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Joint planning of electric vehicle charging station and distributed generation on location and capacity

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Abstract. The widespread application of distributed generation and electric vehicles are two important ways to save energy and reduce emissions. Therefore, the location and capacity of distributed generation and electric vehicle charging stations are particularly important. From the perspective of environmental protection, distributed power generation has obvious advantages over traditional power generation methods. Based on this, this paper establishes a model of location and capacity of electric vehicle charging stations with distributed generation with the lowest sum of investment, operation and maintenance costs, network losses and environmental costs. And this paper uses the Grasshopper Optimization Algorithm to solve the model. Finally, the IEEE 33-node distribution system is used as an example to perform calculations to verify the effectiveness and feasibility of the proposed model and algorithm.

1. Introduction

With the continuous development of the grid technology, new loads and new energy are constantly connected to the electrical power system, among which EV charging stations and distributed generation are typical representatives[1]. Electric vehicles and distributed generation can greatly reduce the burden of energy and environment. Developing electric vehicles and distributed generation vigorously is a new direction for the reform and development of smart distribution network in the future, and is also the mainstay of promoting clean energy, energy conservation and emission reduction[2]. Electric vehicle charging stations and distributed generation access to the power grid will bring new challenges to the distribution network, which requires us to take comprehensive considerations from the aspects of investment cost and power grid stability[2-4]. Therefore, it is of great significance to study the location and capacity planning of distributed generation and EV charging station.

In recent years, many scholars have studied the location and capacity planning of distributed generation and EV charging station respectively, but they didn't combine the two. In fact, the location and capacity planning of EV charging station not only affects the stability of the power distribution network, but also affects the environmental benefits. At the same time, the location and capacity determination of EV charging stations should also be conducive to the local consumption of distributed generation. However, most of the current studies only consider the location and capacity planning of EV charging stations. For example, Zhao[5] analyzed the location and capacity planning of EV charging stations from three aspects: construction of charging stations, driving on the way of charging and waiting for charging stations. Lu[6] analyzed the charging rules of EV users, built a planning model based on the queuing theory of EV users, and finally selected and determines the capacity of EV charging stations. Therefore, in the study of location and capacity should be considered at the same time. In addition, most of the optimization goals of existing research are considering economic benefits, network loss, or voltage levels, etc.[7-9] Most of the economic benefits considered are also construction, maintenance or operating costs, and do not consider the environmental benefits of charging stations with distributed generation. In fact, the development of EV charging stations with distributed generation is very helpful from the perspective of environmental protection. Therefore, when considering location selection and capacity determination, not only the inherent economic benefits must be considered, but also the benefits to the environment.

In conclusion, in view of the lack of existing research on distributed power supply and EV charging station coordination planning, lack of considering the environmental benefits, and etc. This paper proposes a collaborative planning for the location and capacity of distributed power supply and EV charging station. At the same time, the impact of environmental benefits on the research results is considered. A site-specific capacity model aiming at minimizing the sum of total cost and network loss is established. The Grasshopper Optimization Algorithm is used to solve this model, and finally IEEE33 nodes distribution system is taken as an example to validate the research model and methods.

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2. Problem Description

Electric vehicle charging stations mainly charging electric vehicles. This article studies distributed generation, which has little impact on the environment compared to traditional power supply methods. The so-called environmental benefit refers to the difference in the cost to the environment caused by the production of the same amount of electricity and using distributed generation compared with the traditional power generation mode. Because the impact of distributed generation on the environment is negligible and can be ignored. Therefore, it is only necessary to calculate the environment cost generation by the traditional power generation mode, that is, the product of the pollutant gas type and its environmental cost price. This article considers that the total cost is minimized, while meeting the charging needs of electric vehicle users, and building charging stations at appropriate locations.

