q_i^{max} \tag{4}$$

$$T_i^{min} \leq T_i \leq T_i^{max} \tag{5}$$

2.3. Reconstruction objective function of ship regional distribution system

The goal of ship power system reconfiguration is that after a fault occurs, within the range of satisfying the constraint conditions, the operation times of switches are the least, so that the important loads can be restored to power supply first, and the network loss can be minimized[7]. According to the operation conditions of the ship regional distribution system, the optimization objective function is reconstructed as follows:

1) Give priority to the recovery of ship power weapon load and ship main power load, and the objective function considering the priority of power supply load is:

$$\max\,(L_1 + L_2) = \sum_{i=1}^{x} r_i L_{1i} + \sum_{j=1}^{y} r_j L_{2j} \tag{6}$$

2) In order to speed up ship fault recovery, the less the number of switch operations, the shorter the recovery time. The objective function considered from the number of switch operations is expressed as follows:

$$\min \mathrm{F}(\mathrm{X} + Z_X) = \sum_{i=1}^{m}(1 - r_i) + \sum_{j=1}^{n} Z_{Xj} \tag{7}$$

Where, L_1 and L_2 are the primary impact load and the secondary main power load, respectively. When these two loads supply power, the values of r_i and r_j are 1; otherwise, they are 0. Z_{Xj} is the state of switching on and off in reconfiguration. Under special circumstances, when only the flywheel device is used for power supply, the pulse load is used as the load with the highest priority.

3. Design of reconfiguration algorithm for ship regional distribution power system

3.1. Simulated annealing multi-population genetic algorithm

At present, there is little research on the application of simulated annealing algorithm to ship power compensation, because it needs high enough initial temperature and the annealing process must be slow enough to finally converge to the global optimal solution. However, the ship system is large-scale, complex and diverse, and it takes too long to use simulated annealing algorithm alone. Therefore, it is generally applied to reactive power optimization in combination with other intelligent algorithms. Simulated annealing multi-population genetic algorithm decomposes the genetic algorithm into multiple sub-populations in parallel[5]. The optimal individuals among sub-populations exchange information, which can accelerate the convergence speed. In the later stage, the ability of local search of genetic algorithm can be brought into full play. By using the characteristics of simulated annealing algorithm that it moves in a direction worse than the current solution with a certain probability, it can jump out of the local optimal solution and complement each other with traditional genetic algorithm, thus ensuring that the final result converges to the optimal solution[8].

3.2. Steps for fault recovery and reconstruction of ship regional distribution system

The SA-MPGA algorithm is used to generate the optimal self-healing scheme of the ship regional distribution power system. The flow chart is shown in Figure 2.

