Summary of research on distribution network reconfiguration

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Abstract. Distribution network reconfiguration is an important means to optimize the operation of distribution network. The reconfiguration of distribution network can change the opening and closing state of segmentation switch and tie switch in the distribution network without increasing investment. It can achieve the purpose of reducing network loss, balancing load to eliminate overload and light load, improving power supply reliability and improving power supply voltage quality. Therefore, it has important practical significance to accelerate the problem of distribution network reconfiguration. In this paper, the mathematical model of distribution network reconfiguration is given for the characteristics of distribution network, and various algorithms for distribution network reconfiguration are introduced. The advantages and disadvantages of various algorithms are analyzed, and the distribution network is more comprehensively reflected.

1. Introduction

The distribution network generally has the characteristics of closed-loop design and open-loop operation. In any distribution network, there is theoretically an optimal network structure. Under this optimal structure, the coordination of the operating voltage and network loss load balance of each load point is better than other possible solutions. When the load changes, this optimal structure also changes, and the optimal structure is calculated to make the network run in an optimal state. This is the main content of the research on distribution network reconfiguration[1].

On the basis of the existing distribution network, reconfiguring the network can improve the security and economy of the system, and has great economic and social benefits. The significance of distribution network reconfiguration are mainly:(1) Reduce distribution line loss and improve system economy;(2) balance the load, reduce the occurrence of overload conditions and improve the quality of the supply voltage;(3) improve power supply reliability[2].

2. Mathematical Model of Distribution Network Reconfiguration

The distribution network reconfiguration was first proposed by A. Merlin in 1975[3]. This method has attracted much attention because of its important role in improving system power quality and reducing network loss. Early distribution network reconfiguration mainly studied how to supply power to new users through the power supply path to minimize the total cost, that is, to study the distribution network planning problem. Later, domestic and foreign scholars gradually applied the distribution network reconfiguration to the distribution automation system. The research results show that adding network reconfiguration in the distribution automation system can reduce line loss, balance load and improve power quality, etc., but also in economy and technology. It is all feasible[4]. The objective
function of the distribution network reconfiguration can be an indicator or a combination of several indicators. The objective functions of common distribution network reconfiguration are: minimum active loss, load balancing, improved power quality, and improved system stability and reliability[5].

2.1. **Mathematical model with the minimum line loss as the objective function**
The line loss of the distribution network includes the loss of the wire on the line and the copper loss and iron loss of the transformer. Generally, the reconfiguration through the distribution network can only affect the former, so the objective function with the smallest line loss can be expressed as:

$$\min f_i = \sum_{i=1}^{n_b} r_i k_i |I_i|^2$$

(1)

Where $n_b$ is the number of branches in the distribution network; $r_i$ is the resistance of the $i$ branch; $I_i$ is the load current flowing through the $i$ branch; $k_i$ is the state of the switch, 0 means the switch is open, 1 is the switch closure. Generally, it is required to satisfy voltage constraints, branch overload constraints, transformer overload constraints, etc.

2.2. **Mathematical model with a balanced load as the objective function**
The objective function of aiming at uniform load distribution and improving the safety and power quality of the power grid is:

$$\min \sum_{i=1}^{b_N} \left( \frac{S_i}{S_{i,max}} \right)^2$$

$$\min LB_{sys} = \frac{1}{N} \sum_{i=1}^{b_N} \frac{S_i}{S_{i,max}}$$

(2)

(3)

Where $S_i$ and $S_{i,max}$ are the apparent power and capacity of branch $i$, $LB_{sys}$ is the load balance pointer of the system, and $b_N$ is the total number of branches of the system.

2.3. **Mathematical model with an objective function to improve system reliability**
With the goal of improving system stability and reliability, the system can carry more load and reduce the possibility of load shedding. A typical objective function is:

$$\min \sum_{i=1}^{N_p} Lav_i Lu_i (R)$$

(4)

Where $N_p$ is the sum of the number of system load points; $Lav_i$ is the average load of load point $i$; $Lu_i$ is the annual outage time of load point $i$; $R$ is the state of all interval switches in the network.

2.4. **Mathematical model with an objective function to improve voltage quality**
Improving voltage quality is a main goal of distribution network reconfiguration. Bi Pengxiang et al. proposed the voltage balance index as the objective function, $TS_{i,j}$ represents the communication switch between node $i$ and node $j$, and defines $VBL_{i,j}$ is the voltage balance index at the contact switch $TS_{i,j}$ in the loop.

$$VBL_{i,j} = \max[U_i, U_j] / \min[U_i, U_j]$$

(5)

$\max[U_i, U_j]$ means to take the larger one, and $\min[U_i, U_j]$ means to take the smaller one, thereby obtaining an objective function for improving the voltage quality.
\[
\min \sum_{i, j \in a} VBL_{i,j}
\]  

(6)

Where \( a \) is the node at both ends of the contact switch \( TS_{i,j} \).

3. Introduction to Distribution Network Reconfiguration Algorithm

Distribution network reconfiguration algorithm is another research hotspot of distribution network reconfiguration problem. The performance of the algorithm has a great influence on the quality of the solution optimized by distribution network reconfiguration. Since each distribution iteration of the distribution network reconfiguration needs to carry out the power flow calculation of the distribution network, a large number of distribution network power flow calculations require a lot of calculation time. In order to improve the calculation speed, the researchers proposed many different methods to solve the problem of distribution network reconfiguration. At present, the algorithms used to solve the problem of distribution network reconstruction mainly include traditional mathematical methods, heuristic methods, artificial intelligence algorithms and hybrid algorithms[6].

