Research on Electric Vehicle Charging Scheduling Strategy Based on Graph Model

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Abstract. In recent years, electric vehicles (EVs) have gradually become the development trend of the future automotive industry due to its advantages of zero emission, low noise, and high efficiency. At this stage, a large number of EV freely charging without guidance will bring many negative effects on the operation of urban traffic and power distribution systems. Therefore, how to correctly guide the vehicle to charge efficiently has become an urgent problem to be solved. Starting from economic factors, time factors, and user characteristics, this paper proposes an electric vehicle charging recommendation optimization model based on graph calculation. The graph model is generated according to the geographic location of the charging station, and the shortest path algorithm and charging scheduling strategy, which is used to recommend EV to users. The charging station with the smallest comprehensive cost within a certain range of the car.

1. Introduction
In recent years, with the development of battery technology and the decline in costs, electrified transportation with electric vehicles (EV) as the core is developing rapidly, and the degree of coupling between urban transportation systems and power distribution systems is also deepening. China has built some charging infrastructure including charging stations, charging piles and swap stations to meet the charging needs of EVs. Due to the randomness of EV charging load in time and space, a large number of unguided free charging of EVs will have a negative impact on the safe and stable operation of the power distribution system and the transportation system, such as increasing system peak load and network loss, and causing traffic congestion, affecting user experience, etc. Properly guiding EV charging can reduce the peak-valley difference of the system and enhance the system’s ability to absorb renewable energy power generation. Therefore, it is necessary to study an orderly EV charging management strategy.

Graph computing is an abstract expression of a graph structure in the real world (graph database) based on graph theory, and a calculation model based on this data structure. Different from the traditional relational database management system with tables (relationships) as the core, graph databases use "nodes" and "edges" as basic storage units to store data, which can realize distributed storage and parallelism of massive data with complex association relationships deal with. It is very suitable for analyzing a variety of big data platforms including transportation systems and smart grid systems. This paper uses a graph model to simulate real-time information such as EV users’ driving
behaviour, location distribution, state of charge, charging demand, etc., and then proposes a real-time optimal scheduling strategy that takes into account economic costs and user charging waiting costs.

2. Model Structure

2.1. Charging Scheduling Network Graph Model

In the actual environment, electric vehicles are connected to car navigation or smart terminal devices through their own communication modules, and the communication modules are connected to the central cloud through WiFi or 5G networks, and the remaining power, speed, geographic location and other information of the electric vehicles are sent to the cloud computing centre. At the same time, the cloud computing center accesses the edge computing module of the charging station to obtain the location of each charging station and the usage of the charging pile in the charging station. Taking different electric vehicles as root nodes and each charging station as sub-nodes, by locating the real-time location of electric vehicles and the geographic location of charging stations within a certain range nearby, the relationship between electric vehicles and charging stations is abstracted into a graph theory model, using The charging scheduling algorithm dynamically recommends the charging station or the charging pile with the minimum charging cost for electric vehicles. Figure 1 shows the communication architecture of the charging scheduling network.

![Figure 1](image)

**Figure 1.** Communication architecture of the charging scheduling network

2.2. Electric Vehicle Node Model

The main attributes of an electric vehicle node $a_i$ include remaining power $e_i$, charging power $p_{e_i}$, driving power $p_{o_i}$, continued driving range $s_i$, average speed $v_i$ and endurance time $t_i$. 
2.3. Charging Station Node Model

The attributes of a charging station node $c_j$ mainly include the total number of charging piles in the station $n_j$, the number of idle charging piles $r_j$, the number of EV waiting to be charged in the station $w_j$, the waiting probability $l_j$, and the charging time of EV $t_{ij}$.

$$l_j = w_j / n_j$$

2.4. Path Model

As shown in Figure 2, the electric vehicle and charging station are abstracted as a graph model $G$, a directed weighted graph. Define $G=(A,C,E)$, where $A$ is the set of all EV to be charged, $A = \{a_i \mid 0 \leq i \leq n\}$, $a_i$ is the root node of the graph $G$; $C$ is the set of all charging station nodes, $C = \{c_j \mid 0 \leq j \leq n\}$, and the edge set $E$ represents the driving direction of the electric vehicle, that is, the electric vehicle passes through the charging station $i$ to charge Station $j$, the value of $e_{ij}$ represents the distance from the charging station directly to the charging station. The $c_0$ node is the auxiliary node to form a directed acyclic graph, and the weight of each edge is the path distance. For example, the straight line distance from charging station $c_2$ to charging station $c_4$ is 3, and it can be reached directly without passing through other charging stations.

![Figure 2. Path weighted graph G](image)

2.5. Charging Cost Model

The charging cost model is mainly considered in terms of time cost $T$ and economic cost, that is, power consumption $C$. The charging cost from electric vehicle $a_i$ to a charging station $c_j$ is defined as $q_{ij}$:

$$q_{ij} = kCT$$

$$C = P_{ac}T_{ac} + P_{cj}T_{cj}$$

$$s_i = l e_i$$

$$t_i = s_i / v_i$$
\[ T = t_{r} + t_{c} + t_{w} \quad (6) \]
\[ t_{r} = \frac{e_{i}}{v_{i}} \quad (7) \]
\[ t_{w} = \frac{l_{i}}{t_{a}} \quad (8) \]

Among them, \( t_{r} \) is the time for the electric vehicle \( a_{i} \) to arrive \( c_{j} \) through the shortest path; \( e_{i} \) is the shortest path; \( t_{w} \) is the waiting time for the electric vehicle to be charged at the charging station; and \( t_{a} \) is the charging time of the electric vehicle.

