Chapter 12
Research on Optimal Scheduling Model of Direct Supply Electric Vehicle Charging Station of Distributed Photovoltaic Power Station

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Abstract Distributed photovoltaic power generation is an effective way to use renewable energy, direct electric vehicle charging not only alleviates the pressure of the State Grid under the current situation of the popularization of new energy vehicles, but also avoids the energy loss caused by transit, so it has become a real-time energy production and marketing mode. According to the characteristics and laws of distributed photovoltaic power generation, this paper studies the optimal scheduling of direct supply electric vehicles. On the premise of ensuring normal operation, according to the actual operation situation, taking the operation cost of electric vehicle charging station as the objective function, the optimal scheduling mathematical model of electric vehicle charging station directly supplied by distributed photovoltaic power station is established. Combined with the idea of integration, the method and steps of using genetic algorithm to solve real-time adjustment scheduling are designed, the problem of real-time distribution scheme of electric vehicle charging station directly supplied by distributed photovoltaic power station is reasonably solved. This algorithm is simple and easy to implement, and has good scalability. It is suitable for rapid migration and has strong practicability. It provides theoretical basis and technical support for the operation of distributed photovoltaic charging stations in cities.

Keywords Scheduling model · Distributed photovoltaic power station · Genetic algorithm

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12.1 Introduction

With the rapid development of electric vehicles in China, especially in Beijing, Shanghai and other big cities, the number of electric vehicles has increased significantly, exposing new contradictions in the process of energy conservation and emission reduction. On the one hand, the power generation mode dominated by coal power conflicts with the goal of "zero pollution" of electric vehicles. On the other hand, the sharp rise in power consumption has also brought great pressure to the State Grid. The development, allocation and utilization of renewable energy has become an effective way to solve the current contradiction (Li et al. 2009; Wei 2010; Locment et al. 2010).

According to the regional centralized characteristics of electric vehicle charging stations, the development of distributed photovoltaic power stations as the charging source of electric vehicles is a practical, clean and environment-friendly measure. At present, many countries and regions have carried out demonstration projects related to distributed photovoltaic power generation. Distributed photovoltaic power generation is also being promoted in rural areas of China to subsidize households and push to the power grid (Xiangning et al. 2013). Although the distributed photovoltaic power generation technology has been relatively mature, in the urban environment, the capacity configuration and optimal scheduling of distributed photovoltaic power stations directly charging electric vehicles still need to be further studied. In order to realize the instant charging at the peak of power generation and reduce the circulating power of energy storage; Reasonable distribution of peak power consumption, good user protection and analysis of periodic data to optimize the dispatching of charging sources and reduce the load peak valley difference.

12.2 Operation Management and Strategy of Distributed Photovoltaic Charging Station

In short, the distributed photovoltaic charging station takes the energy obtained from photovoltaic power generation as the charging source of electric vehicles. However, due to the volatility and intermittency of photovoltaic power generation, it also needs to be equipped with an energy storage system with a certain capacity. Therefore, compared with conventional charging stations, distributed photovoltaic charging stations need to be equipped with photovoltaic power generation system, energy storage system, AC distribution network and required AC converters and converters. Its operation principle can be summarized as the following three charging methods or their combination: photovoltaic power generation is directly used for electric vehicle charging; The energy of photovoltaic power generation is stored in the energy storage system and then used for electric vehicle charging; The state grid directly charges electric vehicles.

In terms of operation strategy, first of all, ensure sufficient supply; Secondly, ensure the stability of distribution network, that is, avoid excessive peak valley difference of load; Finally, the economic benefit of the charging station is optimized. Taking one day as a time cycle, according to the mobilization and demobilization time of N vehicles, the system allocates the charging source and charging time according to the photovoltaic power generation and step price.

12.3 Analysis of Distributed Photovoltaic DC Output Power

Beijing is located in the middle latitudes of the northern hemisphere, with four distinct seasons and obvious regularity of solar intensity. The monthly total radiation generally presents a parabolic trend. From January, the monthly total radiation begins to increase, and increases the fastest from March to May. May and June are the highest values of the whole year, and begin to decline after June. Since July is the rainy season, the monthly total radiation decreases rapidly, followed by September to November, and December is the lowest value of the whole year. The monthly radiation data of a certain area in Beijing in a certain year are shown in Table 12.1 (kcal/cm^2), and the scatter diagram is shown in Fig. 12.1.

According to the research, the DC output power of photovoltaic power generation is directly proportional to the amount of solar radiation, but has nothing to do with the ambient temperature and other conditions.

Similarly, combined with the specific location of a distributed photovoltaic power station and the solar radiation under different meteorological conditions, the binary function with date and meteorological conditions as independent variables and solar radiation as dependent variables can be fitted to obtain the DC output power function.

12.4 Optimal Dispatching Model and Solution of Distributed Photovoltaic Power Station

12.4.1 Objective Function

According to the actual operation, on the premise of ensuring that the optimal dispatching scheme is not changed, this paper takes the electricity charge of distributed photovoltaic power generation as the benchmark, and the charging cost comes from the power purchase of the power grid, that is, the lowest power purchase cost of the power grid is the objective function.

