Based on Prospect Theory Regional Integrated Energy Electric Vehicle Scheduling Model

Shufeng Li¹, Qiang Yao², Zhankun Xu², Jianwei Gao³ and Yu Yang^{3,*}

¹East Inner Mongolia Electric Power Company Limited, Hohhot 010010, Inner Mongolia, China

²State Grid Inner Mongolia East Electric Power Integrated Energy Service Co. Ltd, Hohhot 010010, Inner Mongolia, China

³School of Economics and Management, North China Electric Power University, Changping, Beijing, 102206;

Abstract. Regional comprehensive energy is the focus of current research, and electric vehicles are an important part of regional energy. The orderly participation of regional EV groups in demand response for optimal scheduling of charge and discharge can not only save the charging cost of EV owners, but also smooth the load fluctuation caused by EV charging. In this paper, an Integrated Energy Electric Vehicle Scheduling Model Based on Prospect Theory is proposed. Firstly, the optimal charging and discharging strategy of each Electric Vehicle is obtained Based on the price demand response Model. Secondly, a decision-making method of participation willingness based on the prospect theory is proposed to consider the risk bias of EV owners. Finally, a case study is provided to verify the effectiveness of the proposed method. Compared with electric vehicles participating in random charging, the optimization model proposed in this paper reduces the cost by 32% and the average hourly load by 67%.

1 Introduction

Electric vehicles (EVs) are rapidly becoming more popular around the world [1], and a high penetration of EVs could result in excessive loads on current grids. Controlled charging of electric vehicles will have a considerable impact on power grid demand [2][3], may provide a solution to the grid's excessive load. As a result, it is necessary to optimize electric vehicle grid connections and select the appropriate charging/discharging strategy in order to avoid the impact of electric vehicle grid connections on distribution network load and improve the distribution network's reliability and effectiveness [4][5].

This paper proposes an Integrated Energy Electric Vehicle Scheduling Model Based on prospect Theory, and makes the EV group participate in the demand response of Electric Energy more flexibly through the optimization of the Scheduling Model, which not only reduces the load peak, but also enables the EV owners to gain some benefits. In the study of regional energy, the group of electric vehicles can not only be regarded as the consumer of electric energy, but also as the virtual storage container that provides electric energy.

* Corresponding author: yang_yang_yu_yu@163.com

This article's contributions can be summarized as follows. Based on prospect theory, this research develops an Integrated Energy Electric Vehicle Scheduling Model. The model proposed in this paper not only takes into account the saving of charging cost of electric vehicle owners, but also takes into account the difference of individual risk preference of electric vehicle owners, so the model proposed has more practical significance. A comparison is made between the based on prospect theory regional integrated energy electric vehicle scheduling model and the disordering charging model.

Nomenclature	
$T_{in,l}$	the time when the vehicle l is connected/leave to grid
$T_{out,l}$	
$S_{O,l}$	the starting state of charge of the vehicle's power battery
$S_{E,l}$	the expected SOC for the vehicle l when leaving grid
Q_l	the battery capacity of the vehicle l
$P_{c,l} / P_{d,l}$	the rated charging/discharge power for the vehicle l
Δx	the change of the decision scheme relative to the reference point
β, α	risk attitude coefficient
$T_{m,l}$	the vehicle l is connected to the grid periods
$C_{1,l}$	the cost of the vehicle l
$e_{k,l}$	the battery loss cost
$I_l(k)$	the charging/discharging state
$\rho(k)$	the time-of-use tariff of the period k
I_0	the basic charging/discharging state variable
$\omega_{m,l}(k)$	the maneuverability of the vehicle battery during the period k
ε	the battery loss factor
ξ_c / ξ_d	the charging/discharging efficiency of the battery
$T_{c,l}$	the shortest time required to charge the vehicle l to the desired level
n	the size and number of vehicles
$\pi(l)$	the actual profit of the vehicle l
$f_{0,l}$	the charge and discharge cost of the vehicle l in the case of disorderly charge

2 Modeling approach

The first phase's purpose is to reduce the cost of charging and discharging electric vehicles. In the first phase, charging and discharging expenses are reduced while EV owners' daily driving habits remain unchanged. Meanwhile, EV users' charging needs are being satisfied. The benefits of EV owners can be achieved by comparing the charge and discharge costs based on this component with the disorderly charge and discharge charges.

