



Research on Location Planning of Multi-station Integration Based on Particle Swarm Optimization

Xincong Li^(✉), Mingze Zhang, Jun Wang, and Minhao Xia

State Grid Shanghai Economic Research Institute, Shanghai, China

Abstract. With the development of national energy strategy, the construction of the Energy Internet has become an important direction for the development of energy systems. The emerging field of multi-station integration has laid a good foundation for the construction of the Energy Internet. Based on the analysis of multi-station integration architecture, a mathematical model for location planning of multi-station integration was proposed. The model is based on the substation and integrates data center, charging station and photovoltaic power station. The particle swarm optimization (PSO) in the artificial intelligence algorithm was used to solve the model and determine the optimal site. Finally, a case was used to verify the correctness and effectiveness of the proposed model and method.

Keywords: Energy Internet · Multi-station Integration · Location Planning · Particle swarm optimization

1 Introduction

Multi-station integration is one of the important applications for the implementation of the Energy Internet. It converges substations, data center, charging stations and photovoltaic power stations to optimize the allocation of urban resources, improve data perception, analysis and computing efficiency, carry out local load consumption and other functions.

At present, the research on the location and planning of single station such as substations, data centers, and photovoltaic power stations is relatively mature. Reference [1] took the sum of the product of the distance from the substation to the load point and the power load of the load point as the objective function, and used the immune optimization algorithm to solve the substation location planning. Reference [2] proposed a solution based on modern heuristic search algorithm for the automatic location of cloud data center. Reference [3] proposed a two-level planning model for distribution network considering the investment income of energy storage stations. The upper-level planning model took the lowest cost of distribution network line construction as the optimization goal, and the lower-level planning model took the highest profit of the energy storage station as the optimization goal, and used genetic algorithms to study the location of energy storage stations. Reference [4] proposed a location model targeting the investment cost of charging station construction, and realized the optimization calculation

of site, scale and service capacity through the global optimization capability of PSO to minimize the total cost; Reference [5] took the photovoltaic power station's voltage index, grid loss index, and harmonic index as the goal to achieve the best comprehensive effect, considered the upper limit of the node voltage harmonic content as constraints, the model is solved by a multi-objective optimization algorithm based on an improved genetic algorithm.

However, there is less research on the location planning of multi-station including substations, data centers, charging stations and data centers. In this paper, each single power station is taken into consideration, the mathematical model of each single power station is constructed with the goal of minimum load distance, and the multi-station location planning model is obtained after addition. And use PSO in the intelligent algorithm to solve the model and select the optimal site. Finally, a case was used to illustrate the accuracy and scientific of the proposed method.

2 Mathematical Model of Multi-station Location

2.1 Multi-station Integration Architecture

There are many types of power stations that can be included in multi-station. This paper mainly studies the collaborative planning between substation, data center, charging station and photovoltaic power station.

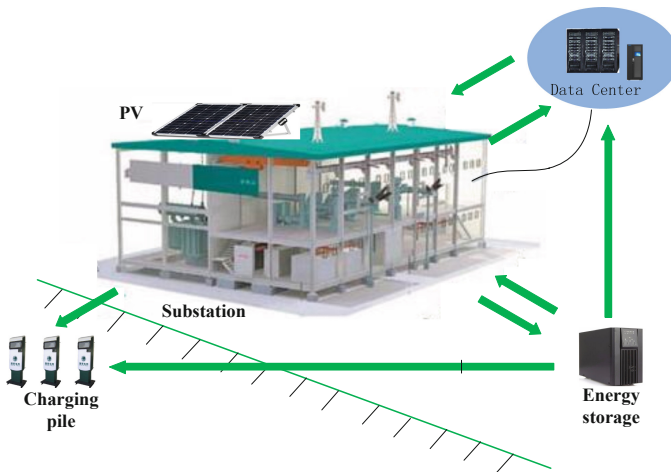


Fig. 1. Diagram of multi-station integration

It can be seen from Fig. 1 that the multi-station is based on the substation, integrating other station equipment to achieve the complementarity and coordination of each equipment, and then making full use of existing land resources to achieve the multi-station function in a single location. The substation provides power for charging piles, data centers, energy storage stations and surrounding users; the energy storage equipment serves as a backup power source for charging piles, substations, and data centers

to improve power supply reliability; the data center provides data storage services for surrounding enterprises, municipalities, etc. Charging piles provide charging services for electric vehicles around the power station.

