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Research on Ordered Charging Strategy of Electric Vehicle with Double Layer Optimization Method

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Abstract. Based on the adverse impact of disorderly charging of large-scale ELECTRIC vehicles on the power grid, the feasibility of orderly charging control is firstly analyzed, the objective function and constraint condition model of orderly charging control are established, and then the charging time of electric vehicles is controlled by reasonable distribution. Then a two level optimization solution strategy based on dynamic programming was proposed to solve the problem. In order to control the order of electric vehicles, the outer layer utilized the dynamic programming method to solve the problem. The inner layer selected various charging schemes for each electric vehicle to find the best charging mode. Finally, the rationality of the two-layer optimization solution strategy was verified by the case analysis.

1. Introduction

With the increasing shortage of fossil energy and the increasing greenhouse effect, large-scale use of electric vehicles, which use secondary energy of environmental protection and low-carbon vehicles, will become an inevitable trend. Due to the spatiotemporal randomness of the electric vehicle load, the large-scale charging load of the electric vehicle will lead to the increase of the peak valley difference of the power grid and disturb the stable operation of the distribution network [1-3]. In order to alleviate the above adverse effects, it is necessary to control the charging load of electric vehicles in order to restore the economic and stable operation state of the power grid [4-5].

In reference [6], the spatial-temporal distribution model of electric vehicle parking demand is established, and the large-scale electric vehicle is simulated by Monte Carlo simulation method, and the charging load is analyzed and predicted. Through the construction and analysis of the response model of peak valley price period in reference [7], the optimization model of peak valley price period is proposed to guide users and realize orderly charging optimization. Reference [8] compared the impact of large-scale charging load on power grid under natural charging and orderly charging and discharging, and adopted genetic algorithm. The algorithm optimizes the charge discharge strategy. In reference [9], aiming at maximizing the revenue of electric vehicle charging station, two-stage optimization of electric vehicle charging was carried out without increasing the burden of power grid. In reference [10], a method combining component analysis and fuzzy clustering was used to study the driving behavior characteristics of users, then charging scheduling of electric vehicles was carried out.

2. Feasibility analysis of electric vehicle charging load control

The charging load of electric vehicles has the characters of random distribution in time and space, which is one of the important reasons for the adverse impact of disordered charging on power grid [11-13]. The charging load formed by a certain scale of electric vehicles is mainly determined by the quantity and its own characteristics, and the characteristics of electric vehicles divided into battery characteristics and driving law. The three factors jointly affect the charging load of EVs, and the specific analysis includes: ownership, charging characteristics, and driving law [14].

For the number of electric vehicles in a region, it can be distinguished and counted according to the office area and residential area, so as to evaluate or determine the number of electric vehicles. According to the model and battery power experiment, the battery power characteristic and charging capacity of EV can be given. For the law of EV driving, it is assumed that the EV user decides where the EV can be charged. The charging mode of electric vehicles can also be determined according to the model of electric vehicles and users' wishes. It is assumed that all electric vehicle users adopt the mode of slow charging. It can then assess the number and power of electric cars to be charged in the area each day.

3. Control objectives and constraints of orderly charging

3.1. Control target of orderly charging

Through the analysis of the current research on orderly charging, this paper finds that there are mainly two aspects to consider the charging control objectives: from the user's perspective and from the grid's perspective. Combining these two problems, the charging load distribution is the most reasonable on the premise of satisfying users' charging demands. The charging load formula of ELECTRIC vehicles involved in orderly control is as follows:

$$P_{Ei}(t) = P_{E(i-1)}(t) + p_{Ei}(t) \tag{1}$$

Where, $P_{Ei}(t)$ is the charging load of the I-1 EV that has participated in orderly control; $P_{E(i-1)}(t)$ is the total charging load of the I-1 EV that has participated in orderly control; $P_{Ei}(t)$ is the total charging load of the I-1 EV that has participated in orderly control after the addition of the I-1 EV.

In order to reflect the influence of orderly control on grid load, other basic loads are regarded as functions with time as independent variable. The aim of orderly charging control is to reduce the daily peak-valley difference and alleviate the load fluctuation. In order to express control objectives more clearly, the objectives are simplified into the following mathematical expressions:

$$\min f_1(P_D) = \lambda_1 \sqrt{\sum_{t-1}^{N_t} (P_{Dt} - P_{avt})^2 / N_t} + \lambda_2 (P_D^{\max} - P_D^{\min}) \tag{2}$$

$$P_{avt} = \sum_{t=1}^{N_t} P_{Lt} / N_t \tag{3}$$

$$P_{Dt} = P_{Loadt} + P_{Et} \tag{4}$$

Where, $P_D^{\max}$ and $P_D^{\min}$ respectively represent the daily maximum load and the minimum load, and the difference is the peak-valley difference; λ_1 and λ_2 represents the mean square error of the load at each moment. By changing the weight coefficient, the bias of the control target can be adjusted, when one side is 0, the control target becomes a single target. P_{Loadt} is the predicted value of daily load of residents; P_{Wt} is the estimated daily power generation of wind power in the power supply area; P_{Ht} is the forecast value of photovoltaic power generation in the power supply area on a daily basis. P_{Et} is the planned charging power value of all electric vehicles in the power supply area.

