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The two-stage optimal model for electric vehicles in an intelligent community

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Abstract. Considering an intelligent community with a large of electric vehicles(EV), a two-stage dispatch optimization approach was proposed in this paper. Firstly, to establish the first phase optimization model with the guidance of time-of-use electricity price, aiming the minimization of user's electricity consumption. Meanwhile, rewards the aggregator for reducing load peak valley, takes direct load control during the period in which the electricity prices is the same and establishes the second phase optimization model aiming the minimization of valley-to-peak. Monte Carlo method is used to simulate the total load curve of the community, respectively under the situation that the EV are disordered charged and orderly charge-discharge under different response rate. The simulation results show that this model ensures the maximization of user's benefit while realizes the peak load shaving of the load curve, and it has a wider range of applications.

Key words. Intelligent community electric vehicles; time-of-use tariff; direct load control; monte carlo method.

1. Introduction

With the increasing consumption of fossil fuels and the deterioration of the environment, EV have huge potential in reducing environmental pollution and greenhouse gas emissions. So its possessing capacity will continue to grow substantially in the next few years. It is inevitable that EV with scale will be integrated into the grid. Vehicle to Grid (V2G) is a rational, far-looking development idea which put forward based on the concept of "two-way interaction" in the smart grid environment, making EV participate in the grid in the form of demand response (DR). This is both an opportunity and a challenge. Mass electric vehicle disordered charging and discharge can result in peak load of the distribution network, causing peak load

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exceeding the device's allowable limit, peak valley difference of the power distribution network intensified and so on , which is not conducive to the economically operation of the system, in the meantime, posing potential safety hazard. For this purpose, study of charge and discharge control strategy which aiming to reduce the influence of large-scale EV integrated to the power distribution network has been one of the hot issues of recent years.

At present, both domestic and foreign scholars have conducted a series of studies on the scale of the electric vehicle. The research of the power distribution market shows that guidance of the tariff is the key to control EV orderly charge and discharge. And it is also a special form to realize distributed control which can help EV users arrange charge and discharge time autonomously. Literature [3] and [4] optimize the charging power of EV during the next day according to the previous forecast results of the real-time tariffs. Literature [5] and [6] guide users to orderly charge and discharge according to the time-of-use tariffs. Literatures above all regard users as passive recipients of the price fluctuation and do not analyze the impact of the user's demand and different response rate to power grid .The Literature [7] puts forward that the important foundation for V2G is market mechanism. The pricing and timing of EV charging and discharging were analyzed and set according to user's custom and demand of electricity from the perspective of economy. And the validity of the method is also verified at the same time. Literature [8] aims for maximum economic gain, controls only the power pass sequence to achieve the desired results by optimizing the EV charging process. Literature [9] introduces the scheduling method of the layered partition of EV, constructs an EV charging-discharge scheduling model based on two-layer optimization and minimizes the load variance of the system to achieve the peak filling. Literature [10] analyzes the large-scale EV parallel network and emphasizes the necessity of group scheduling. It establishes the EV population charging probability distribution model aiming at minimizing the load peak valley, guiding the user to shave peak and fill the valley with the electricity price difference. Literature [11] puts forward the method of orderly charge-discharge with synergies between supply and demand based on the DR. On the basis of this, adopt conditional risk value as a measure of risk will be established for simulation of a smart community. The results show that this method significantly increases the average annual income of EV users; meanwhile, it is effective to reduce load fluctuation and reduce peak valley difference.

The above analysis shows that the optimal model of the EV charging and discharge optimization is a top priority. However, there is very little research on how to implement the ordered charging and discharge of EV in the intelligent community containing the aggregator framework. Based on it, this article takes a large residential scene as an example, proposes a two-stage optimization scheduling model for the EV in an intelligence community. In the first stage, the EV user is guided and discharged in an orderly manner by the time-of-use price, building the first stage optimization model with the goal of minimizing electricity consumption. Then, to prevent excessive response to the tariff guidance policy, the second phase optimization model was established with 15min for a time scale to set up a peak filling valley on the basis of guaranteeing the user's benefit. The simulation results show that this model ensures the interest of the grid company, the aggregator and the EV user and realizes peak shaving of the load curve.

