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Research on Reconstruction Methods of Marine Power System under Fault States

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Abstract

In the ship power system, if some components fail, the whole power system may fail or even collapse due to local faults, so that it is forced to shut down automatically. The research on fault reconstruction of ship power system is to use a certain method to carry out qualitative analysis and calculation. By changing some equipment or connecting wires in the power system, the network structure of the whole power system is reconstructed, so as to restore power supply to the maximum extent and ensure the demand of electricity for important loads. In this way, the vitality of the ship will be improved and the operating performance will be greatly improved. In this paper, the model and constraint conditions of Marine power system fault reconfiguration are summarized firstly, and then the advantages and disadvantages of various algorithms for Marine power system fault reconfiguration are expounded. Finally, the main problems existing in the fault reconstruction methods of Marine power system and the research direction and trend in the future are further explained.

Keywords

Ship Powers Ystem; Faultre Construction; Algorithms; Multi-objective Reconstruction; Power Supply Restoration.

1. Introduction

The essence of fault reconstruction of ship power system is to build an automatic power network management system to regulate, dispatch and control the power grid in fault states.Minimizing the impact of various faults on the ships and increase the vitality of the ships [1,2,3].

According to different application requirements, the research emphasis of ship power system fault reconstruction mainly includes two aspects: under normal operation condition, the ship power system fault reconstruction as a means of optimal control. By optimizing the network running status, such as decrease network loss, eliminate overload, improve the quality of power supply. To improve the power grid operation efficiency for the purpose of the network structure optimization reconstruction. In the case of system failure, the power supply can be restored quickly in the non-fault power outage area mainly through the switching of the on-off states of the segmentalized and contact switches.So as to improve the reliability of power supply.

Ship power system due to the relatively small, and as an independent power grid, the ships sailing on the sea for a long time.Higher requirements on power supply continuity. The research mainly focus on the fast recovery of power supply, the main task is to meet under the premise of distribution network operation constraints, to restore the maximum load, switch operations to minimize, network operation mode optimization as the goal. Through the ship power system fault reconstruction will be restored to power load as much as possible.When the ship power system components damaged, the system load, especially the important load, will be cut off, and even lead to the ship power system

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collapse. Therefore, the efficiency of fault reconfiguration of Marine regional distribution power system is very important. When the ship power system fails, the restorative reconstruction of the ship power system means that the topological structure of the ship power system can be changed by switching operation. To isolate the faults of the ship regional power distribution system, recover the lost load, and optimize some performances of the system in real time. Restorative reconstruction of Marine regional distribution power system is a typical multi-objective nonlinear discrete optimization problem with many discrete variables and additional constraints. Due to the small network loss, the goal of reconfiguration of regional distribution power system is generally not to minimize the network loss. Although minimization of network losses is often an optimization goal for electrical power systems, the two are significantly different.

In this paper, the model and constraint conditions of Marine power system fault reconfiguration are summarized firstly, and then the advantages and disadvantages of various algorithms for Marine power system fault reconfiguration are expounded. Finally, the main problems existing in the fault reconstruction methods of Marine regional distribution power system and the research directions and trends in the future are further explained.

2. Fault reconstruction model of Marine power system

2.1 The objective function

2.1.1 Load recovery index

The ship power system adopts the three-level load classification method, that is, according to the importance of the load, it is divided into first-level important load, second-level secondary important load and third-level general load. The corresponding load sets are respectively L_{g1}, L_{g2} and L_{g3}. The general expression of the load recovery degree index E_L is

$$E_L = \omega_1 \sum_{i\in L_{g1}} x_i I_i + \omega_2 \sum_{j\in L_{g2}} x_j I_j + \omega_3 \sum_{k\in L_{g3}} x_k I_k \tag{1}$$

Among them, ω_1, ω_2, ω_3 are the three levels of load power factor respectively. $\omega_1 > \omega_2 > \omega_3$. x is the cutting states of the load. 1 means power supply, 0 means power outages. I is the rated current of the load. The bigger the indicator E_L, the better.

