Research on Coordinated Charging Control Strategy Load Optimization of Electric Vehicles in Residential Area

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Abstract: For the power utilization load encountered in the construction of electric vehicles (EVs) charging facilities in residential area, the coordinated charging control strategy for EV charging loads is studied. Based on the utilization electric load model, EV model, and distribution network information model of the residential area during the EV user using, the minimizing the fluctuation of the EV users charging cost, utilization power load and EV charging load is established. It is verified by an EV coordinated charging residential area, the sliding recursive algorithm employed can realize peak-load shifting, which can effectively reduce the effect of EV charging peak load and move the power peak to the second half of the night.

1. Introduction
The development of EVs is an important new energy utilization trend to solve the energy crisis and environmental pollution. Up to January 2019, China's new energy vehicle quantities reached 2.61 million. The most common choice for EV users is to charge at home, corresponding to the large-scale construction of charging utilization in residential area. The problem caused is that most of the built residential area did not consider the charging requirements of EVs. The disorderly charging access of large-scale EVs will cause great hidden dangers for the transformers, such as increasing peak-to-valley differences and reducing the rate of equipment utilization. The safe and stable operation of electric grid system will be affected. At the same time, related issues arises such as transformer overload, network loss increased and power quality reduced, so the management of residential areas power distribution load will face huge hidden dangers [1-4]. Therefore, it is necessary to consider the development demands of EV, to regulate the charging behaviours of EV: increasing the utilization rate of transformers, reducing the peak-to-valley load difference, and meeting the demands for more EV charging without increasing the existing distribution capacity. The references [5-12] have studied the...
impact of charging and discharging loads on power distribution in China, but not conducted in residential area.

Based on the power limitation conditions, users cost control, power grid load fluctuation control, power supply capacity limitation of distribution transformer, the load is optimized at time and power to response charging behaviours of EV. Then based on the peak-to-valley time-of-use electricity price policy, an optimal objective function is constructed, a sliding recursive algorithm is used to solve the optimal charging schedule for each EV. Finally, the coordinated charging control strategy of a projects of Henan Province is verified and analysed.

2. Introduction of charging control scheme

The "Notice on Issues Concerning Electricity Pricing Policies for Electric Vehicles" issued by China National Development and Reform Commission in July 2014 points out, charging facilities in residential areas implement residential electricity prices and time-of-use peak-to-valley electricity prices, so, an effective strategy is needed to issue the charging behaviour of EV.

The coordinated charging strategy model within the distribution transform area is mainly based on the following factors: transformer model, EV charger model, load model, EV model, economic model and management measures et al..

![Figure 1. Coordinated charging strategy algorithm flow](image)

As shown in Figure 1, the coordinated charging control strategy of residential area combines the EV model and distribution network model during the user's using time. Based on the stability of the power grid, the goal is to realize residential area economic operation, to stabilize residential load fluctuations, and to minimize the residents charging cost of EV. The detailed design ideals are as follows:

- Calculate the time period of the optimal electricity price that meets the resident's charging needs and the electricity price model. The users will be reminded if the demand is not met;
- Calculate the maximum and minimum values of users predicted loads during the optimal time period for electricity prices;
- Move power up with the specified step within the range from the minimum value to the maximum of the predicted load of the residents mentioned above;
- Within the range of the minimum value to the step value, slide to calculate total lowest load within the charging period based on the time period of the optimal electricity price (excluding the blackout period). If the requirements are met then return; if not, repeat the steps 3 and 4;
• If the charging time electricity price is still not satisfied within the range of the minimum value to the maximum value based on the time period of the optimal electricity price, the charging electricity time period is enlarged to the rechargeable time period (excluding the power outage period) and recalculated repeated the above steps.

3. Coordinated charging load control strategy

Based on the power limit of residential area and the cost of EV users, one of the targets is the fluctuation of the superimposed residential load plus EV charging load which should be as far as possible little.

3.1 Power limiting conditions

\[ \begin{align*}
P_{t}^{\text{plan}} = P_{t}^{R}, & \quad P_{t}^{R} < P_{t}^{\text{limit}} - P_{t}^{\text{basic}} - P_{t}^{K} \\
P_{t}^{\text{plan}} = P_{t}^{R}, & \quad P_{t}^{R} > P_{t}^{\text{limit}} - P_{t}^{\text{basic}} - P_{t}^{K}
\end{align*} \]

In formula (1), the parameters are defined as follows: start time of resident coordinated charging: \( T_{\text{start}} \), EV users pick-up time planned: \( T_{\text{end}} \), EV users charging electric demand quantity: \( Q_{\text{need}} \), charging power planned: \( P_{t}^{\text{plan}} \), EV rated charging power planned: \( P_{t}^{R} \), residential area load limit during the period: \( P_{t}^{\text{limit}} \), current users load predicted: \( Q_{t}^{\text{basic}} \). Charging electric power planned has been scheduled: \( P_{t}^{K} \).

