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Multi-objective Optimal Configuration of Distributed Generation Considering Environmental Factors

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Abstract: Although the demand for power efficiency, safety and reliability in today's society is increasing, large-scale power grids cannot meet this requirement due to their own technical problems. Because of its many advantages, distributed generation occupies an increasingly large proportion in the world power system, and it has also attracted widespread attention from all over the world. The purpose of this paper is to optimize the multi-objective configuration. First, the concept of distributed power generation technology is introduced, and the potential impact of distributed power generation on operation after being connected to the distribution network is systematically analyzed. Introducing particle swarm optimization algorithm to transform multi-objective distributed generative optimization problem into single-objective problem. In the optimization process, the adaptive penalty function method can effectively use the useful information of the infeasible solutions to make appropriate penalties for the infeasible solutions. The results of the optimal location of DG show that when the DG capacity is 2000kW, the optimal access location of DG calculated by the method introduced in this paper is 5 nodes, the active power loss at this time is 153.56kW, and the static voltage stability index is 0.0564.

1. Introduction

In today's rapidly developing society, people's demand for electricity is increasing day by day. Relying on the large power grid system of centralized power generation, as the most important power network in China, it has had a significant impact on the supply of energy demand [1]. The rapid development of microgrid technologies such as distributed generation has brought an effective way to alleviate the world energy crisis and environmental changes. Microgrid operation research has become one of the key points of microgrid development in the world, laying a material foundation for the promotion of key microgrid technologies, and its theoretical and technical significance is becoming increasingly important [2].

At present, distributed generation technology is developing rapidly around the world. Brown DP examines the potential role that demand-side charging (MDC) can play in ensuring the financial viability of facilities such as distributed generation (DG) expansions. We have found that poorly designed MDCs often benefit non-DG customers and generally benefit DG customers. However, under the right conditions, the benefits tend to be balanced. Furthermore, time-of-use pricing generally yields greater utility gains than MDC [3]. Elbasuony GS proposed an index for evaluating the power quality of distributed generation systems using AHP. Since only one number is used for comparison, evaluation is simple and efficient. Furthermore, according to the index values of different systems, it is found that the hybrid system exhibits better energy performance than other systems [4]. Walt H presents common safety challenges associated with integrating distributed generation into medium voltage distribution systems. The therapeutic challenges identified by the general scientific community are discussed in detail. Distributed photovoltaic generators (PVs) are connected to the utility grid through transformers that not only control the active and reactive parts of their production, but also limit the effects of fault currents. Several studies have been proposed to quantify the security risks of distributed generation in traditional energy systems [5]. It is of great scientific to study the optimal multi-plane configuration of distributed generation.

In this paper, the influence of the fluctuation of wind power output power on the distribution network is effectively reduced with the minimum energy storage cost, a potential optimal configuration model of a hybrid energy storage system (HESS) is established. With the increasing awareness of environmental protection and the development of clean energy power generation technologies, distributed energy generation has become a global research field. Small distributed generator sets are flexible and light to install, energy-saving and environmentally friendly, short-distance power generation, and improve power quality and power supply reliability. Distributed generation can complement and coordinate large grids to meet future energy demands. In practice, due to the large number of distribution transformers, it is difficult for power workers to test cost-effective and efficient design commutation through trial and error in numerous combinations. Therefore, in the context of the gradual integration of power generation into the distribution network.

2. Research on Multi-objective Optimal Configuration

2.1. The Impact of Power Generation on the Distribution Network

(1) Network loss

The loss of the distribution network mainly depends on the power flow distribution of the system. The grid connection of DG will change the power flow distribution of the system, thereby affecting the loss of the distribution network [6-7].

(2) Voltage distribution

The voltage must be kept within the specified voltage range to ensure system stability and good power quality. The purpose of voltage regulation of the distribution network is to allow power to flow from the power station to the load, but after the DG is connected to the grid, the distribution system changes from a radial system to a multi-power system, so the distribution of the system becomes more difficult, and the voltage of some parts of the system has changed [8-9].

(3) Impact on power quality

Its influence is mainly reflected in the following two aspects: After the voltageflicker is connected to the grid, the voltage flicker can be direct or indirect in the following cases [10-11].

