Research on an Adaptive Management Model of AC Charging Piles in Community

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***Abstract*—In this paper, a charging pile group management model for residential electric vehicles based on adaptive algorithm is constructed. It proposed a new control strategy for the traditional charging pile plug-and-play charging mode in residential areas, which effectively improved the impact and adverse effect of disorderly charging of residential electric vehicles on the transmission network. Based on the comprehensive consideration of the time-sharing price of electric vehicle charging and the safe and economic operation of transmission network, this control strategy proposes a charging pile group control charging model based on adaptive algorithm. This control algorithm mainly includes dispatching reference load, dispatching load increment and delayed dispatching based on load change rate of power grid. It realizes the smooth operation of district distribution network, improves the profit of charging pile operators and reduces the charging cost of electric vehicle users.**

Keywords—disorder charging; orderly charging; reference load; load increment; delayed regulation

I. INTRODUCTION

In the 21st century, the automobile industry has entered a period of comprehensive transportation energy transformation. As a breakthrough point for further development of the automobile industry, electric vehicles(EV) have entered a new stage of rapid development with the support of governments of various countries. Nowadays, more and more experts and enterprises regard the research of new energy vehicles and the development of electric vehicles as the focus of future development, which is a major trend of new energy development.The charging pile of electric vehicle is the service facility of electric vehicle. It supplements energy for electric vehicle and plays an important role in the development of electric vehicle industry. How to build an efficient, safe and intelligent charging pile for electric vehicles is a key issue in the technical research of electric vehicles industry at present[1-3].

In recent years, the research on charging piles of electric vehicles has achieved valuable results. Literature [4] analyses the parking time of electric vehicles and the acceptable range of users to the change of battery power status, classifies six types of charging areas and establishes the travel and charging model of electric vehicles. Literature [5] presents a short-term load forecasting model for electric vehicle charging based on pulse neural network, and proposes the short-term load forecasting model of electric vehicle charging station based on particle swarm optimization Elman feedback neural network. According to the practical sample data, the probability distribution function of electric vehicle charging access is fitted and constructed in reference [6].And the optimal operation mode of load at rush hour and trough hour is put forward and the effect of peak and valley cutting is also analyzed.

In this paper, a management model of charging piles for residential electric vehicles based on adaptive algorithm is proposed. Combined with the impact of traditional charging pile plug-and-play charging mode on the power grid in residential areas and the economy of electric vehicle charging time-sharing tariff to operators and users. this paper presents an AC charging pile group control charging model based on Monte Carlo simulation for electric vehicle charging load calculation model, and analyses the adaptability of this model to AC charging pile load variation and its effect on "peak-shaving and valley-filling" of transmission network.

II. ANALYSIS ON CHARGING MODE OF ELECTRIC VEHICLE

A. AC charging

First, confirm that you have the correct template for your paper size. This template has been tailored for output on the A4 paper size. If you are using US letter-sized paper, please close this file and download the file “MSW_USltr_format”.AC charging is a single-phase (220V) or three-phase (380V) AC power supplied to electric vehicles, which is characterized by low AC charging power and long charging time. AC charging can be divided into two types, slow charging and conventional charging. Among them, slow charging current is generally 16A, charging time is about 5-8h, suitable for home or residential areas. Conventional charging power is large, power supply is three-phase or single-phase, charging current is large, suitable for residential areas, shopping malls or parking places.

B. DC charging

The DC charging pile is fixed outside the electric vehicle and connected with the AC network to provide a high-power DC power for the electric vehicle power battery[7-8]. DC charging station uses three-phase four-wire system to supply power. It can adjust the output voltage and current, output enough power to realize fast charging. DC charging time is short. It can provide charging service for electric vehicles in 10-20 minutes. And it is suitable for charging and discharging large capacity batteries. DC charging has the advantage of short charging time and can save the time cost of users. However, due to its high charging current and high requirements for charging equipment, the construction cost is high. At the same time, the high current also causes a little impact to the power grid, which affects the safe and stable operation. DC charging is generally applicable to vehicles with frequent use and large driving mileage, such as buses, taxis, etc.

C. Wireless charging

Electromagnetic induction type: Two mutual inductance coils are used for wireless charging. When the current in the input coil changes, the magnetic field of the output coil will change accordingly, which generates the induction current and converts the energy from the input to the output [9]. Inductive wireless charging does not need cable when charging, and electric vehicles have no contact with charging facilities, which can avoid potential charging hazards caused by extreme weather.

