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The Charging Characteristics of Electric Vehicle Group Under the Mode of Shared Travel

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Abstract. In the future, travel revolutions such as shared travel will bring great changes to the structure of transportation, and the charging characteristics of electric vehicle will also be affected. This paper takes the new travel mode as the research background and models the driving and charging behavior of electric vehicle group. Then the multi-agent technology is used to build a large-scale electric vehicle group simulation model. This model fully considers the capacity constraints of traffic network and charging station, which can be used to simulate the actual behavior of electric vehicle group. Finally, the charging load curve of the electric vehicle group under the new travel mode is obtained based on simulation. The result shows that as the proportion of shared travel increases, the daily average charging load keeps increasing, and the charging load peak comes earlier and lasts longer.

1. Introduction

Travel upgrades such as shared travel and electric vehicle (EV) are increasingly affecting the energy structure of the transportation. According to the prediction of BP Energy Outlook, the number of EV worldwide will increase to 350 million by 2040, which accounts for 15 percent of total vehicles, and approximately 25 percent of the passenger vehicle mileage will be provided by EV [1]. However, owing to the uncertainty of EV charging load distribution in time and space with the increasement of EV permeability and change of travel mode, the power system will face unknown challenges.

As a new generation of transportation, EV's charging characteristics have been widely concerned. Reference [2] describes the random behavior of individual EV and analyzes the change of its charging status. Reference [3] designs a smart energy management system to solve the charging problem of large-scale EV group. Since the fundamental function of EV is to serve people's travel, it is necessary to consider its traffic characteristics [4]. Reference [5] uses Markov model to simulate the driving mode of EV and analyzes the influence of its charging load on the power system. Reference [6]-[7] use real traffic network data for simulation and predict the charging demand of urban EV group.

At present, many references have conducted research on the driving and charging characteristic of EV, but when it comes to the modeling, the constraints of traffic capacity and charging station capacity have not been well considered. It is not reasonable to carry out simulation by setting parameters only with uniform values such as average velocity and average charging power. In addition, we have not seen any reference researching on the charging characteristics of the EV group in the shared travel mode. In the traditional mode, private vehicles are idle most of the time. However, the utilization rate of vehicles in the shared travel mode is greatly improved, and the travel service capacity of a shared vehicle is about 7-15 ordinary private vehicles [8]. Therefore, the driving behavior and charging behavior of EV group in the new mode will be quite different.

Given the above problems, this paper will conduct research on the charging characteristics of the EV group in shared travel mode. Firstly, the behavior of EV under the new travel mode are modeled. The capacity constraints of the traffic network and charging station are fully considered. Then the multi-agent technology is used to build the agent model to simulate the driving and charging behavior of EVs. Finally, the actual traffic network data is selected for simulation to analyze the influence of travel upgrades on EV group charging characteristics.

2. Description and model of EV behavior

The behavior of EV can be generally divided into four states: idle, driving, charging, and vehicle-to-grid (V2G). Since the study focuses on the mobile load characteristics of EV, we pay more attention to charging rather than discharging. In addition, in the shared travel mode adopted by the simulation, the utilization rate of EV for driving will be significantly improved, and the proportion of idle EV that can participate in V2G is relatively low. Therefore, the V2G state is not involved in the model.

2.1. Traffic Characteristics

EV is restricted by the traffic network mainly in its driving velocity. The EV velocity varies greatly when driving in different traffic conditions. When the road is clear of traffic, the main constraint of its velocity lies in the velocity limit of the road grade. When the traffic capacity is limited during the travel peak, EV velocity will decrease significantly. Therefore, the influence of traffic network is mainly reflected in the two constraints, including designed velocity and road capacity of different road grades. It is obviously unreasonable to use a uniform average velocity in the simulation, and this paper set the driving velocity based on the road resistance function of the US Bureau of Public Roads (BPR) [9], as shown in (1).

$$t_i = t_i^0 \cdot (1 + \alpha \cdot (\frac{q_i}{c_i})^{\beta}) \tag{1}$$

where, t_i is the driving time of vehicle on the road i with traffic flow q_i; t_i^0 is the free driving time of vehicle when road i is clear; c_i is the traffic capacity of the road i; α and β are the parameters of the function, and the typical values are $\alpha = 0.15$ and $\beta = 4$.

