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LETTER TO THE EDITOR

Economy and Ecology Evaluation of Optimal Electric Vehicle Charging Strategy

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With the rapid increase of electric vehicles (EV), their charging loads will have a significant impact on power grid. It is important to propose an appropriate electric vehicles charging strategy and establish a comprehensive evaluation method. In this paper, the charging strategy of electric vehicles is optimized by considering the users' charging satisfaction and the consumption rate of distributed wind power, and a comprehensive evaluation system of charging strategy is proposed by considering economic indicators and ecological indicators. The evaluation results show that the improvement of electric vehicles charging strategy will reduce the charging cost by 43.7% and the carbon emissions by 5.7%.

I Introduction

Under the pressures of fossil energy crisis and environmental pollution, electric vehicles have incomparable advantages in promoting sustainable development compared with traditional fuel vehicles. Disorderly charging of electric vehicles may increase the peak-valley difference of loads and increase the peak-shaving cost of power grid (Rong *et al.* 2016, Galus *et al.* 2010), while orderly charging can play a role of peak-shaving and valley-filling, avoiding waste of power resources and reducing the economic cost of power grid (Liu *et al.* 2015). Therefore, electric vehicles orderly charging strategy has become the focus of current research. In reference (Esmaili *et al.* 2014), an orderly charging control scheme for electric vehicles is proposed based on the linear programming method. Literature (Hu *et al.* 2014) proposes the centralized charging control system and strategy based on the multi-agent principle. Some scholars have proposed to use electric vehicles as energy storage components to feed back energy to the grid to reduce grid frequency and voltage fluctuations (Kiaee *et al.* 2015, Ebrahimi *et al.* 2017, Yasin *et al.* 2017). This paper proposes an optimized charging strategy for electric vehicles by considering the users' satisfaction and the new energy consumption rate.

In addition, it is also important to evaluate the orderly charging strategy of electric vehicles There are two main evaluation schemes: the first one is to use the lowest system operating cost as the evaluation standard, under the time-of-use electricity price (Ikegami *et al.* 2015), the second one is to take into account grid constraints and charging power constraints, take reduce peak-valley difference and slow load fluctuation as evaluation criteria to evaluate charging strategy (Ni *et al.* 2013). Based on the above two evaluation systems, some experts and scholars adopt the multi-objective double-level optimization charging management method. The upper level optimization takes the minimum fluctuation of power grid load as the evaluation criterion, and the lower level optimization takes the highest degree of customer satisfaction of electric vehicles as the evaluation criterion to realize the energy-saving and economic double-level optimization (Zhang *et al.* 2018). In terms of control algorithm, (Rong *et al.* 2016) combines the power flow approximation method with genetic algorithm to obtain the optimal charging start-up time of each battery group of electric vehicle, so as to reduce the peak-valley difference. Literature (Yang *et al.* 2014) optimizes the electric vehicle charging model with an improved particle swarm optimization algorithm to improve the economic and safety issues of grid operation. This paper evaluates the charging strategy of electric vehicles based on integrated user charging economy, new energy generation consumption rate and carbon emissions.

II Electric vehicle optimized charging strategy

This paper assumes that distributed wind power generation is installed in community, and the charging station is equipped with monitoring and control system, which can detect and record the charging start and end time of the car and the current state of charge (SOC) of the battery. The structure of the charging system is shown in Figure 1:

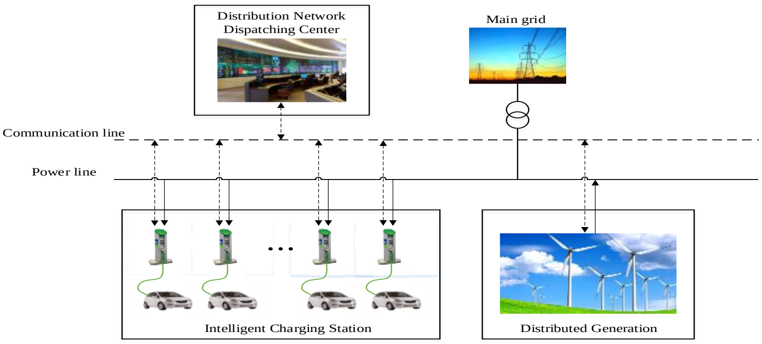

Figure 1 Structure diagram of EV charging system

In this paper, the EV charging strategy is optimized by genetic algorithm by considering the user's charging satisfaction and renewable energy consumption rate.