Magnetic resonance type: The principle is similar to acoustic resonance. As long as two media have the same resonance frequency, they can transfer energy to each other. Magnetic resonance type wireless charging can charge multiple devices at the same time. However, the charging power is relatively low and there is a problem of electromagnetic radiation.

It can be seen that different charging modes are suitable for different types of electric vehicles. In practical applications, electric vehicles with specific functions have their own special charging places, so the charging behavior of electric vehicles is specific. In recent years, with the rapid development of the electric vehicle industry, the number of household electric vehicles has increased significantly. At present, the proportion of ordinary private cars in all the electric vehicles used in the market is the largest. Because the charging behavior of private car owners is more flexible and random, the charging load of this kind of electric vehicle has more and more influence on the power grid. The self-adaptive charging pile group management model proposed in this paper is mainly based on the parking lot of residential area. The charging pile group is equipped with a large number of AC charging piles to meet the actual needs. When forecasting the daily load characteristics of charging stations, we can mainly study the charging demand forecasting based on private cars, design reasonable charging time and energy distribution of electric vehicles, improve the adaptability of the residential quarters′ transmission network to the disorderly charging of electric vehicles, and reduce the charging cost of electric vehicles.

III. EV CHARGING LOAD MODEL AND ITS CALCULATION

Several main factors affecting the charging load of EV are: the scale of electric vehicle, charging power, power battery capacity, charging time and initial state of charge (SOC)[10]. This paper mainly studies the management model of AC charging piles in residential areas, taking the main home electric vehicles on the market as the research object. Among them, the power battery capacity of electric vehicles is fixed, and the scale of electric vehicles takes medium-sized residential areas as an example. The charging power of charging piles refers to the charging power of the main AC charging piles on the market.

A. EV Charging Load Model

The main purpose of establishing the charging load model of electric vehicle is to analyze the charging capacity and charging start time of the vehicle. The charging capacity of electric vehicles is affected by the initial SOC, and the vehicle return time determines the initial charging time. Under normal circumstances, residents of residential areas drive electric vehicles out during the day and return to the charging pile for charging at night. According to the survey report of the United States Department of Transportation in 2009[11], statistical analysis shows that the last car return to the community has regularity. After normalizing the statistical data, it can be found that the last return of private cars to residential parking lots obeys the normal distribution of N (17.47, 3.412). Assuming that the last car returns to the resident parking lot every day is the starting charging time of the vehicle, the probability density distribution function of the starting charging time of the electric vehicle is as follows:

$$f_{T_s} = \begin{cases} \dfrac{1}{\sigma_s\sqrt{2\pi}}\exp[-\dfrac{(x-\mu_s)^2}{2\sigma_s{}^2}] & (\mu_s - 12) < x \le 24 \\ \dfrac{1}{\sigma_s\sqrt{2\pi}}\exp[-\dfrac{(x+24-\mu_s)^2}{2\sigma_s{}^2}] & 0 < x \le (\mu_s - 12) \end{cases} \tag{1}$$

In Formula (1), x is a time constant, μ_σ and σ_σ represents the average value and standard deviation of the starting charging time of electric vehicles, choosing μ_σ=17.47, σ_σ=3.41.

The charging capacity of electric vehicles is determined by the starting power and the ending power. assuming that the rated battery capacity of electric vehicle is Q, the initial charge capacity is Q0, and the initial SOC is SOC0. When charging terminates, the power consumption is Q1, and the SOC termination is SOC1. The charging capacity Qc of the electric vehicle is as follows:

$$Q0 = Q * SOC0 \tag{2}$$

$$Q1 = Q * SOC1 \tag{3}$$

$$Qc = Q1 - Q0 \tag{4}$$

According to the analysis of charging start SOC data provided in reference [12], charging start SOC0 obeys normal distribution：

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \tag{5}$$

In Formula (5), μ=0.46576, σ=0.17924.

By accumulating the charging capacity of each electric vehicle in the residential area, the total charging demand of the electric vehicle is EQ.

$$E_Q = \sum_{i=1}^{N} Q_{ci} \tag{6}$$

In Formula (6), N is the total number of electric vehicles charged in the residential area, Q_{ci} is the charge quantity of the NO.i electric vehicle, and the charging capacity is calculated in days.

B. EV Charging Load Calculation

Assuming that the charging behavior of electric vehicles is not controlled by the power grid, plug-and-play charging mode is adopted. Monte Carlo simulation can be used to extract the initial charging time and SOC of a unit vehicle, and then solve the problem of large-scale charging load simulation of electric vehicles[13]. Its flow chart is shown in Figure 1.