From this, the driving velocity can be obtained like (2).

$$v_i = \frac{v_i^0}{(1 + \alpha \cdot (\frac{q_i}{c_i})^{\beta})} \tag{2}$$

where, v_i is the velocity of the vehicle on the road i where the traffic flow is q_i; v_i^0 is the free velocity of the vehicle when the road i is clear, related to the design velocity of the road.

In addition, the shared travel mode mainly changes the way people travel, not the time. In the actual travel scene, due to the similarity between people's living habits, the travel demand in the daytime is obviously greater than that in the evening, and the travel time will also appear to a certain degree of concentration, such as the rush hour in the commuting period. Therefore, even if the travel pattern changes significantly, travel demand and distribution are still determined by people's own daily schedule, and the temporal distribution of traffic flow caused by this will not be affected too much. Thus, the traffic flow in the shared travel mode basically conforms to the current temporal distribution of local traffic flow. For example, Fig. 1 shows the temporal distribution of traffic flow from 0:00 to 24:00 in Guangzhou, China [10], where one period represents one hour.
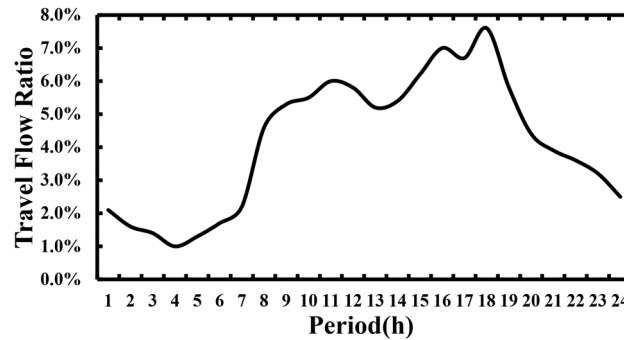
Fig. 1. Temporal distribution of traffic flow in Guangzhou, China

In order to compare the influence brought by different travel modes, it is assumed that the total amount and temporal distribution of travel demand remain unchanged, and the service capability of a vehicle in shared mode is equivalent to that of 10 vehicles of traditional mode [8].

Then, if the total travel demand remains the same, but the service capability of a single vehicle is improved, the total number of vehicles required will correspondingly decrease. When the proportion of shared travel mode is k, the number of vehicles Q_k in the region should meet (3), in which Q_0 is the quantity of vehicles when all vehicles are in the traditional travel mode.

$$Q_0 = 10kQ_k + (1-k)Q_k \qquad (3)$$

2.2. Charging Characteristics

The charging characteristics of EV are constrained by the capacity of charging stations, mainly reflected in the charging power and charging time. Charging stations are usually equipped with fast charging and slow charging spot. When EV is in slow charging, the charging power basically depends on the power of the on-board charger (OBC), and the power of OBC is generally no more than 10kW. On the other hand, EV's fast charging power is determined by its own Battery Management System (BMS) and the output power of charging facilities. On the basis of meeting the power matching of charging facilities, EV's power depends on the fast charging power supported by itself and there are large differences among different EV models.

As for the charging time, EV may not be able to start charging immediately after reaching the charging station when the charging capacity is limited and other peak moments occur. Unlike the fuel vehicle, which only takes a few minutes to refuel, even the Tesla Model 3, the EV with currently the highest fast charging power, takes about half an hour to recharge to 80%. Therefore, the queuing time of EV before charging has a great impact on the charging time, which cannot be ignored.

To sum up, both fast charging and slow charging of charging stations will be included in the modeling. When EV arrives at the charging station, priority should be given to the fast charging spot. Without exceeding the upper limit of the output power of the charging facility, the charging power should be equal to the fast charging power supported by the EV model. When the fast charging is not available, then go for the slow charging and the power is equal to the OBC power. When there is no spare charging facility, the EV needs to queue up.