The model established in this paper is the minimum comprehensive cost model. The model not only considers the comprehensive investment cost of charging station, but also the environmental cost. The mathematical model is shown as follows:

$$\min C = C_1 + C_2 + C_3 \tag{1}$$

$$C_1 = \sum_{i=1}^{N_d} x_i \sum_{k=1}^{M} K_k (V_k + R_k) \times 10^{-4} \tag{2}$$

$$C_2 = \sum_{i=1}^{N_d} x_i \left[\left(\frac{r(1+r)^n}{(1+r)^n - 1} \right) C_i + C_m \right] \tag{3}$$

$$C_3 = \sum_{q=1}^{l} R_q \bullet I_q^2 \tag{4}$$

In the formula, C is the comprehensive cost; C_1 is environmental benefit; C_2 represents the comprehensive cost of charging station investment; C_3 is network loss; M represents the number of types of gases emitted by conventional power generation; K_k refers to the emission intensity of category k pollutants produced by conventional thermal power plants per unit of electricity production; V_k represents the environmental value discount standard of class kth polluted gas; R_k represents the price charged for the emission of class kth pollution gases; r is the discount rate; n represents the period of project investment recovery; N_d represents the number of nodes connected to the charging station; x_i represents the access status of i node charging stations; R_q represents the resistance value of the qth branch; I_q is the current flowing through the qth branch.

(1) System power flow constraint

$$\begin{cases} P_{is} = V_i \sum_{j \in i} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \\ Q_{is} = V_i \sum_{j \in i} V_j (G_{ij} \cos\theta_{ij} - B_{ij} \sin\theta_{ij}) \end{cases} \tag{5}$$

In the formula, P_{is} represents the active power input of node i; V_i represents reactive power injection of node i; V_i represents the voltage amplitude of node i; G_{ij} represents the real part of the node admittance matrix; B_{ij} represents the imaginary part of the node admittance matrix; θ_{ij} said phase Angle difference between nodes i and j.

(2) Node voltage constraint

$$V_{i,\min} \le V_i \le V_{i,\max}, i \in N \tag{6}$$

In the formula, V_i represents the voltage of node i; $V_{i,\max}$ and $V_{i,\min}$ represent the upper and lower voltage limits of node i respectively.

(3) Capacity constraints of charging stations

$$G_{CS,i} \le G_{CS,\max}, i \in N_{CS} \tag{7}$$

In the formula, $G_{CS,i}$ represents the access capacity of the selected node i of the charging station; $G_{CS,\max}$ represents the maximum access capacity of charging stations at each selected node ith.

3. Grasshopper Optimization Algorithm

3.1. Principle of GOA algorithm

Grasshopper Optimization Algorithm[10] is a new intelligent optimization algorithm proposed by Saremi etc. in 2017, which is inspired by the population behavior of locusts in the process of predation. The mathematical model of locust population movement is as follows[11]:

$$X_i = S_i + G_i + A_i \tag{8}$$

In the formula, X_i represents the location of the ith grasshopper; S_i represents the social interaction between the population and the ith grasshopper; G_i denotes the gravity received by the ith grasshopper; A_i is the wind force on the ith grasshopper.

Since the impact of gravity on grasshopper population is negligible, and at the same time, it is assumed that the wind direction is always pointing to the location of the best individual, so the grasshopper location update model can be expressed as:

$$X_i = \sum_{j=1, j\ne i}^{N} c \frac{ub_d - lb_d}{2} s(|x_j - x_i|) \frac{x_j - x_i}{d_{ij}} + \hat{T}_d \tag{9}$$

$$c = c_{\max} - l \frac{c_{\max} - c_{\min}}{L} \tag{10}$$

In the formula, c represents the decreasing coefficient, which decreases the global searching ability of the algorithm and improves the local optimization ability with the increase of iteration times. N is the number of grasshoppers; ub_d and lb_d represent the upper and lower bounds of $s(r)$ in d dimensional space respectively. $\hat{T}_d$ said the location advantage to guide individuals in a population; L represents the maximum number of iterations.