3. Recommended Charging Strategy
The recommended implementation method of the optimal charging station based on positioning is to first abstract the electric vehicle in motion, the charging station within a certain range, and the path between the electric vehicle to the charging station and the charging station as a topology model, with a weighted graph \( G \), as shown in Figure 2. Then use the traversal algorithm and the shortest path algorithm for the weighted graph \( G \) model to evaluate the charging cost of each charging station that can be reached, and dynamically recommend the charging station with the smallest comprehensive cost for electric vehicle users.

The overall idea of the recommended algorithm is as follows: 1) Calculate the cost of the electric vehicle's travel time to the charging station and the mid-way power consumption; 2) Calculate the cost of the time the electric vehicle waits to be charged at the charging station; 3) Calculate the cost of the electric vehicle charging time and the amount of charge, and thus the overall charging cost. This algorithm uses a greedy algorithm. First, the charging station \( C \) is divided into two groups, \( X \) and \( Y \), and \( X \) is defined as the set of charging stations with the lowest charging cost, and \( Y = C - X \) is the set of charging stations for which the lowest charging cost has not been determined. The nodes in \( Y \) are added to \( X \) in the order of increasing minimum charging cost. The minimum charging cost from \( a_{i} \) to charging station \( c_{j} \) in set \( Y \) is the sum of the charging cost on the direct path from \( a_{i} \) to \( c_{j} \) and the charging cost to \( c_{j} \) through other charging stations in \( X \). The steps to find the minimum charge cost are as follows:

Step1: Initialize, make \( X = \{a_{i}\}, Y = \{\text{others}\} \);

Step2: If the electric vehicle can directly reach the charging station, that is, there is a value of \( <a_{i}, c_{j}> \), then the minimum cost corresponding to the node in \( Y \) is the sum of the distance cost and power consumption on the side and the charging time cost in the charging station; If it does not exist, it is set to the infinite value Inf;

Step3: Select a charging station \( c_{w} \) with the smallest sum of charging cost from \( Y \), add \( c_{w} \) to \( X \), and modify the cost value of the node in \( Y \). If after adding \( c_{w} \) as an intermediate node, the charging cost from \( a_{i} \) to \( c_{j} \) is smaller than the charging cost without adding \( c_{w} \), then modify this generation value;

Step4: Repeat Steps 2 and 3 above until all nodes are included in \( X \).

In order to dynamically recommend the charging station with the lowest comprehensive cost to the charging user, the calculated charging cost of each charging station needs to be sorted, and the charging station with the smallest value is the recommended charging station.

4. Result Analysis
Taking the directed graph shown in Figure 2 as an example, there are 7 charging stations in the search range of electric vehicles, namely \( c_{1}, \ldots, c_{7} \). The weight on the path between charging stations is the travel time between the two charging stations. According to the waiting and charging time difference
of each charging station, different weights are assigned to different charging station nodes, so as to obtain Figure 3. For example, if the power is constant and the charging time is fixed for 30 minutes, the electric car is charged at charging station $c_1$, $t_r$ is 5, $t_{o}+t_{w}$ is 90, and the total charging cost $q_{i}$ is 3325; if it is charged at $c_4$, $t_r$ is also 5, $t_{o}+t_{w}$ is 150, and the total charging cost $q_{i}$ is 5425.

![Weighted directed graph of charging station](image)

**Figure 3.** Weighted directed graph of charging station

| $c_j$ | $t_r$ | Shortest path | $t_{o}+t_{w}$ | $q_{i}$ |
|-------|-------|---------------|---------------|--------|
| $C_1$ | 5     | $C_1$         | 90            | 3325   |
| $C_2$ | 2     | $C_2$         | 80            | 2624   |
| $C_3$ | 6     | $C_1$ $C_3$  | 60            | 2376   |
| $C_4$ | 5     | $C_2$ $C_4$  | 150           | 5425   |
| $C_5$ | 21    | $C_1$ $C_3$ $C_5$ | 50 | 3621   |
| $C_6$ | 15    | $C_1$ $C_3$ $C_6$ | 30 | 2025   |
| $C_7$ | 12    | $C_2$ $C_4$ $C_7$ | 80 | 3864   |

According to the calculation results in the table, the shortest path charging station $c_2$ or the charging station with the lowest charging cost $c_i$ can be recommended to electric vehicles to meet the different needs of charging users.

5. **Conclusions**

With the gradual increase in the penetration rate of EVs and the continuous development of charging facilities, the interaction between the power system and the transportation system will become more extensive and deeper. The method of finding the optimal charging station based on the graph algorithm, starting from the needs of the user, recommends the lowest-cost charging station for charging electric vehicles, which is conducive to alleviating traffic congestion near the charging station, improving the user experience of charging, and achieving a balance of the load of each charging station. Subsequent consideration will be given to adding an analysis of the charging
behavior of charging users to make personalized recommendations more accurately based on the characteristics of the travel chain of different users.

6. Acknowledgments
This work is supported by the National major R & D program (No. 2018YFB0904900, 2018YFB0904905).

7. References
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