Summary of Research on Power Flow Optimization Algorithms for Microgrid

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Abstract—With the development of microgrid, more and more scholars have participated in the optimization research of microgrid power flow. This article mainly summarizes the algorithms for power flow optimization of microgrid, including the Newton-Raphson method, PQ decomposition method, nonlinear programming power flow algorithm, interior point method, forward and backward substitution method, and artificial intelligence algorithms such as particle swarm algorithm, genetic algorithm, simulated annealing and various hybrid algorithms.

1. Introduction
The benefits of distributed generation are security, economy, and enhancement of power quality and its development has captured a great deal of attention. The microgrid based on distributed power generation can not only play the virtues of distributed power, but also effectively solve many problems caused by distributed power grid integration. Microgrid refers to a small power generation and distribution system composed of distributed power sources, energy storage devices, energy conversion devices, and monitoring and protection devices¹. The main research object of the microgrid is the operation and control of microgrid. However, there is little researcher on the generation performance of various distributed generation in the microgrid, the cooperation between storage devices and distributed generation, and the influence of microgrid power flow on stable voltage and energy quality. Therefore, it is very urgent to study the optimal power flow of microgrid².

2. Microgrid structure
The AC microgrid has always been the technical core of the AC microgrid at home and abroad. The AC microgrid does not change the original AC grid network structure, and is suitable for transforming the original AC grid structure to form an AC microgrid network structure. Refer to a microgrid system structure diagram proposed by the American Electrical Reliability Technology Solutions Association to get a typical medium and low voltage AC microgrid as shown in Figure 1.
The structure of the microgrid shown in Figure 1 includes three feeders with different loads: A, B and C. Feeder A is an important load. If the power supply is interrupted, there will be a significant loss (sensitive load). Feeder B is capable of realizing a reasonable regulation load. Both feeders are equipped with distributed power supplies. Feeder C is a general load. When the microgrid is operating on an island, the load is insufficient or there is a line fault in the grid, the feeder C can be stopped from the power.

3. Microgrid power flow optimization model

The optimization of the target power flow of the microgrid is to solve the problem by setting all the power output distributed in the micro power supply in the power supply system, the rectified susceptance in the circuit, the phase shift angle and other control variables, so as to meet various microgrid power flow equations. Under the condition of sum inequality power flow restriction, the preset target power flow function of the system can be optimally solved. The primary mathematical calculation mode is described as follows:

\[
\begin{align*}
\text{Min} & \quad f(x, u) \\
\text{s.t.} & \quad g(x, u) = 0 \\
& \quad h(x, u) \leq 0
\end{align*}
\]  

The \( f(x, u) \) in the formula (1) is a predetermined objective function, and different objective functions are given according to the purpose of optimization; \( g(x, u) \) is a constraint on the equation; \( h(x, u) \) is the constraint on the inequality; \( x \) is the state variable, \( u \) is the control variable.

The equality constraints are:

\[
P_{Di} = P_i + \sum_{j=1}^{n} V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \\
Q_{Di} = Q_i + \sum_{j=1}^{n} V_j (G_{ij} \cos \delta_{ij} - B_{ij} \sin \delta_{ij})
\]  

\( i = 1, 2, \cdots, n \)  

The inequality constraints are:

\[
P_{Di} \text{min} < P_i < P_{Di} \text{max} \\
Q_{Di} \text{min} < Q_i < Q_{Di} \text{max} \\
V_{i \text{min}} < V_i < V_{i \text{max}}
\]

Equation (2) is the essential power flow constraint, \( n \) is the number of nodes; \( P_{Di} \) and \( Q_{Di} \) are the active and reactive power generation at node \( i \) of distributed power generation; \( P_i \) and \( Q_i \) are the active load and reactive load of node \( i \); \( V_i \) and \( V_j \) are the voltages of nodes \( i \) and \( j \), respectively; \( \delta_{ij} \) is the phase angle difference between nodes \( i \) and \( j \); \( G_{ij} \) and \( B_{ij} \) are the conductance and susceptance between nodes \( i \) and \( j \), respectively.

In formula (3), \( P_{Di \text{min}} \) and \( P_{Di \text{max}} \) are the minima and maximum active output power of distributed power. In formula (4), \( Q_{Di \text{min}} \) and \( Q_{Di \text{max}} \) are the minima and maximum reactive output power of distributed power. In formula (5), \( V_{i \text{min}} \) and \( V_{i \text{max}} \) are the lowest and highest output voltage.
4. Traditional power flow optimization algorithm

Traditional power flow space optimization algorithms mainly include Newton-Raphson method, P-Q decomposition method based on Newton-Raphson method, and power flow algorithm of nonlinear space planning, interior point method, forward and backward substitution method and so on.

Newton-Raphson method has been widely used in the past few decades because of its convergence and fast calculation speed. However, the initial value of the Newton-Raphson method is more demanding. When the initial value is not set correctly or the system is not working properly, when this method is used to calculate, there will often be too slow convergence, spreading or even oscillation.

Compared with the Newton-Raphson method, the P-Q decomposition method improves the calculation speed. The nonlinear programming power flow algorithm also includes the higher-order terms above the second order in the Taylor series, and then expresses the power flow calculation as a model of an unconstrained nonlinear programming problem.

The interior-point method does not require trial iterations, so programming is more straightforward than Newton’s method and easy to implement[3]. The interior-point method has good convergence ability for solving linear programming with constraints and quadratic constraints.

The forward and backward substitution method calculates the current of each branch from the end, and then calculates the voltage of each node from the root node backwards until the difference between the current iteration value of the voltage of each node and the previous iteration value is less than the preset accuracy, and the power flow calculation Convergence is over[4]. This method occupies a small amount of memory and has a fast iteration speed, so it is widely used.

