Research on Coordinated Charging and Discharging Operation Mode of Electric Vehicle Based on Time-Space Double-layer Optimization

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Abstract: In order to reduce the adverse impact of electric vehicles (EVs) charging load on the grid and guide users to participate in the grid interaction reasonably and effectively, an coordinated charging and discharging control model of EVs based on the two dimensions of time and space is established in this paper to meet the dynamic and economic needs of users' coordinated charging and discharging. Considering the space-time distribution characteristics of EVs, the model is decoupled into an optimal scheduling sub-model based on time and space scale, and the model is solved by genetic algorithm and power flow calculation. The example shows that the model can effectively reduce the peak-to-valley difference, achieve the effect of peak-cutting and valley-filling, and the dual optimization goals of optimizing the operation of the system and encouraging users to participate in V2G are achieved.

1. Introduction

The charging load of EVs is characterized by randomness, mobility and fluctuation [1]. Existing conclusions indicate that the access of large-scale EVs to discoordinated charging will affect the reliability, power quality and economic operation of the grid [2-3]. Therefore, studying the charge and discharge load model of EVs [4-7] is of great significance for improving the reliability of system operation and the intensity of demand side response.

In this paper, a two-dimensional scheduling model of coordinated charging and discharging for EVs is designed. The model can be decoupled into two sub-models: The upper layer is the optimal power scheduling on the time scale, with the goal of minimizing the equivalent load fluctuation of the...
system and maximizing the charging and discharging benefits of the EV owners. The lower spatial scheduling model aims to minimize the active network loss of the system, analyzes and considers the spatial distribution characteristics of the charge-discharge of EVs, and the charge-discharge distribution scheduling plan of each EV is reasonably formulated.

2. Time-space double-layer coordinated charge and discharge

2.1 Upper time model

The upper model is the scheduling model of EVs on the time scale. In V2G mode, through effective charge-discharge strategy, the charge-discharge power of EV in each period can be adjusted dynamically to better meet the operation requirements of grid and user side. The objective function and constraints of the upper model are as follows:

\[
F_1 = \min \left( \sum_{t \in T} \frac{[P_s(t) - P_{av}(t)]^2}{N_k} \right)
\]

\[
P_{av}(t) = \frac{1}{T} \sum_{i=1}^{T} P_s(t)
\]

\[
P_s(t) = P(t) + P_{ev}(t)
\]

Where \( F_1 \) is the objective function to minimize the equivalent load fluctuation of the system; \( T \) is the duration of the day; \( N_k \) is the total number of sampling points in a day, which is 24; \( P_{av}(t) \) is the average load power; \( P_s(t) \), \( P(t) \), \( P_{ev}(t) \) are the equivalent load power, load power, and charge-discharge power of EV in the period \( t \) respectively.

The objective function \( F_2 \) is to maximize the charging and discharging benefits of the user side.

\[
F_2 = \max \left( \sum_{t=1}^{T} \sum_{i=1}^{n} \left[ q(t)P_{dis}(t) - r(t)P_{ch}(t) \right] \Delta t + \sum_{i=1}^{n} C_{loss} \right)
\]

In the formula (2-2), \( q(t) \) is the price of EV owners participating in V2G discharge at time \( t \); \( r(t) \) is the price of EV owners charging at time \( t \); \( \Delta t \) is charging and discharging time at each time period; \( P_{ch}(t) \) and \( P_{dis}(t) \) are the amount of charge and discharge of EVs at time \( t \) respectively; \( C_{loss} \) is a fixed cost to participate in the battery loss compensation cost of V2G for EVs.

2.2 Lower Space Model

The lower level model is the coordinated charging strategy model of EV in spatial dimension. Based on the results of the upper level model, through the power flow calculation of the distribution network, the optimization scheme of charging and discharging of EVs at different nodes is determined with the objective of minimizing the network loss. The objective function of the lower layer model is:

\[
\min \sum_{i=1}^{T} \sum_{j=1}^{L} R_i(I_{i,j}^2 + I_{i,j}^{h2}) \Delta t
\]
In the formula (2-3), $L$ is the total number of branches in the distribution network, $R_l$ is the resistance value of the line $l$ in the distribution network; $I_{ij}^{a2} + I_{ij}^{b2}$ is the current value flowing through the line $l$ in the distribution network; $\Delta t$ is the period of sampling and regulation.

3. Example analysis

3.1 Simulation condition setting

In this paper, IEEE 33-node distribution system is used as an example for simulation. The reference power of the system is 10MVA; the reference voltage is 10.5kv; the unit value of node voltage is 1.05; and the convergence threshold is set to $\varepsilon = 10^{-8}$. The nodes connected with the main network are used as reference nodes, and the rest nodes are PQ nodes, assuming the voltage amplitude remains unchanged. The load curve of the distribution network adopts the typical daily load curve of a region in North China in winter. It is assumed that EVs in the distribution network are evenly distributed at each node for charging and discharging. In order to verify the control effect of the coordinated charging model, the effect of discoordinated and coordinated charging and discharging of EVs are compared in this paper.

(1) Discoordinated charging conditions
   a. Free charge behaviour, charging frequency once a day until the end of filling;
   b. The initial charging segments of EVs satisfy the normal distribution of $N (9, 0.5^2)$ and $N (19.5, 1.5^2)$ with a ratio of 0.3 and 0.7 respectively.
   c. Assuming that the proportion of EVs with the long residence time is 95%, slow charging mode is adopted, and the rest is fast charging.

(2) Coordinated charging conditions
   a. Assuming that all EVs in the distribution network can be scheduled.
   b. The initial SOC (State of Charge) value of EV battery meets the normal distribution $N (0.6, 0.12^2)$.
   c. The battery capacity of EV selected in this paper is 60kWh, the maximum charging power is 12kW, the maximum discharging power is 30kW, the charging and discharging efficiency is 95%, and the battery loss cost is 0.8 yuan / time.
   d. During the charging and discharging process of EV, the maximum and minimum SOC values of battery are 1.0 and 0.2 respectively.

   In this paper, the timed price policy is used to optimize the time-space charging of EVs.

3.2 Simulation results

The total load of each period of EV charging in the discoordinated charging obtained by the Monte Carlo simulation method is added to the initial load curve, and the load curve as shown in Figure 1 is obtained.
It can be seen from the figure that the initial charging time of EV coincides with the peak power consumption of basic load, resulting in the consequence of "peak on peak ", which further expands the peak valley difference of load and increases the power supply cost of distribution system.

Multi-objective non-dominated sorting genetic algorithm is used to solve the optimization model established in this paper. Set the algorithm's convergence accuracy $\varepsilon$ to be $10^{-5}$, population size $\text{pop} = 150$, evolutionary algebra $\text{gen} = 400$, crossover probability $P_c = 0.9$, mutation probability $P_m = 0.05$. The coordinated charge-discharge load of the optimized EV is superposed on the initial load curve, as shown in Figure 2.

Comparing the peak pressure brought by the discoordinated charging in figure 1, the coordinated charging of EVs in V2G can effectively play the role of peak cutting and valley filling, and optimize the system operation. The peak of electric utilities at 18:00 to 21:00 is reduced. The optimization model has a certain practical optimal scheduling utility.

Therefore, the coordinated charging optimization scheme for EVs proposed in this paper can effectively reduce the peak-valley difference, achieve the effect of peak-cutting and valley-filling. From the example it can be seen that the daily load rate can be improved, and the access of large-scale EVs will not negatively affect the dynamic planning of the distribution network under the coordinated charging optimization scheme.
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