2.1.2 Switch operation cost index

Switching operation cost index of power network is an important index to evaluate the operability and recovery speed of Marine power system reconstruction scheme. In Marine power system, different switches have different operating costs, which can be generally divided into generator switches, manual transfer switches and automatic transfer switches. The expression of switch operation cost index E_C is

$$E_C = k_G z_G + k_M z_M + k_A z_A \tag{2}$$

Where, k_G, k_M, k_A, are the weight coefficients of operation costs of different types of switches, mainly including generator switches, manual transfer switches and automatic transfer switches. The operation times of switch are z_G, z_M, z_A. Because the action of the contact switch of the generator has a great impact on the system, and the manual switch needs human operation, the weight coefficients of the three types of switches are generally subject to the conditions $k_G > k_M > k_A$. The smaller the switching operation cost index E_C, the better.

2.1.3 Contact line capacity margin index

In order to ensure the stable and reliable operation of the reconstructed system, the contact lines of the power supply network need to have enough power redundancy. Contact line capacity margin index E_M

$$E_M = \min\left\{\frac{I_{i,rated} - I_i}{I_{i,rated}} \middle| i \in [1,2,\cdots, N_M]\right\} \tag{3}$$

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Where, N_M is the total number of contact lines, and $I_{i,rated}$, I_i are the rated current and actual current of contact line respectively. The capacity margin index E_M of contact lines indicates the minimum capacity margin of all contact lines. The greater the value E_M, the better.

2.1.4 Unevenness index of load distribution

Uneven load distribution will lead to heavy load of some lines, increase of network loss and deterioration of power supply safety. In order to improve the carrying capacity of the reconstructed network lines, it is necessary to ensure the balance of load distribution in the power network. Load distribution unevenness index E_p is

$$E_p = \frac{\sum_{i=1}^{N_D} I_i^2}{\sum_{j=1}^{N_L} I_{Lj}} \tag{4}$$

Where, I_i is the current flowing through line i, I_{Lj} is the current of load j, N_D is the total number of system lines, and N_L is the total number of system loads. The smaller the load distribution unevenness index E_p, the better.

2.1.5 Generator load factor index

Long-term low power operation of generator sets is not only a waste of energy but also harmful to diesel generator sets themselves. Marine power system should try to avoid the generator sets working in the area of too low load. The generator load rate index E_G is

$$E_G = \min\left\{\frac{S_i}{S_{i,rated}} | i \in [1,2,\cdots,N_G]\right\} \tag{5}$$

Where, N_G is the total number of generators, and S_i, $S_{i,rated}$ are the output power and rated power of generator respectively. The generator load rate E_G indicator indicates the lowest load rate for all operating generators. The higher the value, the better.

2.2 Constraint conditions

In order to ensure the stable and safe operation of the Marine power system, the reconstruction scheme must meet certain constraints. According to the topological structure characteristics of Marine power system and the distribution of tidal current. The commonly used constraints in the existing literature mainly include load supply constraint, branch current constraint.

2.2.1 Load supply constraint

According to the requirements of the ship power system relay protection, the load of power supply, to ensure the normal path and backup path only one is conduction.Two way of power supply situation at the same time is banned , the constraint conditions:

$$x_{i1} + x_{i2} \le 1 \tag{6}$$

Where, and x_{i1}, x_{i2} are the working states of the conventional power supply path and the standby power supply path of the transfer switch i respectively. 1 represents the line power supply, and 0 represents the line power cut.

2.2.2 Branch current constraint

The current flowing on the branch should not exceed the maximum allowable current on the working line, that is, the constraint conditions are as follows:

$$I_i \le I_{i,rated} \tag{7}$$

Where, I_i is the working current of branch i, and $I_{i,rated}$ is the maximum allowable current of the corresponding line.

3. Fault reconstruction algorithms of Marine power system

3.1 Traditional Algorithm

The traditional Marine power system fault reconstruction algorithm is divided into simplex method and branch interface, and the model is established by linear or nonlinear method [4,5,6]. Its main

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advantages are as follows: the initial network value has little influence on the algorithm, and it is easy to obtain the optimal solution of the fault recovery of the Marine power system. The power system processing ability of small-scale ships is strong. However, the traditional algorithm has a large amount of computation and low efficiency. It can't deal with the problem of large-scale ship power system fault reconfiguration well.