3. Multi-agent simulation model

As the scale of the research on EV group expand, it is hard to study the EV behavior by conventional linear manner. For this, multi-agent technology has great advantages in simulating the interaction behavior of EV group [11]-[12]. Therefore, this paper uses the Java agent development framework (JADE) platform for modeling, to simulate the driving and charging behavior of EV group. The model consists of four types of agents: map agent, time agent, charging agent and vehicle agent. The information communication between agents is shown in Fig. 2.
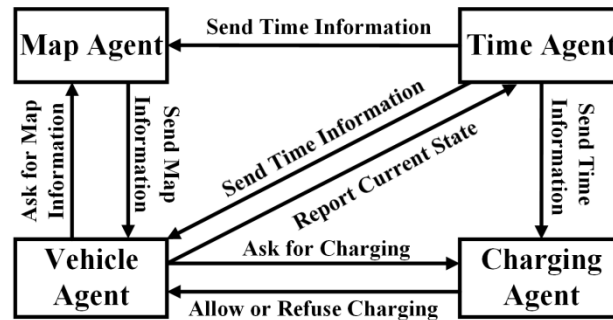
Fig. 2. Information communication among agents in the model

3.1. Basic Assumptions of the Model
The following basic assumptions are made to facilitate the simulation:

1) The topological graph in graph theory is used as the simulation map. The elements in the traffic network are simplified into two kinds of objects: edges and nodes. The edge represents the road, the node represents the intersection or the roadhead, and the weighted degree of node is the sum of weights of connected edges, as shown in (4). Here, the weighted degree of the node is calculated by taking the road grade as the edge weight.

$$G = \sum_{i=1}^{n} g_i \tag{4}$$

where, G is the weighted degree of node; n is the total number of edges connected to the node; g_i is the weight of edge i.

2) The charging facilities are set uniformly with the concept of charging nodes. Every charging node has a certain number of charging spots, and each spot can only serve one EV at a time. In addition, public charging facilities should usually be located at the hub with convenient transportation [13]. In the traffic network, the nodes with a large weighted degree are connected to relatively more roads, with larger traffic flow. Therefore, the charging nodes are preferentially set at these nodes, and the charging node with a larger weighted degree also has more charging spots.

3) The simulated vehicle is the individual transportation such as EV and fuel vehicle, which does not involve public transportation. Vehicle agents are set to simulate EVs and fuel vehicles. EVs have three states: idle, driving, and charging. The position and the state of charge (SOC) of EV in the idle state remain unchanged; the driving state reflects the decrease of the SOC and the change of the position; the charging state reflects the increase of the SOC and the invariable position. And fuel vehicles only consider the idle state and the driving state.

4) As for the travel selection, more vehicles will pass through the traffic hub node in probability. Therefore, the vehicle has a higher probability to go to the node with a large weighted degree when choosing the driving target. When planning the driving path, the shortest time is taken as the path selection basis.

3.2. Map Agent
The main function of the map agent is to provide travel services, such as location initialization, driving path planning, road condition information, etc. In the simulation, every time a vehicle enters or leaves a certain road, the map agent will record accordingly. According to the current traffic flow of each road, the map agent uses (1) to calculate the driving time required for each road and keep it updated. When the travel request of vehicle agent is received, the map agent will provide the driving path. When receiving the request of charging node, considering the charging capacity limit, the map agent will send all charging nodes within a radius of 3 km for the vehicle agent to choose.

3.3. Charging Agent

Charging agent provides charging service for EVs and records charging data. In the simulation, every charging node will update the number of EVs after each time step. When receiving a charging inquiry from an EV, the charging agent will make a judgment based on the current situation of the charging node, which has been questioned. If there is any charging spot available, the charging agent will inform the EV that it can go there for charging; otherwise, it will be informed that the charging spot is full. When the charging agent receives the information that an EV arrives at a certain charging node and requests charging, the EV will be informed to queue up if the charging spot is full. The EV will be allowed to charge if the charging spot is available, priority will be given to the quick-charging spot, and the charging time and charging power will be recorded.

3.4. Time Agent

The time agent provides the update service of simulation time, and at the same time undertakes the regulation task of the temporal distribution of traffic flow. The time agent will calculate the number of vehicles that should be driving in each period according to the temporal distribution of traffic flow. During the simulation, the time agent will continuously update the number of vehicle agents in each state and make corresponding adjustments, so as to regulate the number of vehicles driving in each period basically following the temporal distribution of traffic flow. When the simulation time is over, the time agent will send the signal to other agents to stop the simulation.