2.2. Distributed Power Generation Optimization Configuration Index

(1) Economic Benefit Indicators

Economic benefits are the most important and basic indicators for evaluating distribution networks. Under the premise of satisfying social interests, the economic benefits of distributed generation can be estimated through various calculation formulas [12-13].

(2) Environmental Benefit Index

With the support and encouragement of relevant national policies, distributed generation technology has been widely used, but its environmental benefits have been difficult to truly reflect due to the lack of a reasonable evaluation mechanism and quantitative model. The large-scale use of distributed generation has changed the traditional economic dispatch mode, so that some power generation efficiency is low but the price is higher. After DG replaces these units, it will reduce the environmental pollution caused by these units [14-15].

(3) Voltage index

Voltage stability refers to the ability of a power system to maintain a load voltage level within a required operating range. It is a constant voltage, otherwise the voltage system is said to be unstable. There are basically three reasons for voltage instability: one is insufficient active output, the other is excessive active load, and the third is insufficient reactive power. After the distributed generation is connected to the grid, the original distribution network is transformed from a radial network system to a multi-channel power supply system, which will lead to a great change in the power flow distribution of the distribution network, thereby changing the voltage. Distribution will inevitably affect the stable voltage. system [16-17].

2.3. Particle Swarm Optimization

Particle swarm optimization is a kind of swarm intelligent evolutionary algorithm with parallel evolution. In particle swarm optimization, each particle represents a possible solution to the problem to be optimized. Particle information is updated during flight via position and velocity update types. Each particle can interact with other particles during flight [18-19]. To push itself and other particles to move to the target point, the particle is exactly the way to abandon the disadvantaged points to find the optimal point through continuous updating and comparison, and finally find the optimal solution to the problem. In essence, the core idea of particle swarm optimization is that the particles in the swarm complete the decision under the combined action of their own and peer information [20].

3. Model and Research on Multi-objective Optimal Configuration

3.1. Objective Function

This paper adopts the three indicators in Chapter 4 as the multi-objective of the distributed power optimization configuration problem. Its objective function:

$$\min\ f_{obj} = \min(\Delta E, \Delta U, \Delta P) \tag{1}$$

Among them, ΔP is the sum of the active network losses of the branches of the distribution network, ΔU is the voltage safety index equal to the sum of the voltage offsets of each node, and ΔE is the low-carbon cost index.

3.2. Constraints

(1) The equation constraint is the power flow equation:

$$\begin{cases} P_{Gi} - P_{Li} - U_i \sum_{j=1}^{N} U_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) = 0 \\ Q_{Gi} - Q_{Li} + Q_{Ci} - U_i \sum_{j=1}^{N} U_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}) = 0 \end{cases} \tag{2}$$

Among them, PGi and QGi are the active and reactive power output of distributed generators, respectively.

(2) The inequality constraint is:

$$\begin{cases} P_{d\min} \le P_{di} \le P_{d\max} \\ q_{d\min} \le Q_{di} \le q_{d\max} \\ P_{di} + \sum P_{Gi} \le \sum P_{Li} \end{cases} \tag{3}$$

In the formula, QCi is the reactive power compensation capacity; Ui is the node voltage; Gij and Bij are the system admittance. Pdi and Qdi are the active and reactive outputs of DG, respectively; the subscripts min and max added to the variables represent the lower and upper limits of the variable, respectively.

3.3. Multi-objective Algorithm Process

The process of designing a multi-objective molecular differential evolution (MOMDE) algorithm includes a series of operations such as initialization, population mixing, Pareto non-inferior sorting, population updating, championship selection and molecular differential evolution. Compared with other multi-objective optimization algorithms such as NSDE, the deep optimization performance can be significantly improved in MOMDE because of the above-mentioned molecular differential evolution mutation mechanism.

Example simulation (MOMDE) algorithm flow: 1) Parameter setting. 2) Population initialization: Initialize the parent population Ug and the child population Sg, where the child population is empty. 3) Population mixing: The parent population and the child population are mixed into a temporary new population Tg. 4) Pareto non-inferior sorting: According to the Pareto non-inferior sorting strategy, compare the value of each objective function in the temporary new population Tg, find the set of Pareto non-inferior individuals in the temporary new population as PL(1), and then find the remaining temporary population. Generate a new set of Pareto non-inferior individuals as PL(2) until the hierarchical sorting of all individuals in the temporary new population is completed.