3.2. Process of the algorithm

The algorithm steps are as follows:

(1) Initialization: Firstly, grasshopper population and parameters in the algorithm are initialized;

(2) Calculate the fitness of each grasshopper;

(3) Calculate the current best fitness;

(4) Determine whether the number of iterations has been reached. If so, the program will end and the current position of global optimal solution is the optimal solution；

(5) Update parameter c;

(6) Standardize the distance between grasshoppers and normalize the interval [1,4];

(7) Update the grasshopper position, calculate the updated grasshopper fitness, and compare with the historical best. If the fitness is better than the historical best, then update; otherwise, do not update;

(8) Update the number of iterations and return to (4).

4. Example analysis

4.1. Calculation example parameter setting

In this paper, iEEE33-node distribution system is adopted as the model verification example. The example contains the existing load network in the 33-node system, as shown in Figure 1. The corresponding line impedance and node load parameters are shown in literature[12].

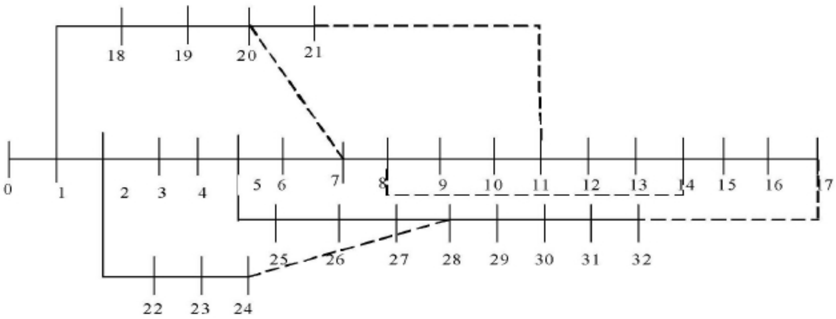

Figure 1 IEEE 33-node network diagram

The parameters of the simulation test are as follows: reference voltage class is 12.66 kV; benchmark capacity is 10MVA; the discount rate is 0.1, the fixed number of year of the planning is 20 years, including the investment cost of distributed generation EV station is 206 thousand/kW, maintenance cost is 20 thousand/kW, the largest number of iterations is 200 times, the power factor of distributed generation is 0.9, the parameters of the environmental benefits references literature[13].

4.2. Results Analysis

The location and volume constant model of the EV charging station with distributed generation is solved, and three groups of typical solutions are selected from the optimal solution set, as shown in Table 1-3.

Table 1 Plan A

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Capacity/kW	0	0	0	20	40	10	40	40	375	0	0	20	10	30	40	30	20
Number	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
Capacity/kW	20	0	10	0	0	0	0	0	30	0	20	10	10	10	20	20	

Table 2 Plan B

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Capacity/kW	0	0	0	10	0	0	0	0	20	0	0	0	0	10	0	20	0
Number	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
Capacity/kW	0	0	10	10	20	0	10	0	30	10	0	0	0	0	10	663	

Table 3 Plan C

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Capacity/kW	0	0	0	0	0	0	0	30	10	0	10	0	20	10	0	200	20
Number	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
Capacity/kW	30	0	0	0	0	10	10	0	10	10	20	20	10	20	380	0	

The voltage curve distribution of each node of the three schemes is shown in Figure 2, which shows that the system voltage after the installation of distributed generation has been significantly improved compared with the voltage without the installation of distributed generation.