2. The set of time-of-use price for V2G

2.1. The set of Time-of-Use Price for Charging

The increased holdings and expanding scale of EV need more rapid and reliable data communication. As a result, the computational burden of the grid dispatching center is aggravated. A single electric vehicle cannot form a scale effect to participate in the operation of the grid scheduling and the optimization algorithm is very complex, with high dimensionality and low efficiency. In order to deal with the above problems, the layered control schedules based on aggregator can effectively solve them.

There are many types of aggregator-managed clusters, of which charge station management and intelligent community management are two typical examples. Although both of them serve for the EV charging service, there are still many differences. The most obvious difference is that the charging battery of the charging station is independent of the charging vehicle, that is, the battery charge is not transferred to the user's needs. But the battery and body of EV in the intelligent community are integrated, it is necessary to consider user's needs and living habits when setting the price. Literature shows that frequent adjustment of tariff will lose its guiding role to the user. So it is different from the implementation of dynamic price to the charging station. It is more practical to set a static time-of-use price to guide users in the intelligent community.

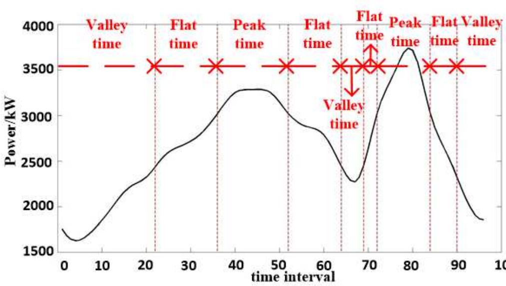

Fig. 1. A time - sharing tariffs chart developed by an intelligent community

Power grid time-of use price is developed for non-special load of a certain area and it is not representative of the aggregator-managed area. So the aggregator performs a K-means clustering analysis on the daily load curve of a large district. The load curve is divided into 15 minutes for a period of time which marked t. The total 96 periods is divided into three periods which are peak period, valley period and smooth period. Then guarantee equation (1) as follows. That is, the user average price doesn't change, which is 1 yuan / kWh. Finally, the time-of-use price of charging period is shown in fig. 1.

$$\frac{1}{96}\sum_{t=1}^{96} Pt = 1 \tag{1}$$

P (t) is the corresponding tariff for time period t; Tariff of peak period is 1.2 yuan / kWh; Tariff of flat period is 1 yuan / kWh; Tariff of peak period is 0.8 yuan / kWh.

2.2. Discharge Period and Price Setting

Professor Kempton of Delaware University in the United States and his research team believe that the optimal control strategy for V2G is difficult to be accepted by electric vehicle users in practice after years of research and analysis [3]. This paper considers that the time in which users are not in the district is uncontrollable when thinking about the discharge period. During this time, peak and valley price is out of guiding function. Therefore, refer to the daily users' peak of the sum of the load power and the disordered charge load power in the other periods as reference for the discharge period selection. Meanwhile, users can only discharge during the selected period of time and it doesn't affect individual users charging to meet their needs during this period. Finally confirm that the discharge period is 73-84, which is 18:00-21:00. The following equation (6) is defined as a charge / discharge specification for EV. On the other hand, to guide users to discharge orderly in the discharge period, the price should be greater than the charging time-of-use price. For the sake of conservatism, this paper sets it to be the same as the peak tariff of charging.

3. A Two - stage Ordered Charge - discharge Model Considering EV User's Requirement

3.1. A. An Orderly Charge and Discharge Model Considering Bicycle Demand

The aggregator who manages the intelligent community is a supplier of electric vehicle charging service and an intermediate control platform for achieving the purpose of the grid company as well. They charge a fee at a certain price on one hand, and pay the grid company according to the purchase price. The difference is the profit of its charging service. On the other hand, they gain the reward given by the grid company by achieving the goal. This paper assumes that the intelligent community that aggregator managed is equipped with a smart charging facility which can control the electric vehicle charge and discharge process. Then, taking 15 mins as a time period, divides one day into 96 intervals to control. If there appears a fractional period, then collectively take the nearest integer period to deal with.