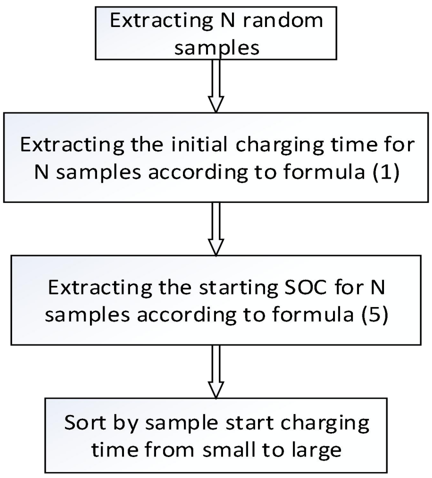


Fig. 1. *Electric vehicle charging load simulation flow chart*

Residents in residential areas charge electric vehicles mostly on a daily basis. The residential parking lot has a long charging time, and the charging piles can fully fill the electric vehicles. So the charging capacity of the electric vehicle Qc is :

$$Q_c = Q * (1 - SOC_0) \tag{7}$$

When AC charging piles in residential area charge electric vehicle in constant power mode, it can be calculated that the time needed for charging Tc is :

$$T_c = Q_c \ / \ P_e \tag{8}$$

In Formula (8), P_e is output power for Charging Pile.

Substituting Formula (7) into Formula (6), the total demand of charging samples for electric vehicles is EQ :

$$E_Q = NQ - Q \sum_{i=1}^{N} SOC_i \tag{9}$$

In Formula (9), SOC_i is the starting SOC of the NO.i sample of electric vehicle.

Monte Carlo simulation is used to extract the initial charging time, and the calculation of charging time Tc is less than the residence time of electric vehicle in residential parking lot. The starting SOC of random sampling should not exceed 1, but also be larger than the minimum SOC of battery of electric vehicle. In practice, considering the durability of electric vehicle batteries, the initial SOC should be no less than 0.1.

IV. Establishing Management Model of Charging Piles

A. Load regulation based on load curve of power grid

In order to improve the disadvantageous effects of disorderly charging of charging piles on residential grid and reduce the charging cost of electric vehicles, this paper proposes load control based on load curve of power grid and delay control based on load change rate of power grid.

Load regulation based on grid load curve is to distribute the total energy required for charging electric vehicles to the low-valley section of grid load in the time dimension, so that the total load curve is relatively stable after charging piles are connected to the grid, so as to achieve the goal of "peak-shaving and valley-filling". In order to effectively regulate the charging behavior of electric vehicles in residential districts, this paper proposes a dispatch reference load Pref and a dispatch load increment Pd based on grid load curve. Among them, the dispatching reference load refers to the charging demand of the electric vehicle group in the residential area, aiming at realizing the "peak-shaving and valley-filling". The simulation diagram of reference load participating in load regulation of residential grid is as follows:

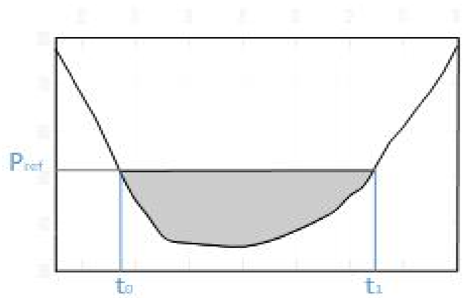


Fig. 2. *Charging load simulation diagram of charging piles with reference load*

In Figure 2, it can be seen that the reference load will delay the access time of electric vehicles in the peak period of power consumption to the peak period of power load, avoiding the peak period of power consumption. At the same time, the valley of the load curve of the power grid is effectively filled by the charging of the electric vehicle group in the idle period of the power grid. However, from formula (1) and formula (5), it can be seen that the time of electric vehicle accessing the power grid is randomness, while the SOC of vehicle battery charging initiation is uncontrollable. In addition, whether the electric vehicle obeys the regulation of charging pile is constrained by user's behavior, such as short parking time at noon and not participating in the regulation of charging pile when charging demand exists. It can be seen that the energy demand of electric vehicle group for power grid is dynamic.