Considering a large-scale EVs connected the grid has an impact on the grid load and power quality, selects the load limit: \( P_{t}^{\text{limit}} \), load predicted: \( Q_{t}^{\text{basic}}, P_{t}^{K} \). When the charging power planned is equal to the rated charging power, if \( P_{t}^{R} = P_{t}^{K} \), then \( P_{t}^{R} \) should be less than \( P_{t}^{\text{limit}} - Q_{t}^{\text{basic}} - P_{t}^{K} \), otherwise, \( P_{t}^{R} \) should be greater than \( P_{t}^{\text{limit}} - Q_{t}^{\text{basic}} - P_{t}^{K} \).

3.2 Objective function of users charging cost control

\[ \begin{align*}
F_{i} = \min \sum_{j=t_{i}}^{T_{i}+\Delta T} Z_{j} P_{j}^{\text{plan}} \Delta t(t) \\
Q_{\text{need}} = \sum_{j=t_{i}}^{T_{i}+\Delta T} Z_{j} P_{j}^{\text{plan}} \Delta t
\end{align*} \]

In formula (2): \( F_{i} \) is the first optimal objective of coordinated charging control strategy, because each EV user selects the cost as their first choice. The parameters are defined as follows: EV users charging start time: \( T_{b} \), EV users charging time interval: \( \Delta T \), planned time unit: \( \Delta t \), current charging period price: \( t(t) \), judgment variable for current charging period: \( Z(t) \) (The value is 0 during power failure, otherwise 1).

Actually, the coordinated control of the user charging cost is the product of the electricity price and the charging time actually. Considering electricity price is constantly changing during different time period, the EV user’s charging total cost is the union of all the start and end time periods that meet the EV user’s requirements: \( (T_{a} | T_{b}) = (T_{a1} | T_{b1}) \cup (T_{a2} | T_{b2}) \cup (T_{a3} | T_{b3}) \cup \ldots \cup (T_{an} | T_{bn}) \).

3.3 Residential area optimal objective function of power load fluctuation control
In formula (3): the parameters are the same as defined above, and \( F_2 \) is the optimal objective function of load fluctuation of the electric grid load of residential area.

The premise of function formula (3) is that EV users cost and charging power is the firstly requirement. The control time interval of EV users cost is as the input condition of charging period of the next-level optimization strategy, then the minimum fluctuation of sum of residential area load and EVs charging load with time is as the second control objective of coordinated charging control strategy of residential area.

3.4 Strategy revision

When the overload situation (load forecast deviation) occurs in the residential area, the system needs automatically to trigger to perform calculation.

According to the principle of "power reducing first and charging later", the power of the EV charger is reduced firstly. Once the power of residential area still overload, the charging of the EV charger is suspended or stopped. When residential transformer power overloads, increasing the charging power following the planned order.

4. Real residential area example and analysis

4.1 Power supply parameters setting and data premise

- Take a residential area (876 households) in Henan Province of China as an example. The rated capacity of the distribution transformer is 160kVA, the power factor is 0.85, and the efficiency is 0.95. The maximum active power output of the transformer is \( PM = 129kW \). The electricity load of electricity meter is recorded in residential area for 24 hours with 30-minute intervals;
- The charging charge (including electricity and service charges) of the residential area is 2 RMB/(kW·h), the electricity charge is based on the time of use electricity price. Peak-to-valley time-of-use electricity price and period of general industry (1 ~ 10 kV) and industry and commerce in Henan Province are shown in Table 1;
- Based on the EVs charging power of 15 - 60kW·h used in China, the power consumption is about 100km per 15kW·h, and the travel of vehicles conforms to the Gaussian distribution.

**Table 1.** Electricity price of time-of-use of Henan Province.

| Type   | Time stage                  | Electricity price/ (rmb/(kW·h)) |
|--------|-----------------------------|---------------------------------|
| Peak   | 18: 00—22: 00; 8: 00—12: 00 | 1.07893                         |
| Valley | 00:00—08: 00                | 0.33717                         |
| Normal | 12: 00—18: 00; 10: 00—24: 00| 0.6292                          |
Figure 2. Residential area load comparative curves

From Figure 2 it can be seen that the maximum rated distribution power (129kW, gray curve) is not exceeded under normal power consumption (92.26kW). The peak electricity consumption of EVs is from 6:00pm to the next day 8:00am, in the case of disorderly charging (orange curve), the total power load is over 129kW after the superposition of normal charging and residential. Then after adopting the coordinated control strategy, load shifting and valley filling is realized, the load peak from 6:00-9:00 pm is missed, and the valley load is filled from 9:00pm-6:00am. Therefore, the coordinated charging control strategy adopted in this example can effectively realize load shifting and valley filling, even adjust load distribution. By analysing the peak electricity prices of electricity consumption in Henan Province of China (Table 1), the EVs charging time is concentrated in the second half of the night, which effectively reduces the user costs.

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