In V2G mode, a single vehicle charge state constraint:

$$SOC_{\min} \leq \mathrm{SOC_i}(t) \leq SOC_{max} \tag{2}$$

$SOC_{\mathrm{i}}(t)$is battery remaining capacity status; $SOC_{\min}$ is minimum battery remaining capacity status; $SOC_{max}$is maximum battery remaining capacity status;

Whether it can participate in the orderly charge and discharge stage depends on equation(3):

$$\begin{gathered} T_{\mathrm{cmax}} \leq T_{long} \\ T_{\mathrm{cmin}} = (SOC_0 + SOC_e) \cdot Q_i / P_{ci}(t) \cdot \eta_c \end{gathered} \tag{3}$$

$T_{\mathrm{long}}$is grid length; $T_{\mathrm{cmax}}$is the shortest charge length; $SOC_0$is the initial state of charge; $SOC_e$is expected status of charge; $Q_i$is the battery capacity; $P_{ci}(t)$is charging power; $\eta_c$is Charging efficiency.

B. *The Goal and Constraints of the First Stage Ordered Charge and Discharge Model*

The first stage is to achieve EV users' independent response and distributed control guided by time-of-use tariff and discharge period tariff. Time-of-use tariff is one of the main means of load optimization in demand side management. On the basis of considering the time-of-use tariff and demand side income situation synthetically as well as meeting the user's charging demand, achieve the goal that users pay the least tariff from vehicles accessing grid to leaving grid. As the tariff that EV user should pay when disorderly charge is uncontrollable, so the objective function only considers the tariff during orderly charge and discharge period. It can be expressed by equation (4) - (7).

$$\max C_{\mathrm{t}} = \sum_{i=1}^{N2} \sum_{t=1}^{96} P(t) \cdot \Delta t \cdot (P_{ci}(t) + P_{\mathrm{di}}(t)) \cdot X_i(t) \tag{4}$$

$$X_i(t) = A_i(t) \cdot W(t) \tag{5}$$

$$V_1 = \int_{-\frac{1}{2}}^{\frac{1}{2}} \int_{-\frac{c}{4b}+\frac{\xi}{2}-\frac{1}{4}-\frac{c\xi}{2b}}^{\frac{c}{4b}-\frac{\xi}{2}+\frac{1}{4}+\frac{c\xi}{2b}} (p_1 p_2)^3 p_3 (G - 2(1-\nu)H)\, \mathrm{d}\eta\, \mathrm{d}\xi\,, \tag{6}$$

$$b_{m1} A_1 + b_{m2} A_2 = 0\,, \quad m = 1, 2\,, \tag{7}$$

$C_t$is the total tariff of responsive vehicles; $N2$is the number of responsive vehicles; P_{di} $(t)$is the discharge power, $\Delta t$is 0.25h; A_i (t) is the charge and discharge situation of vehicle i during period t. $W(t)$ is the grid situation during period t; $T_{\mathrm{o}}$is the period in which a vehicle connected to grid; $T_d$is the period in which a vehicle go off- grid. It is assumed that the total vehicles need to be charged is divided into two groups. One is the vehicles which response to the tariff, the other one is the vehicles which don't response. The Relationship among them can be expressed as$N = N1 + N2$. Nrepresents the total number of vehicles. $N1$represents the number of the vehicles which don't response the guidance of grid.

The user's demand for electricity is expressed as Equation 8.

$$\begin{aligned}&\mathrm{SOC}_0+\textstyle\sum_{\mathrm{t}\in(To,96)\bigcup(1,T_d)}\Delta t\cdot(P_{ci}(t)\cdot\eta_c+P_{di}(t)/\eta_d)\\&\cdot X_i(t)\ \ /Q_i\geq SOC_e\end{aligned}\tag{8}$$

Charge state constraint:

$$\begin{aligned}&\mathrm{SOC_i}(t+1)=\mathrm{SOC_i}(t)+\textstyle\sum_{\mathrm{t}\in(To,96)\bigcup(1,T_d)}\Delta t\cdot\\&(P_{ci}(t)\cdot\eta_c+P_{di}(t)/\eta_d)\cdot X_i(t)/Q_i\end{aligned}\tag{9}$$

$$P_{ci}(t)\cdot P_{di}(t)=0\tag{10}$$

$S_\tau$is the rated capacity of transformer; λ_τ is transformer efficiency.