3.2 Heuristic algorithm

The heuristic algorithm mainly determines the optimal combination states of switches in Marine power system by setting principles. In the fault reconstruction of Marine power system, this algorithm is divided into two kinds: branch switching method and optimal flow mode method.

3.2.1 Branch exchange method

This algorithm was proposed by Civanlar in 1988. It only closes one contact switch at a time, and determines the position of the disconnected segment switch by using the network loss changes before and after branch switching [7]. Literature [8] proposed the method of replacing precise network loss with approximate network loss, and determined the switching combination states with the largest network loss reduction value in the branch loop network of the ship power system by using the transfer load characteristics, which significantly improved the calculation speed of the algorithm. In Literature [9], a new heuristic rule was obtained by constructing load dispersion and path dissipation factor and analyzing their properties, and then a new branch switching method was proposed. Literature [10] proposed the branch switching method based on sensitive analysis, and determined the power flow state before and after the transformation of the distribution network through the analysis value, so as to obtain the optimal distribution network structure. Although the branch switching method can improve the feasible solution, it reduces the convergence speed and increases the difficulty of searching the global optimal solution.

3.2.2 Optimal flow mode algorithm

Firstly, the algorithm closes all the contact switches, calculates the optimal power flow of the distribution network system through the power flow equation, and then selects the branch disconnection switch with the least current. Literature [11] proposed the spanning tree method for reconstruction, which greatly reduced the number of spanning trees under the premise of satisfying the switch closure rule. The optimal flow model has good convergence, but its shortcoming is slow speed and difficult to search for the global optimal solution.

4. Artificial intelligence algorithms

4.1 Ant colony algorithm

Ant Colony Optimization (ACO) is a new heuristic optimization algorithm with distributed computing, positive feedback, heuristic search and self-organization, which simulates the behavior of ant colony searching for the shortest path when foraging. Literature [12] improved the ant colony algorithm and introduced the neighborhood search operator to transform the fault reconstruction of ship power grid into a subset class optimal selection problem for solving and calculation, and achieved good reconstruction results. Literature [13] improves the algorithm's search performance by adopting adaptive adjustment mechanism and limiting the value range of pheromone on the search path for some important parameters (ρ, α, β) involved in the basic ant colony algorithm, so as to overcome its defects of prematurity and slow convergence to a certain extent. Literature [14] puts forward a new strategy that integrates genetic algorithm into ant colony algorithm and uses crossover operation of genetic algorithm to generate new travel path of ant colony algorithm. The global searching ability of ant colony algorithm is improved. Literature [15] proposed the reconstruction and fault recovery of urban distribution network based on graphical ant system algorithm, and modified the edge selection rules and pheromone update rules of traditional ant colony algorithm to avoid the algorithm falling into local optimum.

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Compared with other heuristic algorithms, ant colony algorithm has strong robustness and ability to search better solutions. Ant Colony Algorithm (ACO) is a kind of evolutionary algorithm based on population, which is essentially parallel and easy to be implemented in parallel. Ant colony algorithm can be easily combined with a variety of heuristic algorithms to improve the algorithm performance. However, ant colony algorithm convergence speed is slow and easy to fall into local optimal.

4.2 Genetic algorithm

Literature [16] proposed adaptive genetic algorithm and improved adaptive genetic algorithm for network reconstruction of ship power system. In order to accelerate the convergence speed of the algorithm, the paper proposes the concept of all branch coding, simulating the failure of any branch and the concept of gene complement. Literature [17] proposed a network reconstruction idea of multi-agent Marine power system based on evolutionary genetic algorithm, which proved that genetic algorithm increased the global optimization ability of the system due to the characteristics of the agent itself, improved the optimization effect, and accelerated the convergence of the optimal solution. Literature [18] proposed a chaotic adaptive genetic algorithm, which accelerated the convergence speed and precision of the algorithm. Realize the fault recovery of ship power system.

Genetic algorithm has good convergence, less computation time and higher robustness when the calculation accuracy is required. However, genetic algorithm can't solve the problem of large scale computation well, and its efficiency is low, and it is easy to converge prematurely.