2.1 EV information

Grid system operator must obtain the relevant parameters for each EV once the monitored vehicle fleet is connected to grid. The vehicle's important parameters are expected to be as follows:

$$J * \Delta t = T \quad (1)$$

$$V_l = \{T_{in,l}, T_{out,l}, S_{O,l}, S_{E,l}, Q_l, P_{c,l}, P_{d,l}\} \quad (2)$$

Equation (1) represents the duration of research on electric vehicles, which is equally divided. First, the status of electric vehicles in each period is considered, and then the whole period is comprehensively considered.

When an EV is connected to the grid, it transmits information about the car itself to the grid for deployment. In general, we need to know the driving time of the electric vehicle, the type of electric vehicle and the remaining power when driving into the vehicle.

2.2 Value function of prospect theory s

To characterize psychological influence, value function in prospect theory is used in this paper (Fig. 1). [6].

$$v(\Delta x) = \begin{cases} (\Delta x)^\alpha, & \Delta x \geq 0 \\ -\theta(-\Delta x)^\beta, & \Delta x < 0 \end{cases} \quad (3)$$

Equation (3) is a very accurate description of people's psychological activities. Taking a certain point as a reference point, no matter whether the income change is too large or too small, the impact on the utility value in consumers' minds is in the shape of S.

3 Modeling

3.1 Objective function

The following is the goal function for each vehicle that defines an optimization model based on price demand response:

$$\min_{u_{1,l}} C_{1,l} = \sum_{\substack{k \in T_{m,l} \\ I_l \in u_{1,l}}} [P_{c,l}(k) + P_{d,l}(k)] \cdot I_l(k) \rho(k) \Delta t + \sum_{k \in T_{m,l}} e_{k,l} \quad (4)$$

$$I_l(k) = \omega_{m,l}(k) I_0 \quad (5)$$

$$I_0 \in \{+1, -1, 0\} \quad (6)$$

$$\omega_{m,l}(k) = \begin{cases} 1, & k \in T_{m,l} \\ 0, & \text{other wise} \end{cases} \quad k \in T_{m,l} \quad (7)$$

$$e_{k,l} = [P_{c,l}(k) + P_{d,l}(k)] \cdot I_l(k) \cdot \varepsilon \quad (8)$$

Eq. (4) is the target function. (5) - (7) are to indicate the charging and discharging state of electric vehicles in each time period. In this paper, when the state parameter value is 1, it means that electric vehicles are charged in this period; when the parameter value is -1, it means that electric vehicles are discharged in this period; when the parameter value is zero, it means that electric vehicles are idle. Therefore, the scheduling problem in this paper is a mixed integer programming problem.

3.2 Constraints

Because overcharging and discharging a lithium battery shortens its life, the charge state of the battery must be limited, as illustrated in equations (9) and (14) below:

$$S_l(k) = S_l(k-1) + [P_{c,l}(k)\xi_c + P_{d,l}(k) / \xi_d] I_l(k) \Delta t / Q_l \quad (9)$$

$$P_{c,l}(k)P_{d,l}(k) = 0 \quad (10)$$

$$S_{\min} \leq S_l(k) \leq S_{\max} \quad (11)$$

$$S_{O,l} + \sum_{k \in T_{m,l}} \Delta t \frac{[P_{c,l}(k)\xi_c + P_{d,l}(k) / \xi_d] I_l(k)}{Q_l} \geq S_{E,l} \quad (12)$$

$$T_{pe,l} > T_{c,l}, \quad l = 1, 2, \dots, n \quad (13)$$

$$T_{c,l} = (S_{E,l} - S_{O,l})Q_l / P_{c,l}\xi_c \quad (14)$$

According to the calculation above, the car can only participate in the autonomous demand response process if the vehicle's access to the power network is longer than the shortest time required for charging to the predicted level. Otherwise, it will charge in a disorganized manner.

3.3 Customer willingness decision based on utility value of prospect theory

The actual profit made by electric vehicle owners who participate in automatic demand response is as follows:

$$\pi(l) = f_{0,l} - C_{1,l} \quad (15)$$

Equation (15) gives the income of electric vehicles as defined in this paper. When electric vehicles participate in the optimization scheduling proposed in this paper, the extent to which the cost of unordered charging is reduced will affect the willingness of electric vehicle owners to participate. The greater the cost reduction, the greater the willingness. Therefore, this paper regards this cost difference as the benefit of electric vehicles.