2.2 Mathematical Model of Location

Objective Function. The main content of this paper is to determine the site of the multi-station, and the location of the candidate site has the greatest impact on the line cost. There are not only regular electricity loads, but also other types of loads such as data center loads and charging station loads in multi-station load. In order to reduce power loss and line investment, and ensuring the stability of power supply, this paper takes load distance cost as the optimization goal, and uses a single-dimensional standard to measure multiple types of entities.

The cost calculation of the load distance $C_{l,i}$ between the load point l and the site i is shown in Eq. (1).

$$C_{l,i} = \alpha_l P_l \sqrt{(u_i - x_l)^2 + (v_i - y_l)^2} \quad (1)$$

Where α_l is the cost coefficient of the unit load distance from load point l to candidate site i ; P_l is the power of load point l ; (u_i, v_i) is the coordinate of candidate site i and (x_l, y_l) is the coordinate of load point l .

Due to the different functions and service entities of each single station in the multi-station, the cost coefficients of unit load distance from each type of load point to multi-station are different. The load distance cost of each single station is as follows:

Substation. The load distance cost coefficient and load distance cost between the substation load and multi-station are shown in Eq. (2)–(3), which are measured according to the line investment cost converted to unit capacity and unit distance.

$$\alpha_{substation} = u_{xl} \frac{r(1+r)^{z_1}}{(1+r)^{z_1} - 1} \quad (2)$$

$$C_{substation} = \alpha_{substation} \sum P_{substation} \sqrt{(u_i - x_s)^2 + (v_i - y_s)^2} \quad (3)$$

Where u_{xl} represents the line investment cost per unit capacity and unit distance; r represents the discount rate of funds; z_1 represents the service life of the line, and the line investment cost is converted to each year; $P_{substation}$ represents the substation load; (u_i, v_i) represents the coordinate of multi-station candidate site; (x_s, y_s) represents the coordinate of the load point of the substation.

Data Center. The load distance cost coefficient and load distance cost between data center load and multi-station are shown in Eq. (4)–(5), including the line investment cost coefficient converted to unit capacity and unit load distance.

$$\alpha_{data} = \varphi u_{xl} \frac{r(1+r)^{z_1}}{(1+r)^{z_1} - 1} \quad (4)$$

$$C_{data} = \alpha_{data} \sum P_{data} \sqrt{(u_i - x_d)^2 + (v_i - y_d)^2} \quad (5)$$

Where φ represents the power supply reliability correction factor. The data center has a large load scale and high reliability requirements, so double-circuit lines are used, and φ is 2; P_{data} represents the data center load; (u_d, v_d) represents the coordinates of data center load point.

Charging Station. The load distance cost coefficient and load distance cost between the charging load and multi-station are shown in Eqs. (6)–(7), based on the time cost converted to the unit capacity and unit distance electric vehicle charging demand to go to multi-station charging measure.

$$\alpha_{EV} = \frac{K_{time}}{P_{charge} v_{road}} \quad (6)$$

$$C_{EV} = \alpha_{EV} \sum P_{EV} \sqrt{(u_i - x_e)^2 + (v_i - y_e)^2} \quad (7)$$

Where K_{time} represents the time value coefficient of electric vehicle users per hour; v_{road} represents the average driving speed of electric vehicle users after considering the road conditions in the planning area; P_{charge} represents the single charging pile power of the charging station; P_{EV} represents the charging station load; (u_e, v_e) represents the coordinates of charging station load point.