Large-scale electric vehicles participating in charging scheduling can reduce the cost of the grid and users, and increase the grid peaking capacity, but may affect the user's satisfaction. In order to encourage users to participate more actively in the charging scheduling of the power grid, this paper optimizes the strategy by taking the maximum user's satisfaction as the objective function. The user charging satisfaction can be expressed as:

$$f_1 = 1 - \frac{\sum_{t=1}^{T} \left| P - P_{i,t} \right| \Delta t}{\sum_{t=1}^{T} P \Delta t} \tag{1}$$

where, $P_{i,t}$ is the charging power of the ith car in the tth period, T is the expected maximum residence time of the electric car in the current time period, Δt is the time interval of different periods of time, P is the charging power of electric vehicle i at time t under the condition of maximum user satisfaction.

Another objective function is to improve the renewable energy consumption, and to enable as many electric vehicles as possible to consume distributed energy. Therefore, the objective function can be expressed as follows:

$$f_2 = \sum_{t=1}^{T} (P_{W,t} - P_{load,t}) \tag{2}$$

where, $P_{W,t}$ is the wind power generation output of the system without wind abandonment during t period, $P_{load,t}$ is the load of the whole system during t period.

In this paper, the total objective function is established to realize the optimal electric vehicles charging scheduling by considering the highest customer satisfaction and the maximum wind power consumption. Due to the different units, this paper normalizes f_1 and f_2 to get F_1 and F_2, so the total objective function can be expressed as follows:

$$\max F = \lambda_1 F_1 + \lambda_2 F_2 \tag{3}$$

where, λ_1, λ_2 are the weight coefficients of each target, and $\lambda_1+\lambda_2=1$, λ_1 and $\lambda_2\geq 0$。

Constraints:

(1) System load constraint

The superimposed load constraints can be expressed as:

$$\sum_{i=1}^{n}\left[P_{l,t} + P_{i,t}\right] < P_M \tag{4}$$

where,P_M is maximum load, n is the total number of cars to be charged in the tth time period, $P_{l,t}$ is the basic load of the distribution network at time t.

(2) Total amount of charging electricity constraint

The daily the amount of charging electricity of electric vehicles in the distribution network is:

$$\sum_{i=1}^{n}\sum_{t=1}^{T} P_{i,t}\Delta t = N \times Q_e \tag{5}$$

where, N is the total number of cars charged in a day, Q_e is the amount of electricity required for each EV.

(3) Electric vehicle SOC constraint

The SOC of the electric vehicle should not be less than the amount of charge expected by the user:

$$SOC_{i,\text{expect}} \leq SOC_{i,l} \leq SOC_{\max} \tag{6}$$

where, $SOC_{i,expect}$ is the SOC level expected by the users of the first electric vehicle, $SOC_{i,l}$ is the SOC level of the electric vehicle when the user of the first electric vehicle leaves, $SOC_{\max}$ is the highest SOC limit for electric vehicle batteries.

III Charging strategy evaluation method

In order to evaluate the rationality and completeness of the charging strategy more effectively and accurately, this paper establishes a comprehensive evaluation system of charging strategy for EV by considering economic and ecological indicators.

As the main part of charging dispatch, the economic benefits of electric vehicle users will have a greater impact on their enthusiasm to participate in the dispatch. In order to evaluate the practical feasibility of charging strategy, this paper takes the total charging cost of electric vehicle users as an economic index to evaluate the economy of charging strategy under the time-of-use electricity price. The index can be expressed as follows:

$$I_1 = \sum_{i=1}^{n}\sum_{t=1}^{T} \pi_t P_{i,t}\Delta t \tag{7}$$

where π_t is the electricity price in the t period.