4. Analysis and Research of Multi-objective Optimal Configuration

4.1. Simulation and Analysis

Assume that the simulation time is 2000min, the sampling time Δt=5min, and the threshold value of the wind power smoothing rate interval δ=0.01.The optimal configuration scheme and corresponding performance values are shown in Table 1.

Table 1. Optimal configuration schemes and their corresponding objective function values

Numbering	Super capacitor		Battery		Objective function value	
	Rated capacity (MWh)	Rated power (MW)	Rated capacity (MWh)	Rated power (MW)	f_{cost}	f_{prob}
1	0.2	2	1	2	10.23	7.56
2	0.2	2	2	4	20.45	6.45
3	0.2	2	3	6	36.12	3.43
4	0.2	2	4	8	42.36	7.65
5	0.2	2	5	10	56.45	5.64

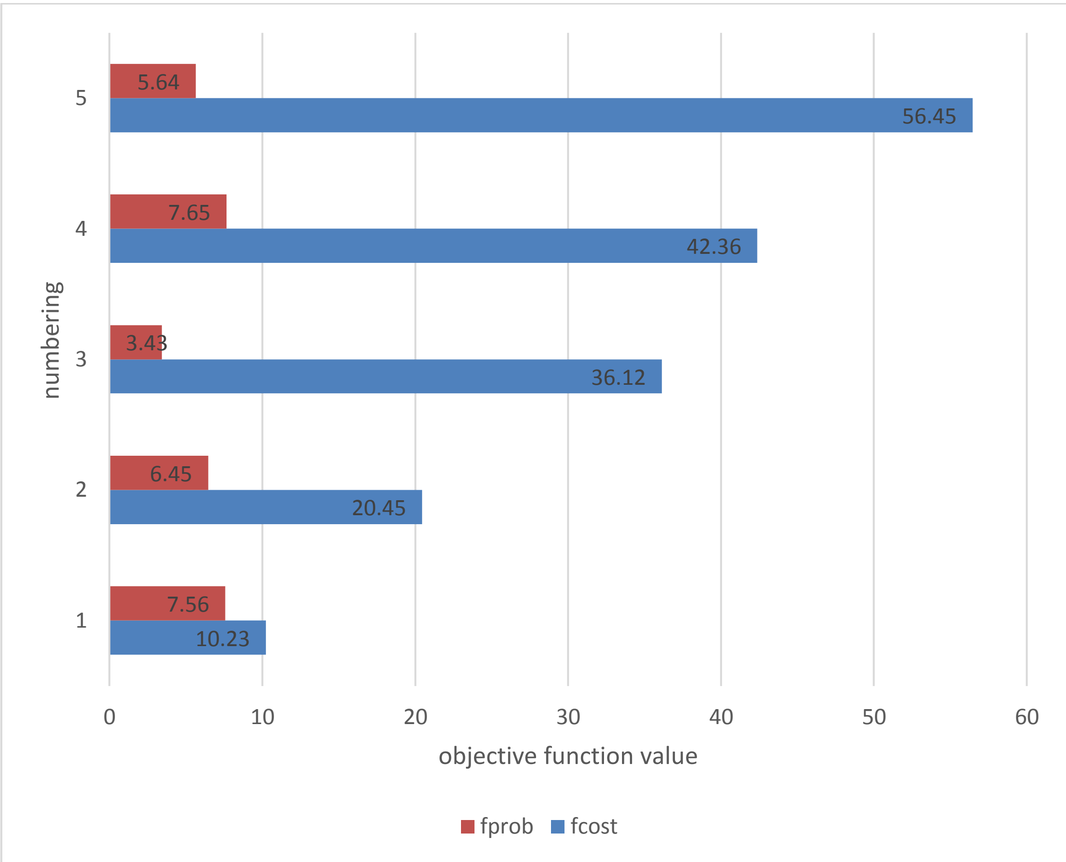

Figure 1. Optimal configuration scheme objective function value

As shown in Figure 1, with the continuous improvement of wind energy collection efficiency, the rated power and capacity of energy storage devices continue to increase, and the cost of hybrid energy storage systems also increases. Especially when the efficiency ratio is greater than 95.76%, the cost of the hybrid energy storage system increases significantly.