3.2. The Goal and Constraints of The Second Stage Ordered Charge and Discharge Model

Because time-of-use tariff has static characteristics and the tariff response of EV is uncertain, the results of the first stage ordered charge and discharge model tend to show new load spikes at low tariffs. That is excessive response or lack of response. For this problem, this paper sets the second stage to optimize the load power. Taking into account the load scheduling during the same tariffs period, use direct load control (DLC) to achieve the minimum load peak valley difference. As shown in Equation (12).

$$\frac{\partial}{\partial A_m}\left(V_1-\lambda^2T_1\right)=0\,,\quad m=1,2\,.\tag{11}$$

$$V=\frac{ab}{2}\frac{E_0h_0^3}{12\,(1-\nu^2)}\int_{-\frac{1}{2}}^{\frac{1}{2}}\int_{-\frac{c}{4b}+\frac{\xi}{2}-\frac{1}{4}-\frac{c\xi}{2b}}^{\frac{c}{4b}-\frac{\xi}{2}+\frac{1}{4}+\frac{c\xi}{2b}}(p_1p_2)^3p_3(G-2(1-\nu)H)\,\mathrm{d}\eta\,\mathrm{d}\xi\,.\tag{12}$$

L(t)is total load curve peak valley difference; Equation (**??**) represents the user benefit constraint; $\mathrm{C_t^*}$is the minimum cost of the user from the first stage. The other constraints are the same as those in 3.1 and 3.2.

$$\begin{aligned}&\mathrm{C_t^*}\geq\textstyle\sum_{i=1}^{N2}\sum_{t=1}^{96}P(t)\cdot\Delta t\cdot(P_{ci}(t)+P_{\mathrm{di}}(t))\\&\cdot X_i(t)\ \ 1<t<96\end{aligned}\tag{13}$$

3.3. The Simulation Flow Chart Description

In the process of charge and discharge control of the intelligent community with the EV managed by the aggregator, the grid company determines whether there is a need for incentives to stimulate aggregators to increase tariff differentiation based on the peak and valley difference of the first stage to set a new reference for the future tariffs. Meanwhile, it has to decide whether to do part of the incentive to stimulate the aggregator to carry out the second stage load optimization to achieve peak load shaving. The final load power curve of the orderly charge and discharge process is shown in Fig. 2. The simulation of this paper uses Matlab to call CPLEX through YALMIP to solve the model, and it can get very good results.

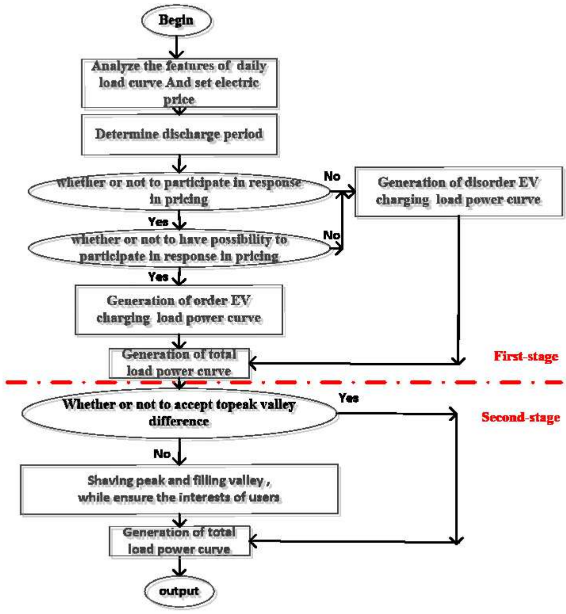

Fig. 2. The process of orderly charge control

4. Numerical simulation

4.1. Parameter Settings

The daily load power of this paper is derived from the power consumption of a distribution line of the IEEE33 node system. Take a large community as an example. There are 950 users and 1000 private vehicles, in which the permeability of EV is 30%.The other basic parameters are shown in Table 1[14].

Table 1

Name	Value	Name	Value
	64kW?h	N	300
	7kW		$\mathrm{T_0} \sim \mathrm{N}(7.5, 1)$
$\eta_\mathrm{c}, \eta_\mathrm{d}$	0.95		$\mathrm{T_d} \sim \mathrm{N}(18, 1)$
	0.95		$\mathrm{SOC_0} \sim \mathrm{N}(0.3, 0.1)$
	0.1	$S_\mathcal{T}$	6400KVA
	0.9	$\lambda_\mathcal{T}$	0.95

4.2. Simulation Results and Analysis

4.2.1. Effects of EV unordered charge under different permeability The load curve obtained by disordered charging in 96 periods in a day respectively under the permeability of 10%, 30% and 50%of the EV in the intelligent community through the Monte Carlo method is shown in Fig.3.

