Multi-objective distribution network planning method with distributed generation based on non dominated sorting differential evolution algorithm

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Abstract—Combined with the specific problems of distribution network planning with distributed generation, this paper constructs a multi-objective optimization model of distribution network planning with distributed generation. According to the distributed generation distribution network layout planning with distributed generation, under the condition of uncertain load prediction value of distributed generation distribution network, taking the minimum voltage stability index, minimum network loss and minimum investment cost of distributed generation as sub objectives, a multi-objective programming model is established, and the model is solved by non dominated sorting differential evolution (NSDE) algorithm.

1. Introduction

Distribution network planning with distributed generation is based on the current situation of distribution network with distributed generation and the growth of existing load, and puts forward a set of scheme for the expansion and transformation of the whole system. After meeting the requirements of power quality and future load power consumption, upgrade the line and wiring mode and expand or increase the capacity of substation, with high efficiency, safety and high quality as the index, The optimal scheme is adopted as the planning scheme to meet the power demand of users and maximize the benefits of the power supply department.

The distribution network layout planning of distributed generation with distributed generation is the planning of power generation. According to the local policies, environment, available resources and other actual conditions, considering the economic interests of power investors, and on the premise of reliable, stable and safe operation of the system, the appropriate capacity distributed generation is connected to the best location of the distribution network with distributed generation; Generally, the interests of the power grid are taken as the center, the minimum economic cost is taken as the goal, and the reliable operation of the power grid is ensured. Considering the annual growth of load, comprehensive planning includes the installation of distributed power generation, substation expansion and feeder upgrading.

Starting from the practical engineering problems in distribution network planning with distributed generation, this paper constructs a multi-objective optimization model for distribution network planning with distributed generation. According to the distributed generation distribution network
layout planning with distributed generation, under the condition of uncertain load prediction value of distributed generation distribution network, taking the minimum voltage stability index, minimum network loss and minimum investment cost of distributed generation as sub objectives, a multi-objective programming model is established, and the model is solved by non dominated sorting differential evolution (NSDE) algorithm.

2. Research on Non Dominated Sorting Differential Evolution (NSDE) algorithm

2.1. Basic idea and process of NSGA-II

Multi-objective evolutionary algorithms (MOEA) uses its global search function to find the optimal solution set, and does not accurately measure the weight relationship between objectives. Fast non dominated sorting genetic algorithm with elite strategy (NSGA-II) is the most commonly used and effective MOEA. It inherits from the state of non dominated sorting genetic algorithm (SGA). In order to ensure the uniform distribution of non inferior solutions and improve the robustness and operation speed of the algorithm, it adopts solution-based non dominated sorting level and congestion distance, elite retention strategy and Pareto non dominated fast sorting selection operator. It is a Pareto optimal multi-objective evolutionary algorithm [104].

![Fig.1 Basic steps of NSGA-II algorithm](image)

The steps of NSGA-II algorithm are as follows: firstly, an arbitrary initial population is obtained and its scale is NP. The first generation population is obtained from the initial population through non dominated sorting and mutation, crossover and selection operations of genetic algorithm. Starting from the second generation, the offspring population and the parent population are combined to obtain a population size of 2np. They are sorted by the fast non dominated sorting method, and the crowding degree of objects at the same level in the sorting results is calculated. A new parent population is obtained according to the crowding degree of individuals and the non support relationship between them. Next, the new offspring population is obtained from the new parent population through genetic algorithm. The specific process is shown in Fig. 1.
2.2. Sorting and selection mechanism of NSGA-II algorithm