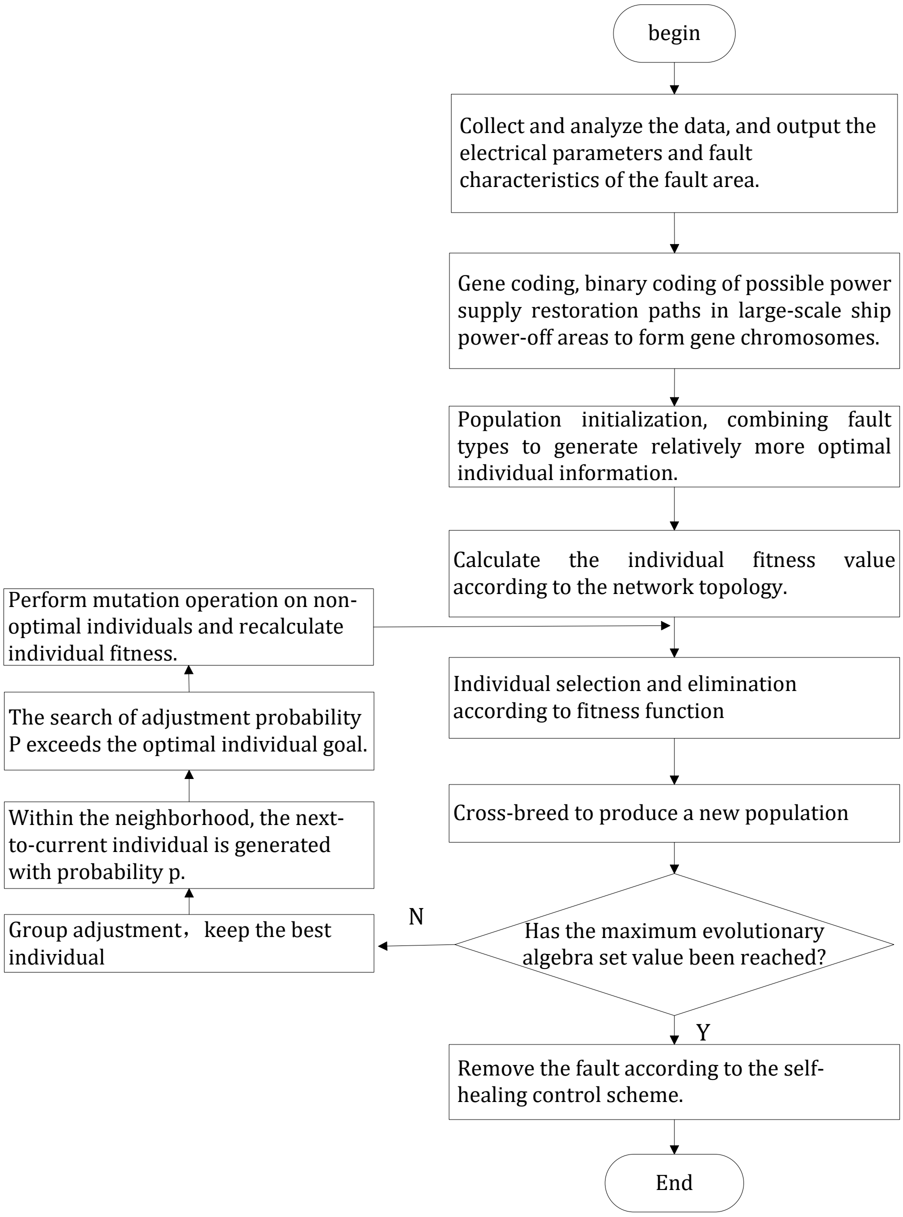

Figure 2: Flow chart of SA-MPGA algorithm

The implementation steps of the algorithm are as follows:

1) Collect ship operation fault information and detect frequency and voltage fluctuation range.

2) Gene coding, binary coding of the possible power supply restoration paths of large groups of ships in power-off areas to form gene chromosomes. The control variables of active power optimization of ships' power system are mainly the output of generators, tap selection of transformers, output of flywheel energy storage devices, etc. ;

3)Population initialization, which randomly generates N numbers $k_1,,,k_i,,,k_N$ in the interval [0,1] in combination with the fault type, and generates relatively more optimal individual information, which is divided into the main population and two auxiliary populations, with specific control variables as follows;

$$X_i = X_{maxi} - k_i(X_{maxi} - X_{mini}) \tag{8}$$

4) System calculation: mapping the gene value of each sub-population individual into the network topology structure of the system, and calculating the fitness value of the individual;

5) According to the fitness function, give priority to ensuring important load power supply for individual selection and elimination; The fitness $f(x_i)$ of individual x_i, then the selection probability of individual x_i is:

$$P(x_i) = \frac{f(x_i)}{\sum_{j=1}^{N} f(x_i)} \tag{9}$$

6) Selecting the optimal individual of the auxiliary population and the excellent individual of the main population to cross breed to generate a new population.

7) Judging the termination condition, if the evolutionary algebra has reached the maximum set value, outputting the optimal self-healing scheme, and the ship system control center receives the fault handling information in the scheme to terminate the cycle; Otherwise, turn to the following steps to start iteration;

8) Population adjustment: if the fitness value of the optimal individual remains unchanged in a certain algebra of evolution, only the optimal individual is retained, and other individuals are randomly generated;

9) Annealing selection, that is, selecting individuals worse than the current individuals in the neighborhood of the obtained optimal individuals with probability p, and continuing to move to find new individuals.

10) If there is an individual who exceeds the current optimum, repeat step 9. If not, decrease the value of probability p until it is 0.

11) Perform mutation operation on non-optimal individuals to avoid evolution stagnation, recalculate individual fitness, and return to step 5 for selection and elimination.

4. Analysis of simulation results

4.1. Simulation results and analysis of network reconfiguration

In order to verify the effectiveness of the improved genetic algorithm in fault recovery and reconfiguration strategy of ship regional distribution power system, the simulation test was carried out on the platform of Matlab 2020. The simulation system breaks down in 10 seconds, and then the unimportant load is disconnected. At 20 seconds, the propulsion starts to accelerate and decelerates at 40 seconds, and at 60 seconds, the system recovers from the failure. The power change of diesel generator and turbogenerator in marine power system is shown in Figure 3.