Because the energy demand of charging piles can not be accurately predicted, a reference load variable can no longer meet the load regulation of charging pile group management model for residential grid. On this basis, in order to adapt to the flexible access of electric vehicles to the residential grid, it is a feasible scheme that dispatching load increment participates in charging pile group management model. Load increment is based on reference load. When there are more electric vehicles connected with charging piles in a certain period of time, the load of charging piles will be increased and more electric vehicles will be allowed to access the power grid.

$$\mathrm{P}_d = \begin{cases} \mathrm{n} * P_e & N_{Ti} > N_{\max} \\ -\mathrm{n} * P_e & N_{Ti} = 0 \\ 0 & \text{others} \ldots \end{cases} \qquad \mathrm{n} = 0,1,2,3\ldots \tag{10}$$

In formula (10), P_d is the load increment of the power grid; P_e is the output power of the charging pile; N_{Ti} is the number of electric vehicles that have not been charged by the charging pile in the Tth time period; N_{max} is the upper limit of the number of electric vehicles that have not been charged by the charging pile in the Tth time period.

In the charge pile group management model, the load capacity Pr of the power grid is:

$$P_r = P_{ref} + P_d \tag{11}$$

Assuming that the base load power is Pb when the charging pile group is not connected to the residential grid at present time, the total load power Pf of the basic charging pile group can be adjusted is as follows:

$$P_f = P_r - P_b \tag{12}$$

B. Delay control based on load change rate of power grid

Although the charging pile group management model based on load curve of power grid can well adapt to the randomness of electric vehicle group's access to power grid and the uncertainty of energy demand, the rapid transition of charging by charging pile group during residential peak period to low period will cause great fluctuation of power grid load, which is not conducive to the smooth operation of power grid. The rated power of a single AC charging pile is usually 7 kW. When multiple charging piles are connected to the power grid together, a smaller fluctuation peak will occur. In order to avoid more charging piles being connected to the power grid at the same time, this paper proposes a delay control method based on the load change rate of the power grid.

The basic idea of delay regulation is to make the next charging pile charge after a period of time according to the load change rate when the load of the power grid drops rapidly. When the load of the power grid increases rapidly, the number of new charging piles will be reduced according to the load change rate. It can be seen that the number of charging piles connected to the grid is negatively correlated with the change rate of load curve. The load change rate v_p (kW(h)) at i time can be expressed as:

$$\begin{aligned} v_p &= \left(P(i) - P(i-1)\right) / \Delta t \times 100\% \\ \Delta t &= t(i) - t(i-1) \end{aligned} \tag{13}$$

In formula (13), P(i) denotes the load power of power grid at i time, the unit is kW; P(i-1) denotes the load power of power grid at (i-1) time, the unit is kW; and Δ t denotes the time difference between i time and (i-1) time, which is usually very small, the unit is hours.

The waiting time Tim (h) for charging a single charging pile is:

$$\mathrm{Tim} = P_e \ / \ v_p \tag{14}$$

The steps of delay control based on load change rate of power grid are as follows:

Step 1: Obtain the current load change rate of the power grid vp;

Step 2: Determine whether vp is less than 0. If the conditions are met, step 3 is executed; otherwise step 6 is executed;

Step 3: Calculate the waiting time Tim of a single charging pile under this change rate;

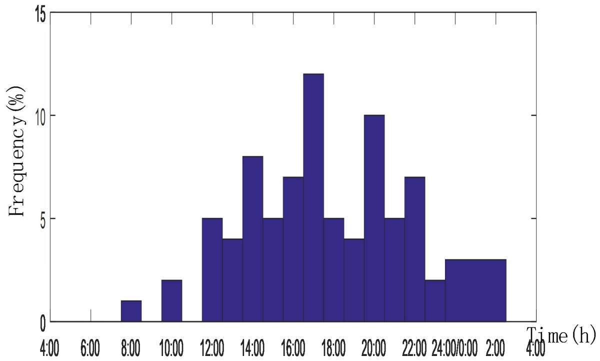
Step 4: In the waiting time Tim, determine whether there is a charging pile connected to the grid. If not, step 5 is executed; otherwise, step 1 is executed;

Step 5: When the waiting time Tim is over, the next charging pile is connected to the power grid. Re-execute step 1;

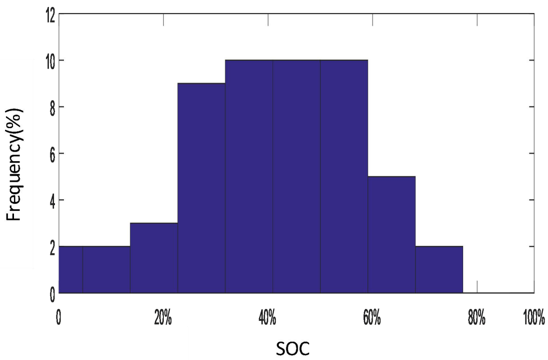
Step 6: If the vp is larger than a certain limit value, the number of charging piles connected to the grid will be reduced by one. Otherwise, no action is performed. Re-execute step 1.