NSGA-II adopts a fast non dominated sorting method which can reduce the computational complexity. In the selection mechanism of individual evolution, only the Pareto sorting algorithm is used, which does not think of the spatial distribution density of individuals and only calculates the dominant relationship between individuals. Therefore, many similar solutions appear, so the diversity of solutions cannot be guaranteed. However, NSGA-II can ensure the diversity of the population and make the population individuals spread to the Pareto domain in the form of uniform distribution. Because the standard of peer comparison after fast sorting is congestion, instead of NSGA, it needs to specify the fitness sharing strategy of sharing radius, and uses the comparison operator of congestion and congestion. In addition, the algorithm uses the elite strategy to save the excellent Goth in the parent generation, expand the sampling space and avoid losing the Pareto optimal solution. The selection mechanism of the algorithm and the main contents of sorting are as follows:

(1) Elite strategy: in order to obtain a better new generation population, the parent individual is retained and directly enters the offspring population to compete with it. The basic steps are:

Step 1: merge all individuals of offspring \( Q^G \) and parent \( P^G \) to form a new species group \( R^G = P^G U Q^G \), and the number of individuals is \( 2N_p \);

Step 2: quickly non dominated sorting the population \( R^G \) to obtain the non dominated solution set \( \{ F_1, F_2, \cdots, F_j \} \), where \( F_i \) represents the individual set with the non inferior frontier level of 1, so that the next generation population can be \( P^{G+1} = \emptyset \) and \( \text{rank} = 1 \), and then individuals can be selected according to the level. When \( |P^{G+1}| + |F_{\text{rank}}| \leq N_p \), \( P^{G+1} = P^{G+1} \cup F_{\text{rank}} \) and \( \text{rank} = \text{rank} + 1 \) can be deduced. Otherwise, the crowding distance of each individual in \( F_{\text{rank}} \) is calculated, and the individual is selected according to the individual crowding degree until the number of individuals reaches \( N_p \), and a new parent population \( P^{G+1} \) is formed;

Step 3: the new offspring population \( Q^{G+1} \) is formed by using variation, crossover and selection operations in genetic evolution.

(2) Selection mechanism: in the selection process, ensure that the optimization direction is the direction of Pareto optimal solution, and the distribution of solutions should be uniform. After crowding distance calculation and non dominated ranking, all individuals in the group have two attributes, namely crowding distance \( i_j \) and non dominated ranking \( i_{\text{rank}} \). When \( i_{\text{rank}} = j_{\text{rank}} \) and \( i_x > j_x \), individual \( i \) is better than individual \( j \). When two individuals are at the same level, the individuals with smaller surrounding density (less crowded) are selected; When the non inferior frontier level (non dominated ranking level) of two individuals is different, the individual with small level (high level) is selected. For the solution with small congestion, under this selection mechanism, we can think that there are more approximate solutions distributed around it. In addition, the next generation population in this mechanism preferentially selects individuals with large crowding distance value to make the evolution move towards the direction of uniform distribution of non inferior solutions, so as to ensure the diversity of the population.

(3) Individual crowding distance: the concept of virtual fitness proposed by NSGA-II algorithm for the first time can avoid the accumulation of individuals in local areas and ensure the diversity of individuals. It refers to the distance between adjacent individuals at the same level in the target space, indicating the differences between individuals. The crowding distance is the sum of the two sides of the rectangle composed of the \( i \) individual in the target space and the individuals \( i+1 \) and \( i-1 \) adjacent to the same non dominated ranking level.

(4) Fast non dominated sorting: first classify the population based on the non dominated relationship of individuals, and then select the operation. The detailed steps are as follows:
Step 1: make all non inferior individuals contained in the selected population the same level, and the non dominated ranking level $i_{\text{rank}} = 1$ can be obtained.

Step 2: move the individual out of the population, and find a new non inferior solution from the remaining individuals, and its non dominated ranking level $i_{\text{rank}} + 1$ can be obtained.

Repeat the above steps until all individuals have their corresponding non dominated ranking levels. This level indicates that an individual can dominate several other individuals. To make the individual quality good, the rank $i_{\text{rank}}$ should be small, which means that the rank should be high. In NSGA-II algorithm, high-level individuals have the priority to enter the next generation population, which can ensure the evolution of the population.