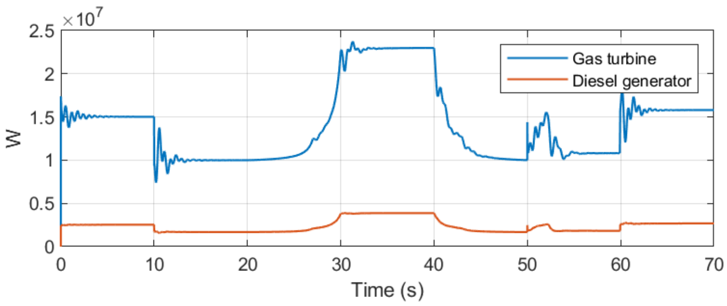

Figure 3: Power change of diesel generator and turbogenerator

In order to make the fault recovery and reconstruction strategy of ship regional distribution power system in this paper comparable, the traditional genetic algorithm is selected for comparative test. First of all, the SA-MPGA algorithm is used to perform fault recovery tests on level 1 load, level 2 load and level 3 load in the marine regional distribution power system. The test times and reconstruction recovery efficiency of the marine power system are shown in Table 1. Among them, the ship's impact weapon and main driving force are level 1 load, the

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ship's functional equipment is level 2 load, and the power supply load to maintain the normal work and life of ship personnel is level 3 load.

Table 1: Number of trials and refactoring recovery efficiency

Load grade	Test times	Recovery efficiency/%
Level 1 load	eight	100
Level 2 load	six	90
Level 3 load	ten	80

The experimental comparison results of genetic algorithm and SA-MPGA algorithm are shown in Table 2. From Table 2, it can be seen that the switching times of SA-MPGA are less than those of traditional genetic algorithm, and the probability of convergence to the optimal solution is higher, which can restore the load power supply requirements to the maximum extent, which indicates that SA-MPGA algorithm is a better scheme for fault recovery and reconstruction of distribution network of naval power system.

Table 2: Comparison of experimental results

Evaluating	Genetic algorithm	SA-MPGA algorithm
Minimum number of switches	7	4
Number of convergence iterations	85	69
Probability of fin optimal solution	80	99

4.2. Energy management strategy of pulse load in ship power system

Impulse load on ships refers to short-term high-power equipment such as laser weapons, radar, electromagnetic gun, etc. [9]. This kind of equipment needs high energy density and high power when it is started, which has great impact on the ship system. In order to avoid the paralysis of fragile ship power system after failure caused by strong impact, flywheel energy storage device is introduced to suppress the fluctuation of output power of distribution power system in ship area [10]. The device can solve the influence of fault disturbance within a few milliseconds [11], and supply power to the important pulse load and the main driving load on the ship urgently after the ship system fails, so as to gain time for the self-healing of the ship fault. Electronic converter is the hub of energy exchange between flywheel energy storage and power grid. By means of rectification, inversion and pulse width modulation technology, it can realize the AC/DC conversion of flywheel energy storage system in charge and discharge state on the one hand, and maintain the DC side voltage of converter at a certain constant value on the other hand [12]. The structure of flywheel energy storage device for standby energy of ship is as follows.

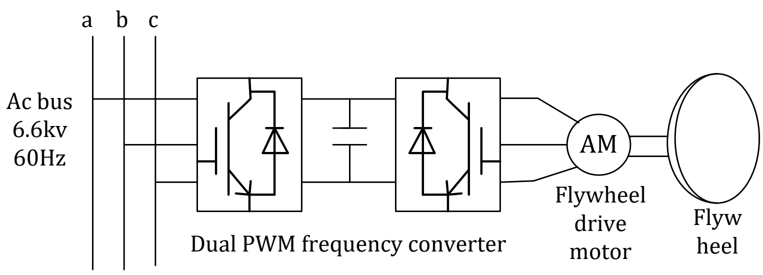

Figure 3: flywheel energy storage for ship impact load

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The flywheel energy storage device can be divided into two parts according to the working principle. Mode, one is the charging mode, the ship power grid supplies power to the device, the flywheel slowly reaches the specified speed from the static state, and keeps the rated speed for a long time in a relatively vacuum environment. The other is the discharge mode, which is used as the power supply, and under special circumstances, the pulse load on the ship is used as the load with the highest priority to supply power, so as to meet the requirement that the weapon of the ship can keep effective operation in combat.

5. Conclusion

Simulated annealing multi-population genetic algorithm (SA-MPGA) uses the main multi-population genetic algorithm to find the optimal scheme of fault recovery and reconstruction, and uses the mechanism of simulated annealing algorithm to avoid falling into the local optimum of genetic algorithm. It is of great significance for the self-healing recovery of marine ships after faults, which improves the safety and reliability of regional distribution power system of ships and has the ability of self-healing recovery for faults. In addition, by introducing the energy management strategy of flywheel energy storage equipment, the device can provide emergency power supply for pulse load and support high-power load under special circumstances, which is of great significance for self-healing recovery of marine ship after failure, and improves the safety and reliability of marine power system.

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