$$P_E(t) = \sum_{i=1}^{N_E} P_{Ei}(t) K_i(t) \tag{5}$$

Where, P_{Ei} is the charging power of a single EV; $K_i(t)$ is the judgment function of whether a single electric vehicle is charged at time T. If it is in charging state, $K_i(t)=1$; otherwise, $K_i(t)=0$.

3.2. Constraints of orderly charging

In this paper, only the slow charging mode in residential areas is taken into account, and once a day is set for EV charging, which is charging of constant power. Then the constraint conditions of orderly charging can be listed as follows:

$$E_{i0} + \sum_{j=1}^{96} P_{Ei}(t_j) K_j(t_j) = E_i \tag{6}$$

$$t_{start-j} > t_{start-j}^{\min} \tag{7}$$

$$t_{end-j} < t_{end-j}^{\max} \tag{8}$$

$$\text{If } \ t_{start-j} < t_j < t_{end-j} \ , \ K_i(t_j) = 1$$

$$\text{otherwise } \ K_i(t_j) = 0$$

Where, $t_{start-j}$ is the moment when electric vehicles are connected to the power grid; t_{end-j} is the moment when the electric vehicle leaves the power grid; $t_{start-j}^{\min}$ is the earliest time when electric cars acceptable to car owners are connected to the power grid; $t_{start-j}^{\max}$ is the last moment for an EV that the owner can accept to leave the grid; $K_i(t_j)$ is the charging state of the *i*-th EV in period J; $P_{Ei}(t_j)$ is the charging power of the *i*-th EV in time period *J*; E_i is the charging capacity of the *i*-th EV; E_{i0} is the initial charged state of the *i*-th EV.

4. Two-layer optimal solution calculation strategy for orderly charging control of ELECTRIC vehicles

In this paper, the initial charging time $t_{start-j}$ of an electric car is taken as the variable to be optimized. By enumerating all the cases of $t_{start-j}$ and combining the requirements of different users, we can find the solution that minimizes the objective function, that is, the optimal solution.

A two-layer optimal solution algorithm based on dynamic programming is proposed to solve the ordered control problem of electric vehicles. The dynamic programming method decomposes a multi-variable optimization problem into multi-variable optimization problems through stage division [9], The load characteristic is taken as the state quantity, and the charging power of each EV at this stage is taken as the decision quantity, and its state transfer equation is:

$$P_{Di}(t) = P_{D(i-1)}(t) + P_{Ei}(t) \tag{9}$$

Where, $P_{Di}(t)$ is the load state of the power supply partition; $P_{D(i-1)}(t)$ is the load state of i-1 vehicle after it is shortlisted in stage i-1. $P_{Ei}(t)$ is the charging load of I vehicles in stage I. In Formula (7), in the stage I, namely the charging load of I cars, the optimization calculation is conducted by means of exhaustive method, taking into account the difference in the initial charging time. Define the weight of the path between two states:

$$P_{Dij}(t) = P_{D(i)}(t) - P_{Dj}(t) \tag{10}$$

Where, $P_{Dij}(t)$ is the change value of the objective function of load characteristics after the transfer from state I to state J, considering the charging strategy of EV J; $P_{Di}(t)$ is the objective function value of system load characteristics after taking into account the charging behavior of all the previous I EV after the I EV is connected to the grid; $P_{Dj}(t)$ is the objective function value of system load characteristics after considering the charging behavior of all the first J EV after the Jth EV is connected to the grid.

5. Case analysis of orderly charging control application

The control objective of this paper is to minimize the peak valley difference and the minimum load fluctuation. Assuming that the penetration rate of electric vehicles in a certain region is 30%, the bias degree of the two sub objectives of minimum peak valley difference and minimum variance is

changed by changing the weight values of λ_1 and λ_2. The load curve after orderly control is shown in Fig.1.