4.2. Reactive Power Optimization Considering Different Objectives

First consider the first case (C1), that is, take floss, fΔV and fQ as the optimization objective function. The optimization schemes and their corresponding objective function values are shown in Table 2.

Table 2. The optimization scheme set of C1 and its corresponding objective function value

Optimization	No DG	Not optimized
S1	60.23	40.56
S2	61.54	40.56
S3	60.56	40.23
S4	61.32	40.78
S5	60.78	40.98

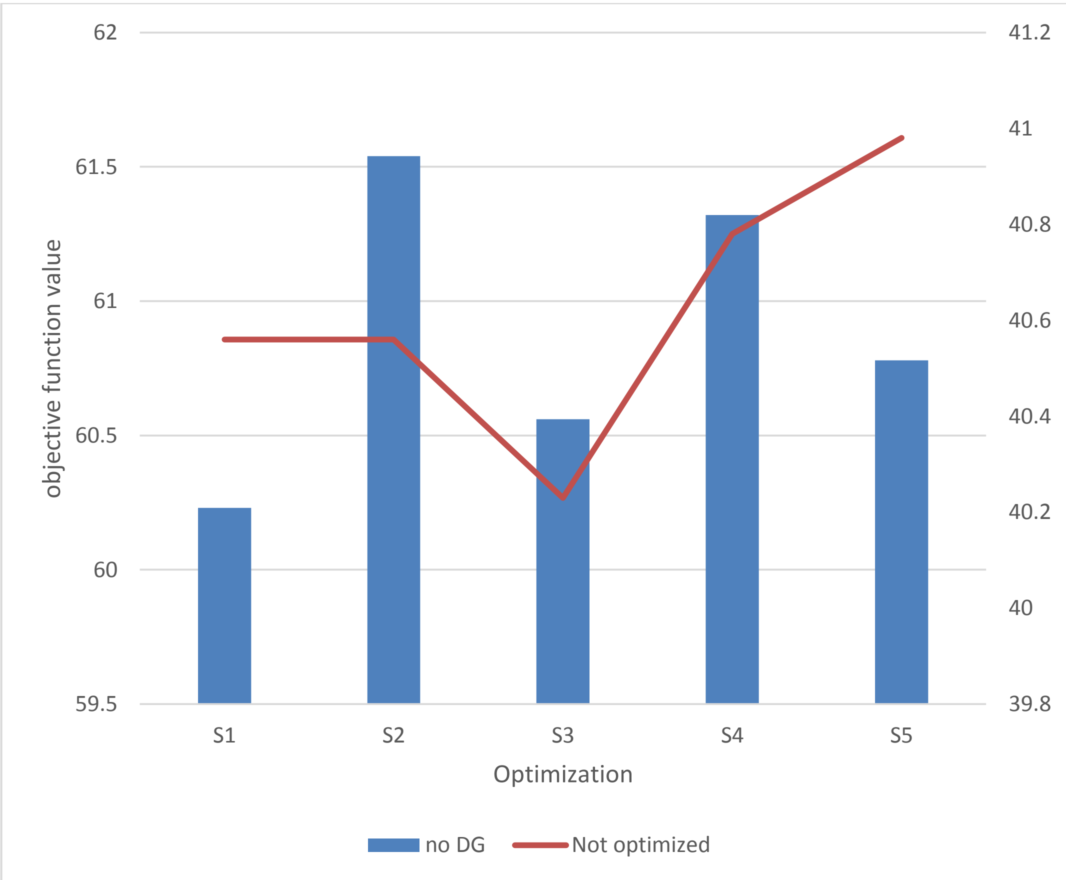

Figure 2. The set of optimization schemes and their corresponding objective function values

It can be seen from Figure 2 that, compared with no DG installed and no reactive power optimization, no matter which optimization scheme, the corresponding system active power loss and voltage deviation are significantly improved.

4.3. Optimum Location of DG

The optimal access position of the distributed generator calculated by the method introduced in this paper is 5 knots, the active power loss at this time is 153.56 kW, and the static voltage stability index is 0.0564. Below is the comparison when all 5 nodes except the power point are respectively used as access points.