5. Intelligent Algorithm

5.1. Particle Swarm Optimization(PSO)

The PSO intelligent algorithm first initializes the particle swarm in the solvable enclosure. A piece granule delegates the latent best solution of the extreme value optimization problem. They use the three criteria of position, speed and adaptability to delegate the peculiarity of the particles. The granule movement is in a solvable space, and the individual extreme value pbest and the population extreme value gbest are tracked to update their individual positions. The extreme value pbest of an individual is the best position for calculating fitness according to the position experienced by the individual, and the extreme value gbest of the population is the best position for the fitness found by all the particles of the population. Each particle changes its position and calculates the fitness value again. By comparing the fitness value of the new particle with the individual extreme value and the population extreme value, the individual extreme value pbest and the group extreme value are updated.

At every turn iteration process, the particles update their velocity and place through unit extreme values and population extreme values. The formula is as follows:

\[ V_{id}^{k+1} = \omega V_{id}^{k} + c_1 r_1 (p_{id}^{k} - V_{id}^{k}) + c_2 r_2 (p_{gd}^{k} - V_{id}^{k}) \]  

\[ X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \]

In the above formula, V is speed, and two correction terms are added to the current speed: the distance between the individual and the optimal individual in the current path, and the deviation from the optimal value of the group. c_1 and c_2 are coefficients, r_1 and r_2 are random numbers.

X is the position, the current position is added to the speed. According to the adjacent time interval, the default is a time unit, so the speed and distance can be added directly.

5.2. Genetic algorithm

Genetic algorithm mainly follows the principle of survival of the fittest. It refers to a random search algorithm used to learn from the natural laws of human biology to select and study the genetic evolution mechanism of natural organisms. Genetic algorithm is mainly used to simulate a process of modern human biological population genetic evolution. Through the three mechanisms of static selection, crossover and dynamic mutation, individuals in a set of candidates are retained in each iteration. After
successive generations of evolution, the population environmental adaptability has reached the approximate optimal population level. Since the concept of genetic algorithm was put forward, genetic algorithm has been playing an important guiding role in pattern recognition, neural network, custom adaptive control and other aspects, which has improved our work efficiency in solving these problems. The flow chart of genetic algorithm is shown in Figure 2.

![Flow chart of genetic algorithm](image)

**Figure 2 Flow chart of genetic algorithm**

5.3. *Simulated annealing*

The simulated annealing algorithm is a method for approximately solving optimization problems based on the Monte Carlo method. The simulated annealing algorithm is actually a greedy algorithm, but random factors are introduced in the search process. The simulated annealing algorithm accepts a solution that is worse than the current solution with a certain probability, thereby jumping out of the optimal local solution and reaching the optimal global solution.

The main advantages of the SA algorithm are: First, the algorithm can accept a certain solution, so it effectively increases the diversity of the population, so that the algorithm jumps out of the local advantage; second, the algorithm has a better local search function, which is useful for finding Complicated optimization problems are of great help [5].

5.4. *Ant Colony Algorithm*

Marco Dorigo proposed an ant colony foraging algorithm in 1992. Its design is mainly inspired by the foraging in the colony. No matter what the relationship between their main food and the entire ant colony, ants hope to find the shortest quickly. Foraging paths, no matter what they eat. The results of the study show that ants may leave behind a volatile chemical substance called on pheromone when they climb the road. This volatile substance has provided a way for other ants to climb the road to exchange food information.

In the process of path selection, the ants adopt a random probability path selection method. If no other ant chooses to leave a pheromone, it is completely random path selection, otherwise, choose this random path Probability is not inversely proportional to the strength of this pheromone. After a period of time, when choosing an ant path, the more ant information becomes, the greater the quality and intensity of the remaining ant information, the ants can choose the shortest path through this method [6].

Ant colony algorithm is an essentially parallel algorithm. The individual ants must be independent of each other in the search and analysis process. They communicate with each other only through the hormones in the information. They can simultaneously perform data search independently in a problem.
analysis space, which not only greatly improves the reliability of the ant algorithm, but also greatly improves the reliability of the ant algorithm. Improve the global data analysis ability of the ant algorithm.

5.5. Hybrid algorithm

Literature [7] proposed an improved hybrid particle swarm optimization algorithm. The traditional BPSO (Discrete Binary Particle Swarm Optimization Algorithm) has a powerful global search function, but it cannot converge to the optimal global value, and as the algorithm iteratively searches, The randomness is getting stronger and stronger, and the local search ability in the later stage is lacking. The concept of hybridization in genetic algorithms is introduced into BPSO to increase the diversity of individuals. Then use the metropolis mechanism to increase the diversity of individuals and avoid precocity.

Literature [8] uses a dynamic penalty function to convert the power flow optimization problem into an unconstrained extreme value, and uses the PSO algorithm to solve it. The solution method of introducing penalty function is to introduce equality constraints and inequality constraints into the objective function, thereby generating a new function.

Literature [9] integrates the advantages of particle swarm optimization and cuckoo search algorithm by adopting the upper and lower layer architecture, uses PSO to optimize in the lower layer, and sends the optimal solution of the population to the upper layer for deep optimization by the cuckoo search algorithm. The CS-PSO algorithm effectively reduces the active power loss and improves the voltage level of each node.

Literature [10] is an algorithm based on artificial fish school, which draws on the advantages of chaos optimization algorithm on its basis. Solve the problem that the convergence speed of artificial fish school is slow and it is easy to fall into the local optimal solution.

6. Research prospects

With the development of distributed power sources and microgrids, smart grids are playing an increasingly important role in the grid system. The purely optimized power flow algorithm can no longer satisfy the online calculation of power flow. Therefore, a combination algorithm based on traditional and intelligent algorithms will be a new direction for power flow optimization algorithms.

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