The charging station purchases electricity from the power grid using the time of use price, and divides 24 h into three sections according to the peak and valley characteristics of the load, as shown in Table 12.2 (Xinyi et al. 2014).

Table 12.1 Monthly radiation data of a district in Beijing

January	February	March	April	May	June	July	August	September	October	November	December
6.4	7.8	11.6	12.9	15.7	15.5	12.8	12.2	11.3	9.0	6.1	5.6

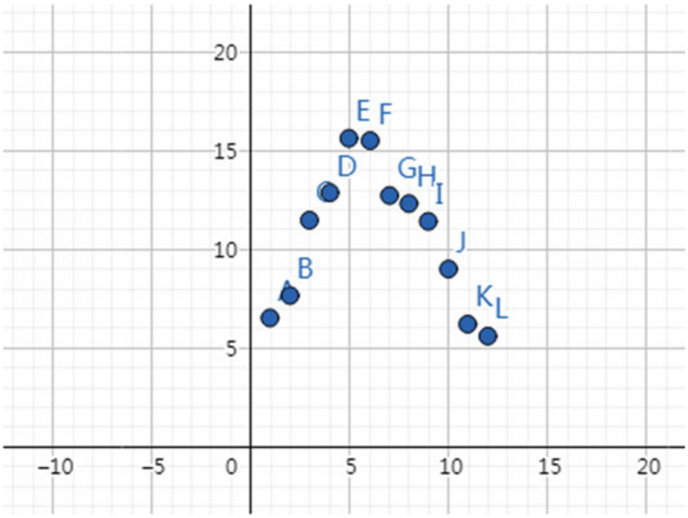

Fig. 12.1 Scatter diagram of monthly radiation in an area of Beijing

Table 12.2 Time of use tariff for power purchase of power grid

Time interval	Electricity price I (yuan/kWh)
Peak period (8:00–12:00, 17:00–21:00)	0.869 (I_1)
Peacetime period (12:00–17:00, 21:00–0:00)	0.365 (I_2)
Valley period (12:00–8:00)	0.687 (I_3)

According to the electricity price of the above periods, according to the power demand, the power purchase cost of the power grid is

$$C = I_1 \cdot q_1 + I_2 \cdot q_2 + I_3 \cdot q_3 \quad (12.1)$$

where q_1, q_2, q_3 is the electricity consumption in each period.

In the actual operation process, the charging scheme needs to be optimized in real time according to photovoltaic power generation and automobile power consumption.

Since the DC output power of photovoltaic power generation is directly proportional to the amount of solar radiation, the prediction function of daily DC output power can be obtained by fitting and analyzing the historical data in combination with meteorological information $p(t)$, then the power generation is predicted in $t_1 \sim t_2$ time period

$$E = \int_{t_1}^{t_2} p(t)dt \tag{12.2}$$

If $t_1 \sim t_2$ time period is set, the power storage consumption is D and the power demand of the vehicle is W, it can be divided into the following situations:

If $E + D \geq W$, continue to increase energy storage and power purchase fee $C = 0$;

If $E + D < W$, the power grid power purchase cost will be incurred,

$$C = \sum_{i=1}^{3} a \Delta t_i I_i \tag{12.3}$$

Among them, a is the output power of the power grid, Δt_i is the charging time in the i th time period, and I_i is the electricity price in the i th time period.

Therefore, the objective function is:

$$\min C = \sum_{i=1}^{3} a \Delta t_i I_i \tag{12.4}$$

Constraints:

$$W - E - D \geq \sum_{i=1}^{3} a \Delta t_i \tag{12.5}$$

12.4.2 Solution Method

Collect the charging demand information of all vehicles when the k-th vehicle enters the site. The charging power distribution results of each vehicle are expressed in −1, +1 and 00 respectively, which can be distributed according to the time period of segmented pricing, as shown in Table 12.3.

Combined with the coding design of genetic algorithm, assuming that the charging mode is not changed every half an hour, Then the charging distribution results can be divided into half an hour according to the time period of segmented pricing. For example, the charging power distribution result of the k-th vehicle can be designed as follows: $\underbrace{00 + 1 + 1 - 1 \ldots 00}_{96\,\text{bits}}$, every two of them are one cell, if the distribution result is photovoltaic charging, it will display +1; if the distribution result is grid

Table 12.3 Charging distribution scheme

Vehicle	Peak period 18:00–12:00			Peacetime period 1 12:00–17:00			Peak period 2 17:00–21:00			Peacetime period 2 21:00–24:00			Valley period 0:00–8:00		
	−1	+1	00	−1	+1	00	−1	+1	00	−1	+1	00	−1	+1	00
1															
⋮															
k															

charging, it will display −1; if not charging, it will display 00. The first 16 bits are a unit, followed by 20 bits, 16 bits, 12 bits and 32 bits. Then the charging allocation scheme of k vehicles generates a matrix of k rows and 48 columns.