Photovoltaic Station. The load distance cost coefficient and load distance cost between the photovoltaic power station load and multi-station are shown in Eq. (8)–(9). Photovoltaic loads mainly include rural road lights, park lights, and other loads that require less power supply reliability and consume less electricity. The cost coefficient of the load distance between the photovoltaic power station load and multi-station is measured according to the solar cell converted to unit capacity and the line investment cost per unit distance.

$$\alpha_{PV} = \left(\frac{u_{PV} V_{PV}}{R_{PV}} \right) \frac{r(1+r)^{z_2}}{r(1+r)^{z_2} - 1} + u_{xl} \frac{r(1+r)^{z_1}}{r(1+r)^{z_1} - 1} \quad (8)$$

$$C_{PV} = \alpha_{PV} \sum P_{PV} \sqrt{(u_i - x_p)^2 + (v_i - y_p)^2} \quad (9)$$

Where u_{PV} represents the investment cost of solar cells per unit capacity; V_{PV} represents the capacity of a solar cell; R_{PV} represents the service radius of the energy storage to the photovoltaic power station, z_2 represents the service life of the solar cell; P_{PV} represents the photovoltaic power plant load; (x_p, y_p) represents the coordinates of photovoltaic power plant load point.

Multi-station location planning is essentially a multi-objective collaborative optimization problem. The optimization objectives include substation, data center, charging station and photovoltaic power station. This paper takes the minimum load distance cost as the objective function, and uses a single-dimensional standard to measure multiple targets to be optimized, and solves the problem of diversification of multi-station service entities. The objective function of multi-station location is shown in Eq. (10):

$$\min C = C_{substation} + C_{data} + C_{EV} + C_{PV} \quad (10)$$

Where $C_{substation}$ represents the cost of substation load distance; C_{data} represents the cost of data center load distance; C_{EV} represents the cost of charging station load distance; C_{PV} represents the cost of photovoltaic power station load distance.

Restrictions

Power Supply Radius of Substation.

$$l_{ik} = \sqrt{(u_i - x_k)^2 + (v_i - y_k)^2} \leq R_{substation} \quad (11)$$

Where l_{ik} represents the straight-line distance from multi-station to the load of the substation; $R_{substation}$ represents the maximum power supply radius of the substation under the current voltage level.

Charging Station Service Radius.

$$l_{ig} = \sqrt{(u_i - x_g)^2 + (v_i - y_g)^2} \leq R_{EV} \quad (12)$$

Where l_{ig} represents the straight-line distance from multi-station to the charging load; R_{EV} represents the average service radius of the city's public charging network.

3 Solution of Multi-station Location Model

3.1 Particle Swarm Optimization (PSO)

PSO is a widely used artificial intelligence algorithm, which was proposed by Kennedy and Eberhart from the process of finding food by birds. The idea of the algorithm is to initialize the solution space of the optimization problem into a group of random vectors called particles. The properties of each particle include two: particle speed and particle position. The optimization process of the optimal solution set is a process in which particles continuously update their velocity and position through iteration. Assuming that the velocity and position of particle a in dimension b are v_{ab} and x_{ab} , respectively, the velocity of the particle is updated as shown in Eq. (13).

$$l_{ig} = \sqrt{(u_i - x_g)^2 + (v_i - y_g)^2} \leq R_{EV} \quad (13)$$

Where v and x are respectively expressed as the velocity variable and position variable of the particle in the iterative process; the equation contains three weighting factors: inertia factor ω , particle swarm algorithm acceleration coefficient c_1 and c_2 ; r_1 and r_2

are random adjustment coefficients between 0 and 1, which are conducive to the random flight of particles to find more possible optimal solutions; pb and gb are individual optimal particles and global optimal particles.

The PSO update is shown in Eq. (14).

$$x_{ab}(k + 1) = x_{ab}(k) + v_{ab}(k + 1) \quad (14)$$

With the continuous update of particle speed and position, the PSO ends when the optimal solution meets the preset requirements or reaches the maximum number of iterations.