3.5. Vehicle Agent

There are multiple vehicle agents in the simulation, and each vehicle agent represents one EV or fuel vehicle. The following uses EV as an example to introduce the algorithm.

EV is firstly initialized and then enter the idle state. EV in idle state will first check the SOC. When the SOC is less than 20%, EV will ask the map agent for the nearby charging nodes and drive to the corresponding node for charging. If the SOC is sufficient, EV will remain idle until it receives the driving task, and then it will change to the driving state. The EV in the driving state updates its velocity according to (2) every time it passes a simulation step, and notifies the map agent to update the traffic flow of the road every time it enters a certain road. When it arrives at the destination, the EV will stop driving, go into idle state, wait for the next trip, and decide whether it needs to be recharged based on the SOC. After reaching the charging node, EV will start charging or wait in line according to the current condition of charging spots. After charging, EV will check the driving task. If there is an unfinished task, EV will enter the driving state and continue the trip; otherwise, EV will enter the idle state. Fig. 3 below shows the algorithm flow.
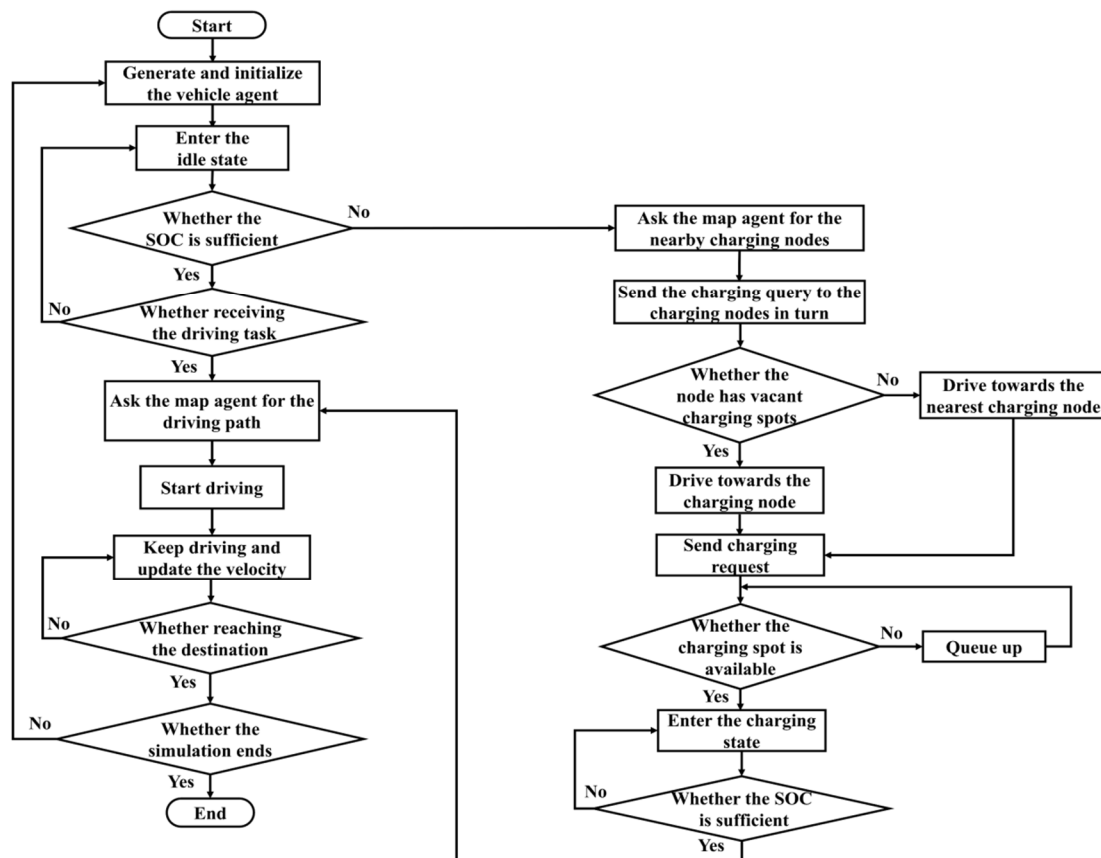
Fig. 3. The algorithm flow chart of vehicle agent.