4.3 Artificial neural network algorithm

In Literature [19], BP neural network is applied to fault diagnosis and maintenance of Marine electric propulsion system, which can improve the learning speed and diagnosis effect of the network. There are mainly two kinds of optimization models in neural network: Hopfield feedback neural network and BP network. The pattern recognition method is used to generate input and output data pairs for training, and then the BP network is trained off-line. By using its nonlinear mapping ability, the corresponding system control strategy is given for the specific system running state in the actual operation. Since it takes a lot of time to learn the connection weights and bias parameters of the network and requires a large number of samples, this method also has poor ability to use system information [20]. Hopfield feedback neural network is suitable for the calculation of combinatorial class optimization problems, and has been successfully applied to the solution of combinatorial optimization problems such as TSP. The energy function of gradient descent is established, the minimum point of the function corresponds to the stability point of the system, and then the minimum value of the function corresponds to the optimal solution of the optimization problem. In the optimization process, the energy function and output of the neuron should be corresponding with the system constraints, given conditions and solutions of the problem to construct the energy function.

The most important feature of artificial neural network algorithm in the optimization process of network reconstruction is that it can use neurons to store the relationship between input and output. Therefore, once the weight of ANN is determined, as long as the input is given, the output can be obtained immediately, which can greatly reduce the calculation time of reconstruction. However, the shortcoming of artificial neural network lies in the great relationship between its optimal solution and the data of the training group, and the frequent changes of the structure and correspondence of the power grid, so its weight needs to be changed frequently, which limits its practicability. Moreover, this optimization algorithm is easy to fall into the defect of local optimal solution, and for large-scale system optimization, the convergence time is more expensive.

4.4 Particle Swarm Optimization Algorithm

Literature [21] improved the particle swarm optimization (PSO) algorithm and dual particle swarm optimization (DSO) algorithm, and compared with other intelligent algorithms, it can quickly obtain a more perfect scheme for ship power grid reconfiguration. Literature [22] adopts the particle swarm optimization algorithm and the improved particle swarm optimization algorithm. Through discretization, the improved particle swarm optimization algorithm is converted into binary

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application during fault recovery to obtain the best recovery scheme. Compared with the genetic algorithm under the same circumstances, the improved particle swarm optimization algorithm has better performance. Literature [23] proposed an improved particle swarm optimization algorithm combining "knapsack strategy" and simulated annealing operator for solution, which can obtain a better and more complete scheme for ship power system reconstruction, and the algorithm has better optimization performance. Literature [24] proposed an improved dual particle swarm optimization algorithm. Through chaos initialization, adaptive adjustment of parameters and learning factors, and chaotic local search strategy, the optimization ability and convergence accuracy of the algorithm were improved, and the stability and rapidity of system fault reconstruction were guaranteed.

Particle Swarm Optimization (PSO) algorithm has fast searching speed, high efficiency, simple algorithm and is suitable for real value processing. However, the discrete optimization problem is not well handled, and it is easy to fall into local optimum.

4.5 Differential evolution algorithm

Literature [25] proposed a kind of composite adaptive multi-objective differential evolution algorithm. The composite adaptive differential evolution algorithm is combined with the optimization framework of multi-objective evolutionary algorithm NSGA-II to improve the ability of ship power grid reconstruction. Literature [26] proposed a chaotic adaptive differential evolution algorithm, which used chaos optimization to generate the initial population and ensure the diversity of the population. The adaptive mutation operator and crossover operator were introduced to accelerate the convergence speed of the algorithm. Literature [27] proposed a distribution network reconstruction method based on differential evolution, and adopted the decimal based ring coding method to solve the problem that binary coding produces a large number of infeasible solutions. Literature [28] proposes an improved binary differential evolution algorithm, which adaptively improves the scaling factor F of the control parameters and the crossover probability CR, so as to ensure a fast convergence speed and greatly improve the ability of global optimization. Literature [29] proposed a hybrid algorithm based on particle swarm optimization and differential evolution, which significantly reduced the power loss of the network.

The basic differential evolution algorithm is easy to converge to the local minimum prematurely, or cause the algorithm to stagnate. The differential evolution algorithm can be combined with other intelligent algorithms to improve its defects.