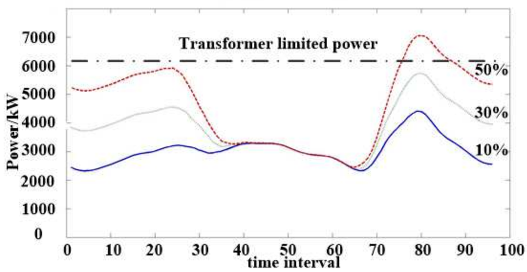

Fig. 3. The total load curve of disordered charge under different permeability

The figure shows that EV charging load curve fluctuated obviously without orderly guidance and control. The peak-valley differences continue to expand with the increase of the permeability. When the permeability reaches 50%, the peak-valley difference is as high as 4479.8798kW and the load peak exceeds the transformer power limit in the community which will cause security risks of residential electricity. From an economic point of view, the increase in the difference between the peak and valley makes the grid company buy more electric energy. Meanwhile, generating unit start and stop intensified results in energy waste. It does no good to energy saving and emission reduction as well as the construction of low - carbon society. From the aggregator side, they lost the grid company's bonus. EV users can not enjoy the benefits of electricity reform. On the contrary, their electricity costs continue to increase.

4.2.2. Contrastive analysis of ordered charge and discharge of the two stages under different response rates Time-of-use tariffs have static characteristics. Therefore, the effect of different response levels on the load power curve should be considered when optimizing EV charge and discharge based on the second stage optimization model. For ease of analysis, the simulation is carried out with EV permeability of 30%, response rate of 10%, 50% and 90% respectively. The comparison is shown in Table 2.

Table 2

Response rate/%	First stage	Second stage
	Peak-valley difference /kW	
10	2894.6362	2856.0022
50	1891.5793	1428.2784
90	2556.8392	1482.2413

Through the comparison of the peak-valley difference of the two stages in Table 2, we can know that the more users respond to the boot, the more opportunities aggregator has to carry out DLC at the same price period and the more obvious the second-stage optimization effect is. Take the 90% response rate as an example. As shown in Fig.4.

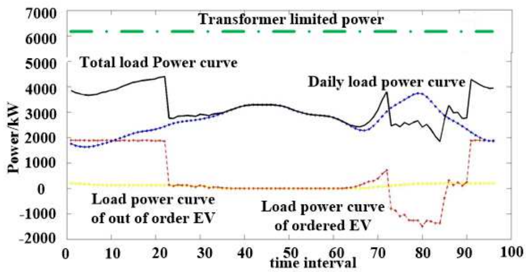

Fig. 4. Ordered charge and discharge load power curve when the response rate is 90%

However, there is also the possibility that EV user response poor. The effect of the peak-valley difference is not obvious when the EV response rate is 10%. It indicates that the price guide does not work for the users' response. It is necessary to re-analyze the tariffs. For an example, expand the price distinction. That is to raise the peak time price while reducing the valley time price to guide more users to respond.

5. Conclusions

Through the simulation analysis of the two stages optimized charge and discharge scheduling model, the following conclusions are obtained:

(1) The two - stage optimization method of charge and discharge proposed by this paper takes users' charging demand and living habits into account and can effectively achieve peak load shaving of the total load. The more users who accept the guidance, the more obvious the effect is. Increase the tariff distinction to strengthen the impact on EV users when their response is insufficient. The reasonable tariff can be found in field tests.

(2) The EV users in the intelligent community managed by the aggregator are

suitable for charging and discharging by the way of time-of-use tariff and the specified discharge period. The hierarchical control based on the aggregator can regulate the charge and discharge of EV through the control method of the combination of distributed control and centralized control.

(3) This paper verifies the validity of the two - stage EV Sequential Charge - discharge Method to peak load shaving by simulation. It provides a new method for designing the load curve forecasted the day before. This method is universal. It can simulate other management areas such as large shopping malls and companies as long as modifying the target and changing parameters.

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