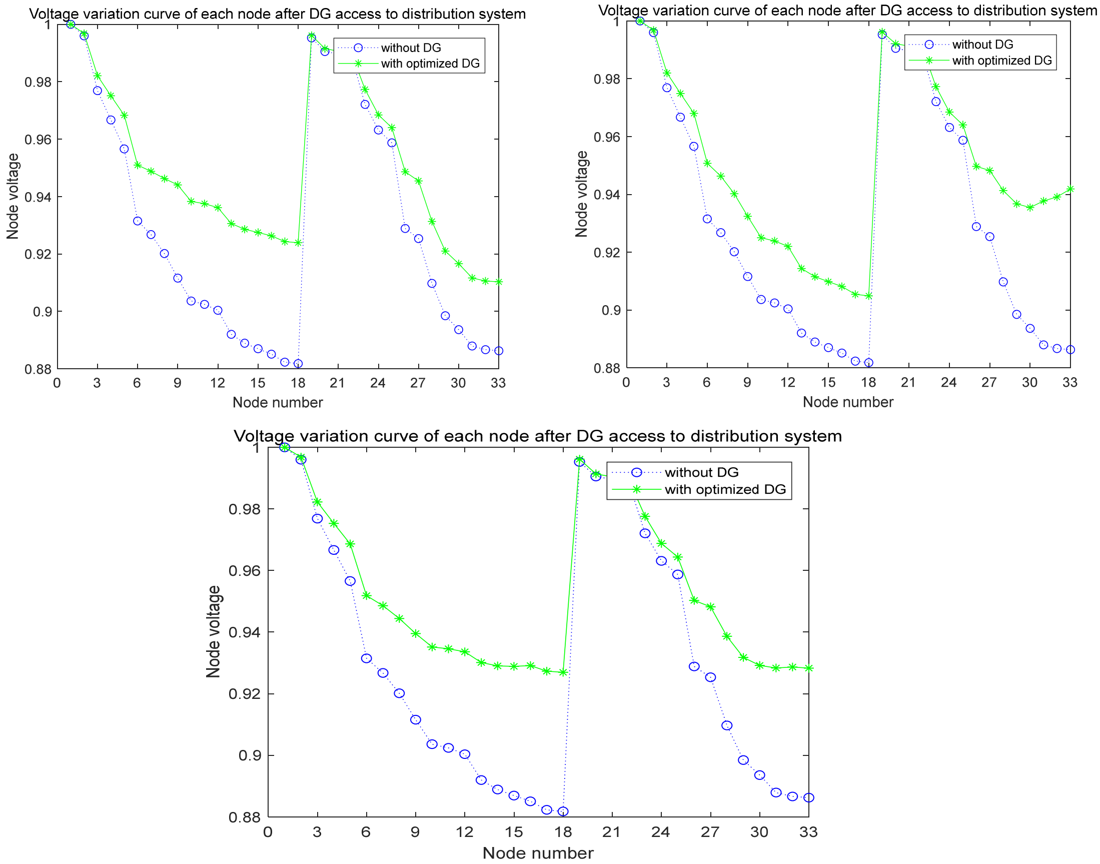

Figure 2 The voltage curve distribution of each node of the three schemes

The calculation results of the three schemes are analyzed. When the decision maker pursues the lowest cost of investment and operation, Plan C is the best choice. When the decision maker pursues the lowest network loss and environmental cost, Plan C is the best choice. The investment and operation cost and network loss cost corresponding to Plan B are not optimal, but the environmental cost is optimal, which can better protect the environment.

Table 4 Analysis of algorithm results

	Plan A	Plan B	Plan C
Investment operation and maintenance/million	1.2155e+03	1.2152e+03	1.2138e+03
Network loss/kW	163.2469	156.0997	141.5980
Environment benefits/thousand	34.610	34.950	34.822

5 Conclusion

For distributed generation and the EV charging station distribution network access to the location and capacity planning, this paper will be distributed generation and EV charging stations at the same time as the optimization goal, analyzed by pure EV charging stations on the environment of distributed power supply, is established considering investment and operational costs, the cost is the sum of the minimum network loss and environment's location and capacity model, uses the GOA to solve the optimization algorithm, the main conclusions are as follows:

(1) Distributed generation is beneficial to the environment, so it is more in line with the reality to take into account the location and capacity determination.

(2) The location and capacity determination of EV charging stations is closely related to the access capacity and site selection of distributed power supply, which are also crucial to the construction of distribution network. Therefore, the location and capacity determination should be considered simultaneously.

(3) When solving such problems, GOA has simple

structure, strong stability and fast convergence, which is worthy of further study.

On the basis of this paper, there are still some shortcomings. For example, environmental factors are not considered in the study of distributed generation. The uncertainties of load and distributed generation are not taken into account. In the following research, the economy, environment and reliability of distribution network will be taken into consideration in the study of location and capacity determination of EV charging stations containing distributed power supply.

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