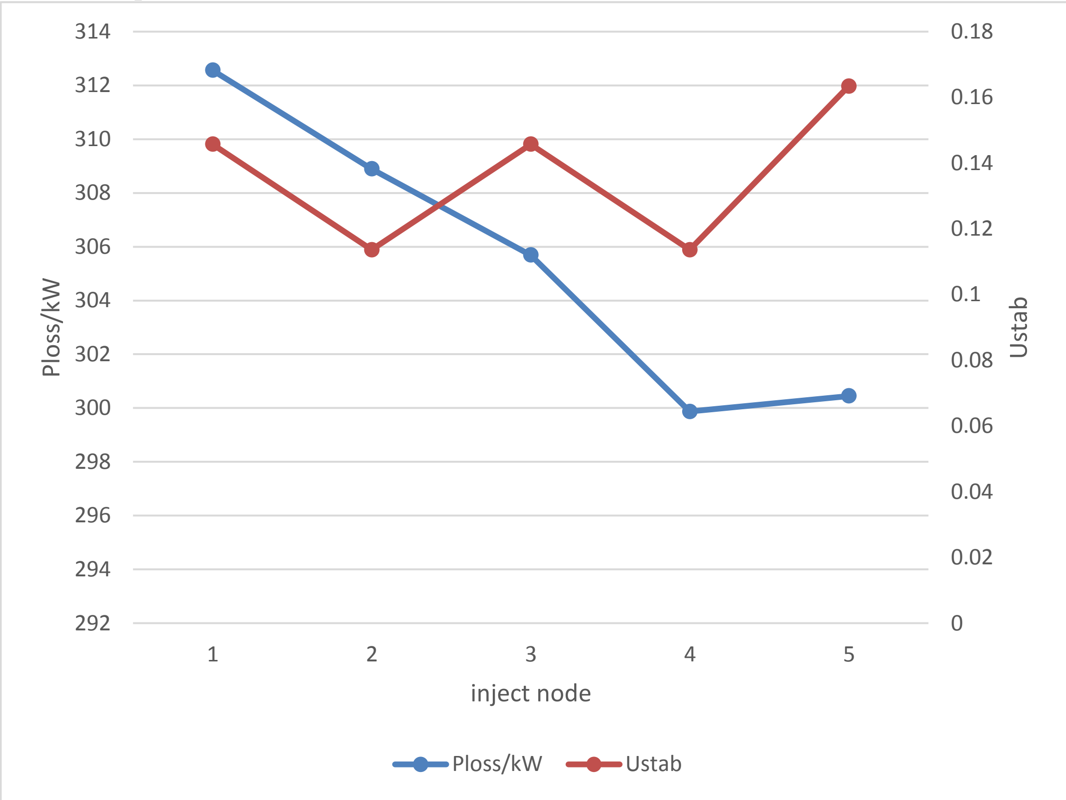

Figure 3. Best address comparison

As shown in Figure 3, when the injection node is 1, the P_{loss} is 312.56kW, and U_{stab} is 0.1457; when the injection node is 2, the P_{loss} is 308.89kW, and the U_{stab} is 0.1136; when the injection node is 3, the P_{loss} is 305.69kW, and the U_{stab} is 0.1457; When the node is 4, the P_{loss} is 299.87kW, and the U_{stab} is 0.1136; when the injection node is 5, the P_{loss} is 300.45kW, and the U_{stab} is 0.1634. By comparison, it is not difficult to find that when DG is connected to node 5, both the active power loss and the voltage stability are the optimal solutions.

5. Conclusion

In this paper, basic research is carried out on the establishment of the multi-objective optimization problem model of distribution network with distributed power generation and the multi-objective optimization solution method based on swarm intelligence and Pareto dominance relationship. The research on distribution network operation optimization problem enriches the multi-objective group intelligent optimization algorithm. The rapid development of distributed generation and microgrid technology provides an effective way to solve the global energy crisis and environmental degradation. As one of the key technologies in the development of microgrid, the theory of optimal operation of microgrid has laid a solid foundation, and its theoretical value and engineering value are becoming more and more important.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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