V. Result Analysis

Taking a residential district of a city as an example, the distribution network capacity of the district is 1000 kVA, and the number of private passenger cars is 200. Assuming that the penetration rate of electric vehicles in the district is 30%, the number of electric vehicles is 60. The power battery capacity of electric vehicle is 30 kW.h, the charging power of charging pile is 7 kW, and the charging efficiency is 97%. Because the electric vehicle in the residential area returns to charge at night and leaves the parking lot during the day, it will stay for a short time at noon, and will not participate in the regulation and control of the power grid. Therefore, this paper mainly studies the management model of electric vehicle charging from 16:00 on the same day to 8:00 on the next day.



(a)initial charging time distribution map



(b) initial SOC distribution map

Fig. 3. *Charging load simulation diagram of electric vehicle group*

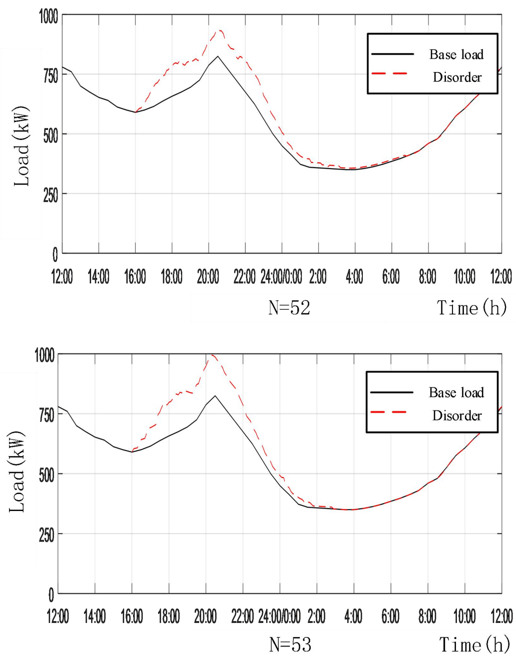


Fig. 4. *Not optimized load curve of residential area power network (24h)*

Fig.3 is a charging load simulation diagram of electric vehicle group participating in grid regulation, which includes the initial charging time and initial SOC distribution. Fig. 4 shows the load curve of residential power grid caused by the disorderly charging of different number of charging piles during the period from 16:00 on the same day to 8:00 on the next day, and N is the number of charging piles participating in the regulation and control of power grid. From Figure 4, it can be seen that when the number of charging piles connected to the grid is close, the charge curve of the district grid also changes greatly, which reflects the time and space randomness of charging demand of electric vehicles. In order to adapt to this randomness, this paper adds a variable - load increment based on the model of dispatching reference load participating in charge pile group management. In addition, the trend of grid load caused by the disorderly charging of charging piles is basically consistent with the trend of daily electricity consumption of residents in residential areas. The access of charging piles will increase the load of residential power grid, and form a larger peak load on the basis of the original electric load. It will even exceed the bearing range of residential power grid, affecting the safe and stable operation of residential power grid. At the same time, the enlargement of peak-valley difference will increase the power loss and reduce the service life of transformer in residential area.