a Minimum mean square deviation

b Peak and valley differences are minimal
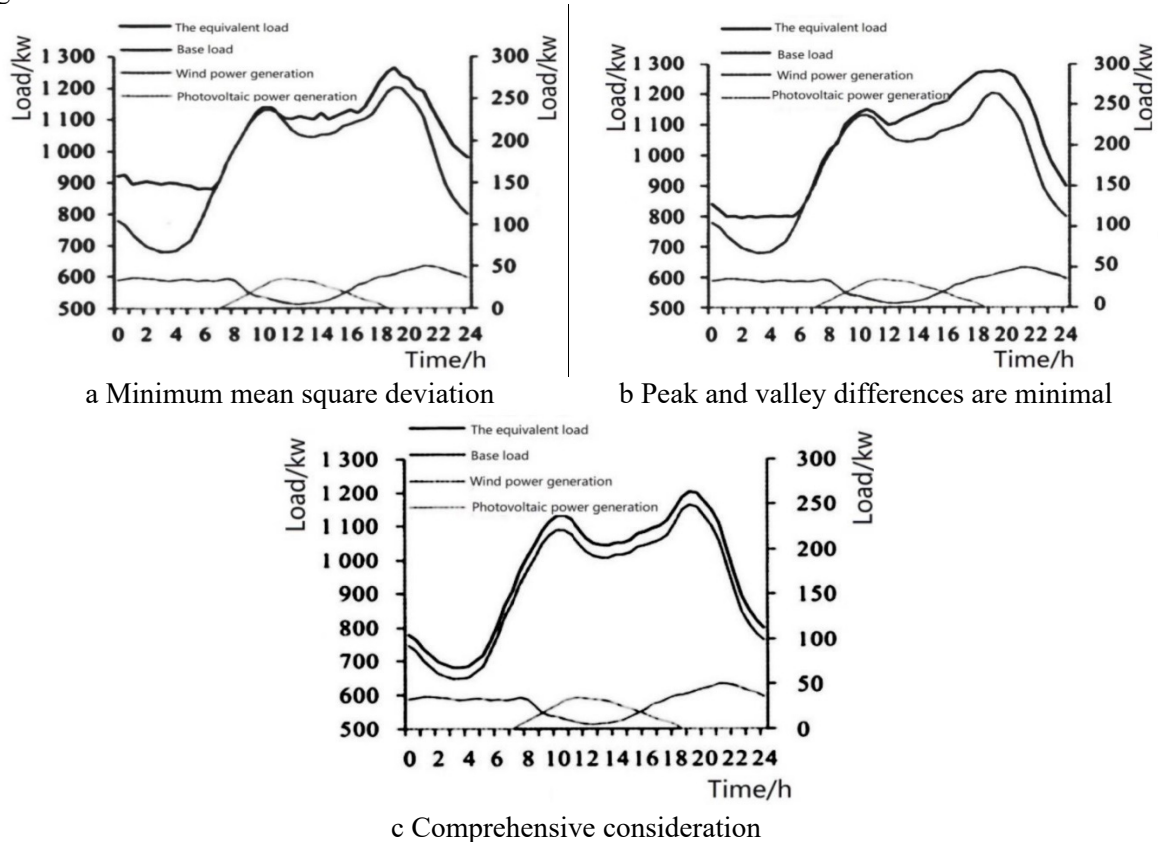

c Comprehensive consideration

Figure 1. Same as the orderly control condition under control objective.

By comparing figure 1a, 1b, 1c, you can see that the two points target orderly focuses on three different levels of charging method, both to control charging load effectively, relieve the poor peak valley and load fluctuations, will focus on 16 ~ 21 when the peak period of charging load transfer and filling to 0 ~ 6 and 12 ~ 16 when two load trough the mid-term. Table 1 shows the peak load increases of unordered charging and the three control targets. According to the data in the table, considering the control objectives of peak-valley difference and mean square error comprehensively, the control effect is the best, and the reduction effect of peak-valley difference is the most obvious when the load peak increment is the smallest.

Table.1 Load peak and peak-to-valley difference data sheet.

	Base load	Disordered charge	Minimum variance	Minimum peak-valley difference	Comprehensive consideration
The peak load / kW	12033.33	13628.65	12724.83	12528.74	12633.53
Increase / kW	0	1595.33	691.49	495.41	600.21
Reduced ratio	0.00%	-10.22%	18.25%	32.67%	26.22%
Mean square error /kW	1727.69	1732.70	1180.22	1358.82	1262.91

To sum up, by comparing orderly charging control with disordered charging, it can be concluded that orderly controlled charging load can effectively alleviate the problem of load peak increase, and obviously reduce the peak and valley difference compared with the load of electric vehicles before they are connected to the grid. By comparing the three control targets with different bias, it can be

seen that the control target with the minimum mean square deviation and peak-valley difference has the best control effect.

6. Conclusion

This paper mainly studies an EV orderly charging strategy based on double layer optimization algorithm. The specific steps of the control strategy include taking into account the battery characteristics and driving law of different EVs to establish dynamic programming layer by layer for optimization. The optimal charging strategy of a single EV is determined by using the exhaustive method. The outer layer is optimized according to the inner layer optimization results, and the outer layer USES dynamic programming method to perform active sequencing control on the charging progress of EV. Through the analysis of the application cases, it can be concluded that the control target with the minimum mean square deviation and peak/valley difference is considered to have the best effect of sequential control.

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