Based on the prospect theory of EV owners, the utility value of the value function is:

$$v(\pi(l)) = \begin{cases} (\pi(l))^\alpha, & \Delta x \geq 0 \\ -\theta(-\pi(l))^\beta, & \Delta x < 0 \end{cases} \quad (16)$$

$$v(\pi(l)) \geq \lambda \quad (17)$$

Set the selection intention parameter λ . When the utility value of the electric vehicle owner is greater than the intention parameter, the owner has the intention to participate in the optimization scheduling. When the utility value of the electric vehicle owner is less than the desired parameter, the owner chooses to conduct disordered charging.

4 Case

4.1 Electric vehicle parameters

A total of 300 electric vehicles were chosen in the area to undertake an empirical analysis based on the daily load.

Table 1. Regional electric vehicle classification

Classification	Proportion(%)	Battery capacity(kw•h)	Power(kW)
1	40	24	3.3
2	40	30	4
3	20	53	7

Table 2. Owners of electric vehicles' risk aversion

classification	Risk seeking	Risk averse
The proportion	70%	30%

According to reference [7], the risk attitudes of EV owners can be anticipated, as indicated in Table.2. The data in the reference illustrates the risk attitude of electric vehicle users in Beijing, China. Based on their risk attitudes, this article splits EV owners into two groups.

Fig. 1. Utility curve of value function.

Fig.2. The electricity price of two days

When EV owners are at risk, among the utility value of the value function based on the prospect theory of EV owners: $\alpha = \beta = 0.88$, $\theta = 2.25$; When electric vehicle owners are risk averse: $\alpha = \beta = 1.21$, $\theta = 2.25$ [9], $\lambda = 1$. The duration of charging and daily miles are determined by the EV owner's travel patterns and driving characteristics. According to the information presented in [9]. In this situation, the calculated time length is 48 hours. Figure 2 depicts the trend in electricity prices and basis load. The change trend of the price and the change trend of the base load are fairly consistent, as seen in the graph.

4.2 Case result analysis

As shown in Figure 3, when the EV group participates in disordered charging, the peak load value is much higher than the peak load value when the EV group participates in the optimal scheduling of charging and discharging. This is because the EV owners have similar driving and rest habits. Those who go to work in the daytime spend more time on charging at night. Such disordered charging behavior has a great impact on the distribution network and affects the security of the distribution network.

In this paper, based on the segmented electricity price and taking into account the utility preferences of EV owners, an optimal scheduling model based on the prospect theory value function is proposed to optimize the charging and discharging habits of EV owners, so that the power load is relatively flat. This is because at peak load times, due to price guidance, electric vehicle owners tend to discharge to suppress peak load. However, when the load valley value is reached, EV owners tend to charge to maximize their own interests.

Fig.3. The load of two days

Fig.4. The cost of every EV

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As shown in Figure 4, the cost of participating in disordered charging for EV owners is higher than that of participating in optimal scheduling. In the optimization scheduling model, some electric vehicle owners choose not to participate in the optimization scheduling because the benefits of participating in the scheduling are low and the participation utility value is lower than the participation willingness value. As shown in Table 3, participation in the optimal scheduling model can reduce the average cost of each vehicle by 3.23 yuan, The total cost decreased by 967.68358 yuan , that is, by 32%, compared with the average cost of participating in disordered charging.

Table 3.Case result analysis

classification	Average(yuan/EV)	Total(yuan)
Disordered charge	10.0709472	3021.28416
Optimize charging	6.845335267	2053.60058

5 Conclusion

This paper proposes an Integrated Energy Electric Vehicle Scheduling Model Based on prospect Theory, and makes the EV group participate in the demand response of Electric Energy more flexibly through the optimization of the Scheduling Model, which not only reduces the load peak, but also enables the EV owners to gain some benefits.In the study of regional energy, the group of electric vehicles can not only be regarded as the consumer of electric energy, but also as the virtual storage container that provides electric energy.

In the absence of optimal scheduling, EV owners have similar driving habits, so EV charging will increase the pressure of distribution network and affect the safety of distribution network. Through the application of the optimization scheduling model proposed in this paper, decentralized charging of electric vehicles is realized, load peak is suppressed, and charging and discharging costs of electric vehicle owners are also saved. As the case analysis shows, the charging cost of EVs participating in optimal scheduling is reduced by 30% compared with that of EVs participating in disordered charging, and the average hourly load is reduced by 67%. Therefore, it can be seen that "Based on Prospect Theory Regional Integrated Energy Electric Vehicle Scheduling Model" proposed in this paper has certain practical significance.

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