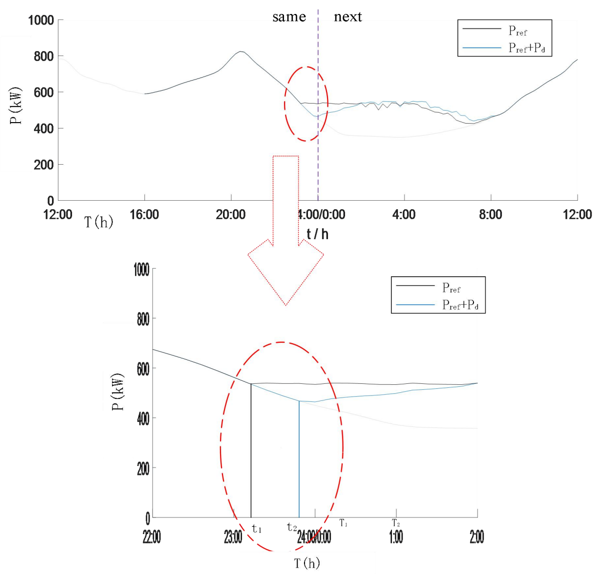


Fig. 5. *Comparison of grid load with or without load increments*

Fig. 5 is a comparison chart of load increment participating in load dispatching. Pref is the reference load and Pd is the load increment. From the figure, it can be seen that when only dispatching reference load is involved in the management model of charging pile group, the reference load determines the total energy that the district grid can provide to electric vehicles. The demand load power of charging pile group is affected by the charging status of electric vehicle group. The change of the number of electric vehicles participating in the regulation and control of the power grid will result in that the demand energy of electric vehicles can not match the power supply of the power grid completely, and the "valley filling" effect is poor or the electric vehicles are not charged, or even there is no charging phenomenon. After adding dispatching load increment, the charging start time of charging pile group moves back, and the power grid will provide more load power in the normal "valley" section to adapt to the randomness of electric vehicles participating in load regulation. At the same time, considering the low price of residential electricity in valley period, the reference load can be reduced and the load increment can be increased appropriately, and the energy demand of electric vehicle group can be allocated to the valley price period as far as possible, so as to reduce the charging cost of users and improve the profit of charging pile operators.

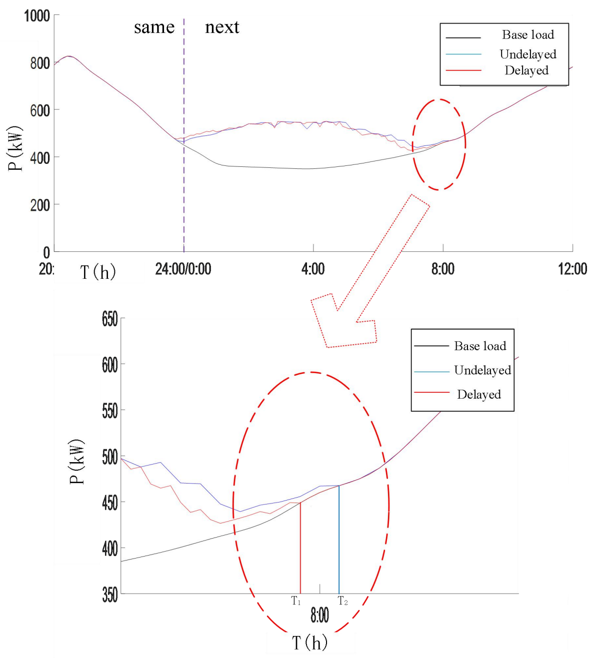


Fig. 6. *Comparison of Ordered Charging with or without Delay*

Fig. 6 is a comparison of charging pile group management models with and without delay optimization. The impact of the two charging pile group management models on the residential grid is shown in Table 1. In contrast, the average and variance of load power are smaller than those of the non-delay optimization when the charging pile group management model has delay optimization. Delay control based on load change rate of power grid can restrain the fluctuation of power grid caused by more charging piles connected to power grid, which is conducive to the safe and economic operation of power grid. In addition, the charging pile group management model with delay regulation and orderly charging can connect electric vehicles into the power grid in time, reduce the waiting time for electric vehicles to access the power grid while meeting the charging demand, and improve the adaptability of the charging pile group management center to the load change of the power grid.

TABLE I. COMMUNITY GRID PARAMETERS UNDER DIFFERENT CHARGING PILE GROUP MANAGEMENT MODELS (24H)

Parameters	**Optimal charging**	
	without delay	***with delay***
Average(kW)	602.83	602.60
Variance(kW)	101.64	101.08

VI. Conclusion

After analyzing the charging mode of EV, this paper establishes the charging load model of EV cluster in residential area power grid, analyses the harm of disorderly charging, and constructs the charging pile group management model with delayed load regulation. This management model has strong adaptability to electric vehicles access to the grid. The reference load based on the charging demand of the electric vehicle group can reasonably distribute the charging time of each charging pile. With the addition of load increment, the charging pile group can better adapt to the changing charging demand of electric vehicle group. At the same time, the reasonable combination of reference load and load increment can adjust the charging load distribution of electric vehicle group, adapt to the time-sharing pricing mechanism of power grid, and reduce the charging cost of users. The delay regulation under the management model of charging pile group can distribute the load power of distribution network to charging pile group in time, reduce the total charging time and improve the operation efficiency of charging pile group. In addition, the delay regulation also optimizes the load curve of the power grid, which plays an important role in reducing transmission line losses.

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