4. Example analysis

The traffic network of Tianhe district, Guangzhou, China, is selected as the simulation map. Its current quantity of small passenger vehicles is about 300,000. The traffic flow temporal distribution is shown in Fig. 1, and the driving demand of vehicles under different travel modes all obeys this distribution. The simulation parameters are shown in Table 1.

Table 1 Simulation parameters of each agent

Agent	Parameter settings
Map	There are a total of 4819 nodes and 5928 roads.
Charging	There are a total of 22 charging nodes and a total of 862 charging spots.
Time	The simulation starting at 0:00 and ending at 24:00. The time step is 60s.
Vehicle	The EV permeability is 15%, and the total number of vehicles in different travel mode ratios is calculated according to (4).

Then the different proportions for different travel modes are set to simulate, and the result are shown in Fig. 4. The percentage in the figure respectively represents the percentage of vehicles in the shared travel mode, while the rest are in the traditional travel mode.
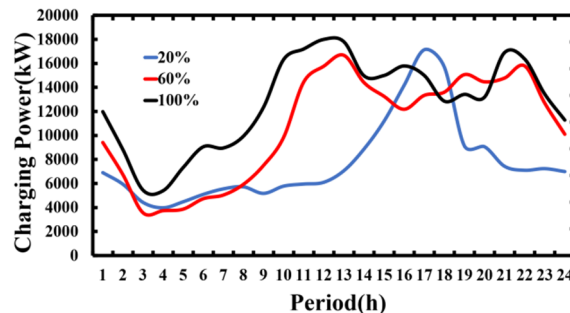
Fig. 4. The charging load curves of EV group under different shared travel proportion

As for Fig. 1 and Fig. 4, there is a certain correlation between the charging curve and traffic flow curve. From the peak and valley periods, the temporal distribution of charging load lags behind traffic flow for a period of time. In addition, as the proportion of shared travel increases, the daily average charging load keeps increasing, the charging load peak comes earlier and lasts longer, and the correlation with the traffic flow curve is higher.

In the traditional mode, the EV driving utilization rate is low. The behavior of a single EV is completely dependent on the schedule of its owner, and the behavior pattern is relatively dispersed. On the contrary, the shared travel mode has brought the higher driving efficiency and lower vehicles quantity. An EV serve multiple users. The behavior of EV group have higher similarity in probability, so their driving and charging time are more concentrated. Thus, the correlation between charging load curve and traffic flow curve is higher. At the same time, most EVs in the shared travel mode are in the driving state during the travel peak and then cause the charging peak. However, due to the influence of the endurance millage, the charging peak usually lags behind the travel peak for a period of time, which is related to the average velocity of power consumption. The EV in the shared travel mode has a higher average number of trips, so its average velocity of power consumption is faster. Therefore, the higher the proportion of new travel mode, the earlier the charging peak.

As for the daily average charging load, since the travel demand is similar, the total driving mileage in different travel modes is also similar, so the total power consumption is approximately the same. However, under the traditional mode, the quantity of EVs is large and its utilization rate is low, so the average power consumption of a single EV is much less, and many EV with higher initial SOC even do not need to be recharged. On the other hand, shared EVs almost all have charging demand after a day's driving, and some with small battery capacity even need to be charged more than once. Thus, the total charging times are more and the daily average charging load in shared travel mode is higher. Coupled with the capacity constraint of charging station, the charging limitation of EVs in the new travel mode is more serious in the charging peak. Therefore, although the peak value is similar, the charging peak in the shared travel mode lasts longer and fades slowly.

5. Conclusion
This paper takes the shared travel as the background and uses multi-agent simulation to conduct research on the charging characteristic of EV group. The behavior of the EV group in the mode of shared travel is described and modeled in detail, and a large-scale EV group simulation model was built by the multi-agent technology. Through simulation, the influence of shared travel on EV charging load was preliminarily found. With the increasement of shared travel proportion, the daily average charging load and variation range of EV group will increase, and the charging peak will come earlier and last longer, which will easily bring adverse effects to the power system.

In the future, we will conduct in-depth research on the impact of travel revolution and study other travel upgrades such as autonomous driving and the increase of EV permeability. At the same time, the simulation modeling of charging station and traffic network will be improved to better simulate the

actual scene. Then, the influence of the travel revolution on EV charging characteristics can be more fully discovered.

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