3.2 Solution Process of Location Model Based on PSO

The model proposed in this paper is to solve the problem of single-location within a certain range. Therefore, the location of multi-station is represented as a two-dimensional plane coordinate geographically, and the two coordinates of the location of multi-station are each as a variable. The search space of PSO is a two-dimensional space, and each point in the space represents a feasible position of multi-station. In the search process, the fitness value of the particle represents the load distance cost of multi-station planning. The current fitness value of the particle can be calculated by substituting the current position of the particle in the objective function. This fitness value is used to evaluate the degree of the solution, which is the quality of the multi-station position. The lower the fitness value, the lower the load distance cost and the better the multi-station location. In the search space, there is an optimal point. This point has the lowest fitness value and corresponds to the optimal position of multi-station. The ultimate goal is to let the particles find the best points through search. The specific process is as follows:

Step 1: Initialize the coordinates of multi-station in the planning area, and set various load power, coordinates, line costs, discount rates, service life and other parameters in the planning area;

Step 2: Calculate the fitness value of the initial value, and obtain the initial fitness value of each coordinate of the multi-station according to Eq. (10);

Step 3: Calculate the optimal fitness value of the individual and the overall optimal fitness value in the entire population.

Step 4: Update the particle velocity. According to Eq. (13) and (14), get the updated velocity and position of the particles.

Step 5: Determine whether the iteration is over, that is, whether the set convergence condition is met. If satisfied, the optimal result will be output, if not satisfied, go to step 2 and continue the iteration.

The iterative flowchart of PSO is shown in Fig. 2.

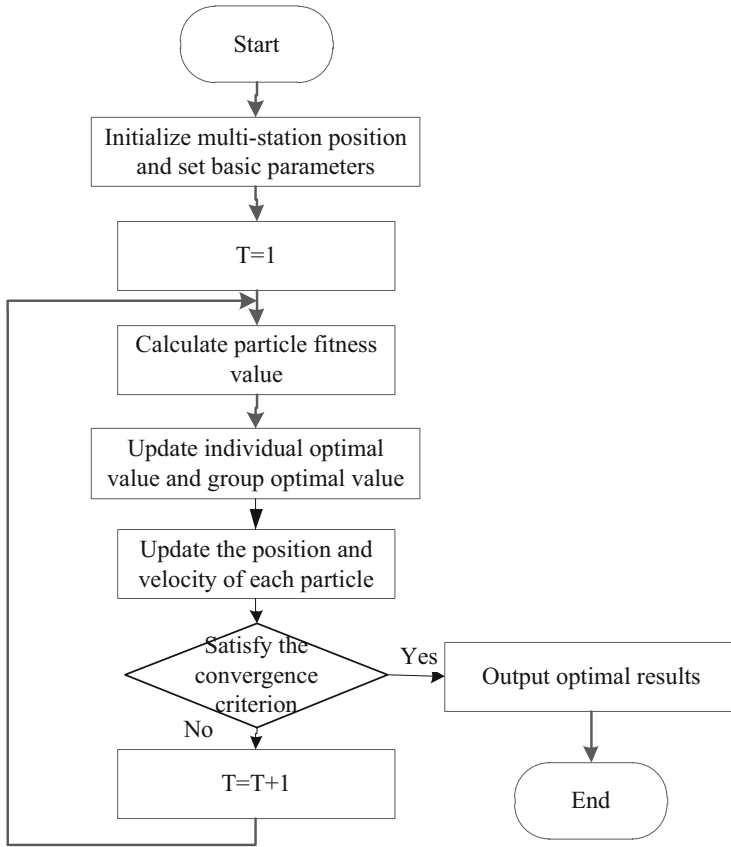


Fig. 2. Iterative flowchart of PSO

4 Case Study

This paper takes the development zone of a city as an example to verify the correctness and rationality of the method. The area spans 30 km from east to west and 25 km from north to south. According to local planning and development, it is planned to build a multi-station integrating substation, data center, charging station and photovoltaic power station. There are more regular electricity load and charging load in this area, as well as a certain amount of data center load and photovoltaic power station load.