- Step 1: construct chromosome and generate initial population

According to the charging distribution scheme, the subject adopts decimal system for chromosome coding, and the representation of chromosome adopts matrix form:

$$X_{k\times 48} = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1,48} \\ x_{21} & x_{22} & \cdots & x_{2,48} \\ \vdots & \vdots & \ddots & \vdots \\ x_{k1} & x_{k2} & \cdots & x_{k,48} \end{pmatrix} \tag{12.6}$$

Each element in the matrix is based on the charging distribution scheme every half an hour from 8:00 a.m. to 8:00 the next day, the row vector represents the charging allocation scheme of each vehicle, after determining the element values in the matrix, the general charging distribution scheme for the k-th vehicle is determined.

We use the following rules to generate the initial population: ① The parking time period of each vehicle shall be divided according to the time period specified by the chromosome. If it is less than half an hour, it shall be automatically assigned as power grid charging, with a value of −1 and no charging time period of 00; ② Calculate the sum of $m_1 = \sum_{j=1}^{48}\sum_{i=1}^{k}\left|x_{ij}\right|$ after the initial assignment and the number of unassigned time periods m_2, Calculate the total power generation of distributed photovoltaic power generation in the current parking period, and convert it into the total charging time according to the power (converted into the number of charging time periods n in half an hour); ③ According to an order in the matrix, the values of the elements in the matrix are determined one by one, and a chromosome is generated. The method is to randomly assign −1 or +1 to the unassigned element, At this time, $\sum_{j=1}^{48}\sum_{i=1}^{k}\left|x_{ij}\right| - m_1 = m_2$ is satisfied, And extract the number of time periods n_1 assigned with value +1, And meet $n_1 \le n$; ④ Cycle according to the above method until the number of initial population is reached. To ensure population diversity, we can also generate several chromosomes in line order (changing the position of the starting line by line or interlaced exchange). Several chromosomes are also produced in the order of columns, the initial population is generated when a number of chromosomes are produced in diagonal order in both directions and the number of the initial population is reached.

- Step 2: determine the fitness function

Because the fitness function requires the maximum, the fitness function is determined as $C_l = \frac{1}{C(k)}$.Where $C(k)$ is the objective function, and the maximum value of fitness function is the optimal scheme.

- Step 3: natural selection

The selection is made according to the proportion of adaptive values, and the elite retention strategy is adopted:L chromosomes in each generation population are arranged in descending order according to the fitness value C_l ($l = 1, 2, \ldots, L$), and the first 10 chromosomes are selected directly into the next generation population. $L - 10$ chromosomes are generated by the chromosome roulette of the previous generation population. In this way, the best ones can survive to the next generation. It can also avoid the huge difference of selection opportunities caused by different fitness values between individuals, maintain the diversity of individuals in the next generation population, and effectively improve the convergence speed of the algorithm.

- Step 4: chromosome cross recombination

Select individuals according to probability p_c for multi-point crossing, in this paper, the crossover rate is set as $p_c = 0.4$, Since the element exchange of $x_{i1} \sim x_{i8}(i = 1, 2, \ldots k)$, $x_{i,9} \sim x_{i,18}(i = 1, 2, \ldots k)$, $x_{i,19} \sim x_{i,26}(i = 1, 2, \ldots k)$, $x_{i,27} \sim x_{i,32}(i = 1, 2, \ldots k)$ and $x_{i,33} \sim x_{i,48}(i = 1, 2, \ldots k)$ in the distribution scheme does not affect the fitness value, the method of crossing between different sections is designed. After proper adjustment, the fitness function value of each chromosome of the new generation is calculated, and the fitness function value of the mother is compared, and the one with the larger function value of the two chromosomes is selected to enter the next generation.

- Step 5: variation

The new population created by the crossing, special mutation strategies should also be adopted to mutate the chromosome with the mutation rate $p_m = 0.02$, the specific operation process is as follows:

Find an element from the element assigned with -1 by generating a random number, and mutate the element into $+1$, verify the constraint conditions. The number of mutations should not exceed 10.

- Step 6: judge the conditions for stopping evolution

In the algorithm design, the reasonable design of each parameter is an important factor for success. Crossover rate and mutation rate according to the design in this paper, we set for 200 largest evolution algebra, operation is as follows: if the iterative algebra is 200, then stop the evolution, select the best chromosome as a charging scheme, or for 50 generations equals the best fitness function value of the chromosome is terminated, output the optimal chromosome as the charging scheme.

12.5 Conclusion

This paper analyzes the generation characteristics and laws of distributed photovoltaic power stations, taking the lowest operation cost of electric vehicle charging station as the objective function, the optimal dispatching mathematical model of direct supply electric vehicle charging station of distributed photovoltaic power station is established. In solving the model, the integration idea is combined with genetic algorithm, and a real-time optimal scheduling algorithm is designed to reasonably solve the real-time scheduling problem of direct supply electric vehicle charging station of distributed photovoltaic power station. In practical application, the parameters and data involved in this algorithm are easy to extract, the programming steps are universal and simple, can realize rapid migration, and has strong practicability.

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