In addition, this paper takes carbon emission as the ecological indicator to evaluate the electric vehicles charging strategy. Carbon emission can be expressed by the following formula:

$$I_2 = Q_{grid} \cdot EF_{grid} \tag{8}$$

In the formula, I_2 is the carbon emission, Q_{grid} is the electricity purchased from the main grid, and EF_{grid} is the average carbon emission factor of the grid. In this paper, it is $0.7143kgCO_2/kWh$.

IV Case Study

This paper takes a community as an example to simulate and analyze. There are 860 households and 120 electric vehicles. According to the charging interface standard set by the state, the charging power is set to 7 kW, and each electric vehicle is charged once a day. This paper records the loads data of the community in 24 hours a day, and draws the normal loads curve as shown in Figure 2. This paper uses the time-of-use electricity price, and the charging price is set as shown in Table 1.

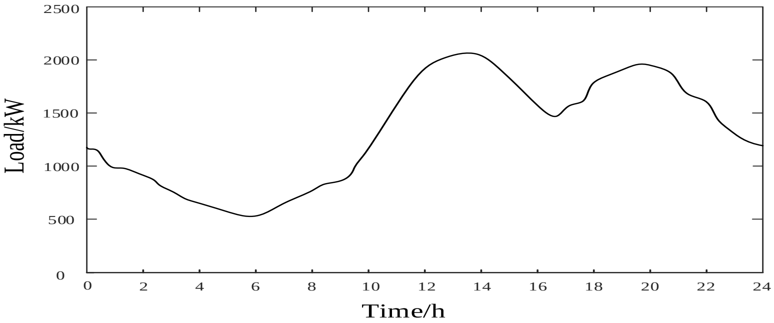

Figure 2 Electrical loads curves in community

Table 1 Time-of-use electricity price table

time	electricity price($/kWh)
Peak hours(10:00-14:00; 18:00-22:00)	0.2376
Valley time(0:00-6:00; 22:00-24:00)	0.0594
Flat time(6:00-10:00; 14:00-18:00)	0.1633

V Results and analysis

Figure 3 shows the original electric loads curve and the total electric loads curve under the condition of orderly and disorderly charging. In the case of disorderly charging, most users charging the electric vehicles between 16:00-8:00, and the charging loads reach 460 kW at 20:00. And the peak value of the total electric loads is sharply increased to 2453 kW, which seriously affects the power supply stability.

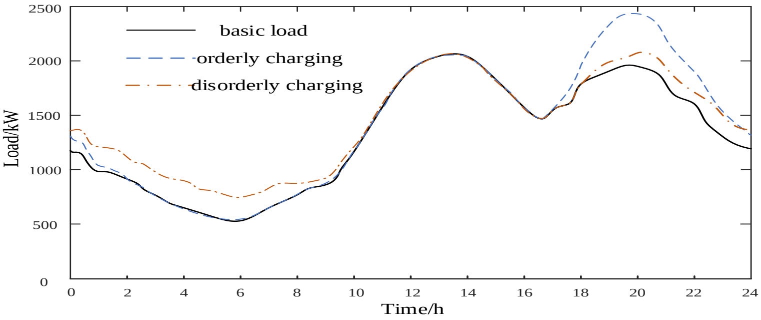

Figure 3 Electrical loads curve in the case of orderly and disorderly charging

As can be seen from Figure 3, after the optimization of electric vehicle charging strategy, the users no longer charging the electric vehicle during the nighttime peak load period, and put off the charging time until the low load down period (0:00-8:00). Under the condition of satisfying customers' charging demand, the charging loads of electric vehicles is effectively and evenly transferred to night by orderly charging, which reduces the peak-valley difference of electricity loads by 31.4%.