4.1 Basic Parameters

In order to verify the feasibility and effectiveness of the PSO in multi-station location planning, the location coordinates and loads of various major loads in the area are collected. The distribution data is shown in Tables 1–4. The investment cost per unit length of the line is 200,000 yuan/km, the discount rate is 0.08, the line depreciation period is 16 years, the photovoltaic cell depreciation period is 10 years, the power

supply reliability correction factor is 2, and the charging power of a single charging pile is 80 kW, which is expected to average Every day, 260 electric vehicles have a charging demand. The average speed of electric vehicles is 40 km/h, and the average time cost for each owner is 50 yuan/h. The investment cost of solar cells is 8 yuan/W, and the power generation of solar panels is 250 W/m².

Table 1. Regular electricity load distribution data

Number	Abscissa/km	Ordinate/km	Load/kW
1	1	20	617
2	24	9	127
3	20	17	363
4	7	15	617
5	10	19	577
6	23	14	4830
7	17	15	707
8	7	8	1300
9	1	10	3845
10	7	18	617
11	5	15	443
12	8	17	617
13	6	15	1243
14	7	16	517
15	8	18	880
16	2	16	450
17	5	14	1110
18	24	20	280

Table 2. Data center load distribution data

Number	Abscissa/km	Ordinate/km	Load/kW
1	14	17	3240
2	16	22	2407

Table 3. Charging load distribution data

Number	Abscissa/km	Ordinate/km	Load/kW
1	12	2	1237
2	21	11	637
3	22	12	1643
4	14	7	637
5	19	5	1510
6	21	4	1237
7	24	4	1063
8	25	2	710
18	26	4	830

Table 4. PV load distribution data

Number	Abscissa/km	Ordinate/km	Load/kW
1	13	4	22
2	26	7	27
3	30	8	30
18	21	5	33

4.2 Case Results and Analysis

The PSO is used to solve the multi-station location planning model, and the maximum number of iterations is set to 100. The optimization results are shown in Table 5, and the convergence situation is shown in Fig. 3. The distribution diagrams of various loads and optimal site locations are shown in Fig. 4.

Table 5. Optimal site result

Optimal site	Minimum cost/yuan
(15.814,15.353)	8604900

It can be seen from Fig. 3 that when the PSO is used to solve the multi-station location planning model, the convergence speed is very fast. The objective function tends to converge when the number of iterations reaches about 30 times and the optimal site location and the minimum load distance cost are obtained. It can be seen from Fig. 4 that the optimal site location is located at the center of all loads. It means that the sum of the distances from the site to each load is relatively small, and it is logical to find the minimum load distance cost at this point.