3. Case study

A 54 node system is used as an example of distribution network planning with distributed generation (the system wiring diagram is shown in Fig. 2. The points in the diagram represent the load, line intersection and power supply point. The solid line represents the existing line and the dotted line represents the expected line corridor. In the relevant parameters of power grid planning, the unit electricity charge is 0.5 yuan / kWh, the planning cycle is 5 years, and the annual average power consumption is 6000h, including distributed power consumption. The rated voltage of the power distribution network is 10kV, the power factor of the load point is 0.85, and the construction cost per unit line is 5000 yuan / km. The running environment of the simulation program is the CPU frequency of 2.2GHz, the memory is 4GB, the compiling environment is MATLAB2009A, and the nsde algorithm parameters include population size 20, crossover rate 0.75 and mutation rate 0.1.

[Fig.2 Area to be planned]

The initial grid structure is obtained by prim algorithm, as shown in Fig. 3. The solid line represents the planned line of the initial grid, and the dotted line represents the line outside the initial grid. Based on the initial grid, code in combination with the parameters set above.
The NSDE algorithm is used for multi-objective optimization traversal of the initial grid structure to obtain the optimal result. Fig. 4 shows the optimized system structure. From the optimization results, the optimization performance of nsde algorithm and NSGA-II algorithm is compared. In terms of investment cost and network loss cost, nsde algorithm is better than ordinary nsga-Ⅱ algorithm. At the same time, the scheme calculated by nsde algorithm does not significantly aggravate the environmental impact. It can be seen from Fig. 5 and Fig. 6 that the nsde algorithm adopted in this chapter can effectively improve the search ability of Pareto preface. Compared with the traditional NSGA-II algorithm, the integrity, uniform distribution and convergence of Pareto frontier are significantly improved.
Fig. 4 Grid planning results of distribution network with distributed generation

Fig. 5 Single diode model of photovoltaic cell
It can be seen from Fig. 5 and Fig. 6 that the connection of distributed generation to the end of feeder is conducive to reduce the network loss of the system, improve the node voltage distribution of the system, and reduce the transformation investment of the line.

4. Conclusion

Combined with the specific problems of distribution network planning with distributed generation, this chapter constructs a multi-objective optimization model of distribution network planning with distributed generation. According to the distributed generation distribution network layout planning with distributed generation, a multi-objective planning model is established with the minimum investment cost, the minimum network loss and the minimum voltage stability index of distributed generation as the sub objectives, focusing on economy, stability and reliability. Based on the multi-objective optimization algorithm (NSGA-II), a non dominated sorting differential evolution (NSDE) algorithm is proposed. The feasibility and effectiveness of non dominated sorting differential evolution are verified by the example analysis of IEEE 54 node system and the comparison of NSGA-II algorithm.

References

[1] Baoyi, W., Shuo, Z., Shaomin, Z. (2014) A Distributed Load Forecasting Algorithm Based on Cloud Computing and Extreme Learning Machine, Power System Technology, 2: 526-531.

[2] Jie, W., Guozhong, W., Yanchang, L. (2009) Application of ant colony gray neural network combined forecasting model in load forecasting, Power System Protection and Control, 37:48-52.

[3] Bo, W., Zezhu, X., Songbo, G. (2009) Application of New Particle Swarm Optimization Algorithm Based on Chaotic Mapping Inertia Weight in Identifying ARMAX Model for Short-Term Load Forecasting. Water Resources and Power, 27:214-217.

[4] Shuaihua, Z., Yunpeng, J., Ping, L. (2019) Short-term Power Load Forecasting Based on Improved PSO-BP Neural Network, Industrial Control Computer, 31:145-147.

[5] Yongkang, Z., Weirong, C., Chaohua, D., Weibo, W., (2009) Gaussian Wavelet SVM and Its Applications to Chaotic Time Series Forecasting. Control Engineering of China, 4:90-93.