3.1. Branch Exchange Method

The branch exchange method is a method of determining the opening and closing of the switch according to the amount of change in the network loss caused by the opening and closing state of the switch. Most of these methods are based on a network loss estimation formula. Compared with traditional mathematical optimization methods, the computational complexity is small, and combined with heuristic rules can get better calculation speed, which has a good application prospect, but may be caused by reconfiguration. Large load transfer and voltage change, so the network loss estimation may have a large error, and the algorithm can’t guarantee to obtain the global optimal solution, and the obtained optimization result is related to the initial structure of the network[7].

3.2. Optimal Flow Pattern

The optimal flow pattern is derived from the minimum net loss as the objective function under the premise of satisfying the load demand, and is a heuristic algorithm for solving the problem of distribution network reconfiguration. It takes the minimum power loss as the objective function. In the solution process, all the switches are first closed to form a multi-ring network, and then the reactance part of all the branch impedances in the network is removed, and the current distribution of the pure resistor network is obtained as the optimal system. In the flow mode, the switch that flows the least current in this optimal flow mode is opened to unwind a loop. Then further calculate the optimal flow of the network after unwinding and open the switch with the smallest current in the resulting network, and then repeat the calculation until the network returns to radial[8-9].

3.3. Simulated Annealing

The simulated annealing simulates the physical annealing of molten metal and uses the random search optimization process to find the optimal solution. It has good convergence and can generally obtain the global optimal solution or suboptimal solution. It is an effective algorithm to solve the hybrid optimization problem. The main point of the SA is to design a suitable global cooling process, such as to determine the initial cooling temperature, the cooling rate, the number of switches per exchange, and the total number of exchange switches at each temperature. The network structure formed by the exchange switch, the calculator trend and the network loss, if there is a small network loss, it is retained, otherwise it is accepted according to a certain probability. Continue to exchange switches until the maximum number of switch exchanges is reached. Continue cooling until the end criterion is met[10].

3.4. Genetic Algorithm

Genetic algorithm is derived from evolutionary theory. It is a search algorithm based on the principle of natural selection and genetic genetics. It introduces the biological evolution principle of “survival of
the fittest, survival of the fittest” into the coding string group formed by the parameters to be optimized, and the superiority of the simulated gene string. Method for searching and optimizing information for survival and random exchange of information. The genetic algorithm encodes the switch state in the network into a binary string, each corresponding to a fitness function, and through a large number of calculations, selects the most suitable network structure as the optimization. The genetic algorithm is simple, robust, and easy to find the global optimal solution or suboptimal solution. Although the calculation is large, the calculation time is still less than the simulated annealing algorithm[11].

3.5. Ant Colony Optimization
The ant colony algorithm is a global combination optimization algorithm that mimics the ant colony foraging behavior. The ant colony algorithm is a new type of bionic optimization algorithm proposed by M. Dorigo, and successfully solves some combinatorial optimization problems. In the process of searching for food in the ant colony, communication and collaboration with the entire ant colony is carried out through the pheromones left on the way he passes, forming positive feedback throughout the ant colony: the more ants that pass through a path, there will be more ants to choose the path, so that the ant colony slowly gathers to the shortest path[12].

3.6. Particle Swarm Optimization
The particle swarm optimization algorithm continuously adjusts each particle through local optimal and global optimal information, and the individuals in the group use the method of cooperation and information sharing to find the optimal solution. The particle swarm optimization algorithm is a swarm intelligence optimization algorithm that mimics the migration and clustering behavior of the bird foraging process. The particle swarm optimization algorithm has the characteristics of parallel processing, good robustness, etc. It has the advantages of less setting parameters, simple and easy implementation of the algorithm, fast convergence, and easy combination with other algorithms. However, the particle swarm optimization algorithm has poor global search ability and has the disadvantage of being easily trapped in local optimum[13].

3.7. Tabu Search
The tabu search algorithm is a heuristic search method that extends the neighborhood. It is a simulation of human intelligence and an effective algorithm developed in recent years to solve large-scale combinatorial optimization problems. The algorithm can jump out of the local best advantage with a large probability, avoiding the roundabout search by introducing a flexible storage structure and corresponding taboo criteria, and avoiding some excellent conditions of taboo by scorning the criteria, thus ensuring effective exploration of diversification. Ultimately achieve global optimization. One of the biggest advantages of the tabu search algorithm is to use the taboo table to record the local best of the arrivals, to avoid searching for these points in the next search, in order to avoid convergence to the local optimal solution, but the algorithm's dependence on the initial state. It is relatively strong, and the tabu search algorithm algorithm adopts single-point search optimization, which is easy to fall into the local optimal solution, not parallel search[12-14].

4. Conclusion
The objective function of the distribution network reconfiguration can be an indicator, or it can be comprehensive optimization of some indicators. When solving practical problems, each algorithm has certain deficiencies. The single algorithm has contradictions in the acquisition of global solutions and the computational time. Therefore, the hybrid algorithm that combines the advantages of two or more algorithms is paid more attention. Distribution network reconfiguration is an important part of distribution automation. In recent years, scholars from various countries have done a lot of work on the comprehensive optimization of multi-objective functions and various optimization solutions in
order to find the best solution for distribution network reconfiguration research, which is reliable and safe for distribution network, and it have important significance of economics.

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