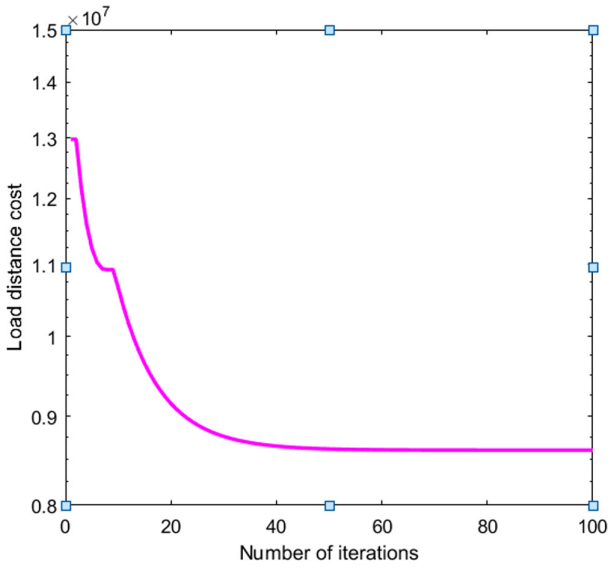


Fig. 3. Convergence curve of PSO

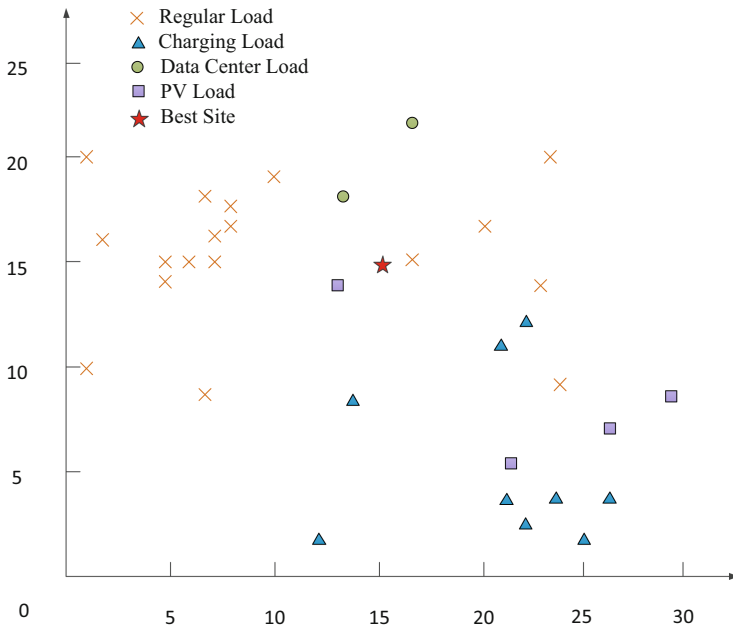


Fig. 4. Convergence curve of PSO

5 Conclusion

The multi-station mentioned in this article is the integration of four types of power stations: substation, data center, charging station and photovoltaic power station. First, this paper constructs a multi-station location model, and then applies the PSO to the multi-station location planning problem. Finally, selects the optimal site location with the load distance cost as the objective function. The main conclusions obtained from the study are as follows:

- (1) This article integrates the multi-agent planning problem into a unified master plan. Taking the load distance cost as the objective function and builds a unified standard to measure multi-objective entities including substation, data center, charging station and photovoltaic power plant;
- (2) When calculating the load distance, this paper considers the differences between substation, data center, charging station and photovoltaic power station, and sets different load distance cost coefficients.
- (3) Using the PSO in artificial intelligence algorithm to calculate and analyze the location of multi-station, and select the optimal station location. In practical applications, the optimal candidate site can be compared with existing substations, and the most suitable substations for transformation can be screened out to provide reference for the implementation of multi-station projects.

References

1. Yonghui, L.: Substation location planning based on immune optimization algorithm. *Autom. Instrum.* **08**, 104–106 (2017)
2. Renming, Z., Bo, Z.: Research on cloud data center automatic location model based on modern heuristic search algorithm. *Software Guide* **12**(12), 44–46 (2013)
3. Jifeng, H., et al.: distribution network planning model considering investment income of energy storage station. *Electr. Power Constr.* **38**(06), 92–99 (2017)
4. Haiqing, C.: Study on Planning Model of Electric Vehicle Swapping Station Based on Microgrid. Shanghai Institute of applied technology (2015)
5. Ke, W.: Research on Evaluation Method of Photovoltaic Grid Connection Site Selection and Capacity Determination Scheme and Access Mode. Wuhan University (2018)
6. Zilong, C., Pin, W., Jian, S., Bo, Y.: Location planning model of electric vehicle public emergency charging station. *Power Syst. Protect. Control* **48**(16), 62–68 (2020)
7. Jiuxing, W., Jiumiao, C.: Study on site selection and planning of photovoltaic power station – taking Wuhu City as an example. *J. Ludong Univ. (Nat. Sci. Ed.)* **35**(01), 59-65+89 (2019)
8. Man, W., Wuyang, Z.: Location planning of mobile substation based on discrete particle swarm optimization. *J. Electr. Power* **33**(02), 134–139 (2018)
9. Wenjie, P., Zhe, W., Yanghong, T., Fangwei, L., Jian, Y.: Opportunity constrained planning of electric vehicle charging station with photovoltaic distributed generation distribution network. *J. Power Syst. Autom.* **29**(06), 45–52 (2017)
10. Xiaorong, L., Jie, W., Jianmin, D., Hua, M., Cheng, Y.: Site selection and sizing optimization of multi station integrated substation based on Voronoi diagram. *Power Grid Clean Energy* **36**(02), 44–54 (2020)
11. Xiao, Z.: Multi Objective Optimization of Substation Engineering Projects Based on Particle Swarm Optimization Algorithm. North China Electric Power University (2018)