Figure 4 shows the charging loads curve of electric vehicle under the condition of orderly and disorderly electric vehicles charging within 24 hours of the day. It can be clearly seen from the figure that, compared with the disorderly charging, the orderly charging transfers the electric loads of 1590 kWh during the high electricity price period to the flat and low electricity price period. For electric vehicle users, the charging cost is cut down from 525.69 to 295.97 dollars, a 43.7% reduction, which greatly reduces the charging cost of users.

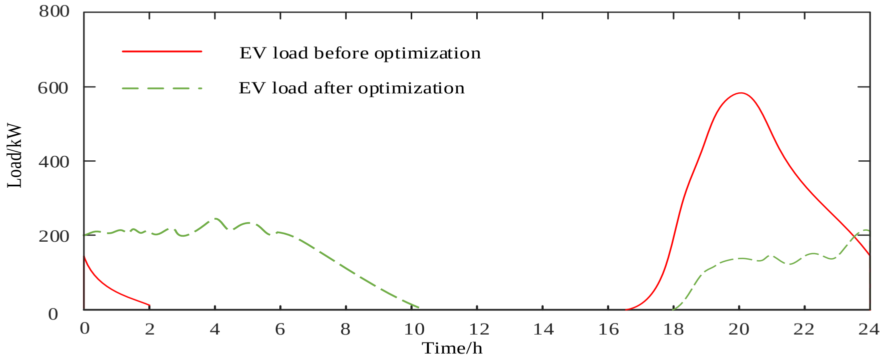

Figure 4 Charging loads curve of electric vehicle in the case of orderly and disorderly charging

Figure 5 shows the output curve of wind power generation. The remaining wind power at night can be effectively consumed by shifting the charging loads, and the consumption rate of distributed wind power generation can be improved, thereby the power purchases from main grid can be reduced.

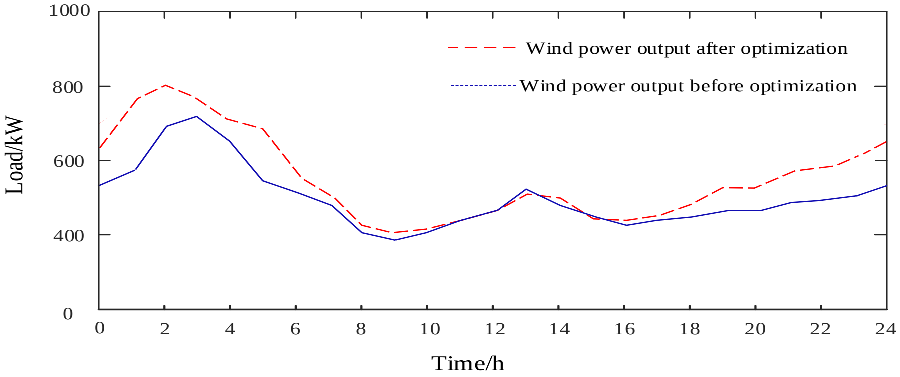

Figure 5 Wind power generation curve under orderly and disorderly charging

According to the calculated data, the wind power consumption rate has increased by 8.1% and the carbon emission has decreased by 1021.8 kg, which is about 5.7% of the carbon emission of community before optimization. With the increasing number of electric vehicles, orderly charging strategy can significantly improve the new energy consumption rate and reduce carbon emissions.

VI Conclusion

This paper proposes an optimal charging strategy for electric vehicles considering the user's charging satisfaction and distributed wind power consumption rate, and establishes a comprehensive evaluation method for charging strategy. Firstly, this paper proposes the centralized and orderly charging mode for electric vehicles, and defines the charging system. Then, taking the electric vehicle users charging satisfaction and the new energy power generation consumption rate as the objective function, and solves it by genetic algorithm. The user's charging cost and carbon emission is taken as economic and ecological indicator to establish a comprehensive evaluation system.

Finally, taking a community as a case, the proposed charging strategy is evaluated and analyzed through a comprehensive evaluation method. The results show that this strategy can reduce the charging cost from 525.69 dollars to 295.97 dollars, and reduce the carbon emissions by 5.7%.

Acknowledgements

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