4.6 Tabu search algorithm

Tabu search algorithm uses the "memory" technology to avoid repeated work in the optimization process. Tabu table is set to record the points of the local optimal solution to avoid falling into the local optimal point in the process, so as to get the global optimal result. The advantages of this method are that it is easy to obtain the global optimal solution, has the tolerance to the non-optimal solution, and has the flexible memory. However, the disadvantage is that the results are greatly affected by the initial solution, and the parallel search of the optimized results cannot be realized, so the solution process takes a long time.

4.7 Simulated annealing algorithm

The simulated annealing algorithm is not limited by the initial structure of the system and has no special requirements on the objective function, so the global optimal solution is obtained. However, the calculation amount, solution time and solution accuracy of this method are easily affected by the number of iterations, temperature design and other parameters. Literature [30] adopts the genetic simulated annealing algorithm based on two-dimensional coding to realize the fault recovery of integrated power system.

4.8 Multi-agent algorithm [31]

In recent years, multi-agent network reconstruction technology has been paid attention to by many countries. This intelligent algorithm has the advantages of fast convergence speed and strong

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optimization ability, which is more practical and efficient for solving the network reconstruction of large ship power system.

Literature [32] proposes a multi-agent and particle swarm optimization algorithm, which can better reconfigure the ship power system network. Literature [33] proposes a fault recovery method of ship power system based on multi-agent system, so as to restore power supply of high-priority outage loads as much as possible. Literature [34] proposes an idea of network reconstruction of multi-agent ship power system based on particle swarm optimization algorithm. Based on the particle swarm optimization algorithm, the global optimal solution of multi-agent system is given to realize the freedom of network reconstruction and power supply.

4.9 Hybrid intelligent optimization algorithm

In Literature [35], genetic algorithm and simulated annealing algorithm are combined to carry out fault reconstruction of Marine power system. This method can give consideration to multiple indicators of Marine power system fault reconstruction, effectively avoid the generation of extreme solution, and can flexibly adjust the propulsion load recovery power of Marine power system, and the optimal fault recovery scheme obtained is more in line with the reality. Literature [36] combining particle swarm optimization (PSO) algorithm and ant colony algorithm, and put forward the suitable for ship power system fault after the reconstruction of a mixture of ant colony algorithm, particle swarm optimization results show that after selecting suitable parameters, the proposed algorithm compared with particle swarm optimization (PSO) algorithm and ant colony algorithm, the search has faster speed and higher probability convergence to the global optimal solution, prove the feasibility and effectiveness of the algorithm. Literature [37] combines binary particle swarm optimization algorithm with differential evolution algorithm to improve the fault reconstruction efficiency of ship power system

5. Conclusion

In this paper, the existing methods of Marine power system fault reconstruction are summarized for Marine power system faults. According to the mathematical optimization algorithm, heuristic algorithm and intelligent optimization algorithm, this paper mainly introduces the model and constraint conditions of Marine power system fault reconfiguration, and the advantages and disadvantages of various intelligent optimization algorithms for Marine power system fault reconfiguration. Genetic algorithm, particle swarm optimization algorithm, multi-agent algorithm and other intelligent optimization algorithms are used to reconstruct the Marine power system in the research of fault reconfiguration. However, the optimization time of artificial intelligence algorithm is long and its efficiency is low. Therefore, it is necessary to put forward an algorithm which can not only shorten the time of reconfiguration of Marine power system, but also obtain global or approximate global optimal solution through further optimization or combination, so as to realize the rapid recovery of Marine regional distribution power system after failure. This is a direction of future efforts. Current study of fault system of regional distribution power system reconstruction are not considering the influence of uncertainty factors, how to conform to the actual the uncertainty information expression and use, how to uncertain data into intelligent fault reconstruction algorithm, in order to improve the system of restorative reconstruction results to optimize the credibility of the requirements for applicability is to improve the reconstruction algorithm. Due to the different operation modes of the ship in wartime and in normal sailing, the fault reconstruction strategy should be adjusted accordingly, and different fault reconstruction modes should be implemented according to the different operation states of the ship's power system. To solve this problem, the methods of combining island division with network reconstruction can be considered to eliminate the nodes connected with the contact switch branch, reduce the isolated branches and nodes, and improve the efficiency of fault reconstruction of ship power system. This method is applicable to all kinds of complex network structures and will be the focus of future research.

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