Research on the Choice Strategy of Electric Vehicle Charging Users

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Abstract. Starting from the perspective of electric vehicle users, this paper analyzes the service needs of different users for charging electric vehicles and considers various objective conditions of electric vehicles: the remaining electric vehicles, the driving distance from the charging pile / station, the charging of electric vehicles Charging time, the location of the charging equipment, etc., gives several user selection strategies that minimize the energy loss of electric vehicles, minimize the time spent by electric vehicle users, and optimize the comprehensive cost of users. Through the theoretical analysis and experimental simulation results, the advantages and disadvantages of several user selection strategies are compared to provide users with a good charging service for electric vehicles, and at the same time, the optimal choice of charging options for users is realized. The service quality of the car is conducive to the promotion and sustainable development of electric vehicles and charging equipment.

1. Introduction

With the continuous advancement of science and technology in our country, the urbanization and the improvement of people's material life quality, the automobile industry has developed rapidly. Energy crisis, environmental pollution is worsening, people's health and depleting fossil fuels are threatened\cite{1,2}. In recent years, a number of studies have shown that automobile exhaust pollution has risen to the major air pollution, threatening the natural environment upon which human beings depend\cite{3}. In order to reduce pollution and reduce dependence on fossil fuels to the maximum extent under the intensification of contradictions between economic development, energy crisis and environmental protection, China will vigorously develop new energy vehicles and relying on new energy technologies to realize the automobile industry The transition to new energy vehicles\cite{4}.

In this paper, aiming at the various needs of a single EV charging, it recommends the best charging pile charging for the user, reduces the user charging cost and improves the user satisfaction. And research on the best state of charge for a single charging pile, improve the utilization rate of charging pile, and realize the best choice scheme of charging pile for electric vehicle users\cite{5,6}. Considering the remaining capacity of electric vehicles, mileage, charging time, charging pile facilities, design a variety of decision-making tools for different optimization objectives for the appropriate strategy to meet the corresponding needs of different roles to provide users with convenient and efficient charging service. To minimize social costs and improve higher social benefits\cite{7,8}. 
2. electric car charging model analysis

2.1 electric car battery model

In this paper, in order to facilitate the study, electric car battery power in 0-100% of the range is considered. The total battery capacity is the sum of the remaining capacity of the battery and the amount of power to be replenished:

\[ E_{all} = e_y + e_w \]  

(1)

Where \( E_{all} \) is the total battery capacity, \( e_y \) is the remaining battery capacity, and \( e_w \) is the battery to be fully charged.

2.2 electric car charging model

The characteristic matrix of electric vehicle charging behavior is characterized by electric vehicle number, coordinates, distance from charging pile, time spent on the road, energy consumption on the road, charging time of electric energy, ending time of charging, time cost, cost cost and comprehensive cost [9]. The characteristic matrix is as follows:

\[
\begin{bmatrix}
  y & Che_d & Dis_{xy} \\
  T_{dx} & T_{char} & T_{end} \\
  CT_{xy} & CP_{xy} & W_{xy}
\end{bmatrix}
\]

(2)

Where, \( x, i \), respectively, said the number and number of charging pile, \( y, j \), respectively, that the number and number of electric vehicles. \( Che_d \) is the coordinates of the car, \( Dis_{xy} \) is the distance from the electric car to \( x \) charging pile, \( T_{dx} \) is the time it takes for the car to charge the pile, \( T_{char} \) is the charging time of the electric car, \( T_{end} \) is the charging end time, \( CT \) is the electric car charging time cost, \( CP \) is the cost of charging electric vehicles. \( W \) is the total cost of charging electric vehicles.

Initial position of electric vehicle user; initialized place is randomly generated by the system, with the initial coordinates as the starting point of the user:

\[ Che_{_d} = (X_i, Y_i), j \in [1, n(t)] \]

(3)

\( X_i \) and \( Y_i \) represent the abscissa and ordinate of the electric vehicle, respectively, and \( n(t) \) represents the electric vehicle time function.

Electric car to charging pile distance:

\[ Dis_{xy} = \sqrt{(x - x_j)^2 + (y - y_j)^2} \]

(4)

\( Dis_{xy} \) means that the electric car \( y \) to the charging pile \( x \) distance, \( CS_{d_j} \) said charging pile \( x \) position coordinates.

Car to charging pile time; Assuming the normal speed of each car is constant and the same as \( v \), the distance and time proportional relationship as follows:

\[ T_{dx} = \frac{Dis_{xy}}{v} \]

(5)

The energy consumption of the car to the charging pile; electric car energy consumption per hundred kilometers 19.5kw.h, the energy consumption of electric vehicles on the road:

\[ Ed_{xy} = Dis_{xy} \times 19.5/100 \]

(6)

\( Ed_{xy} \) represents the energy used by the electric car \( y \) to the charging pile \( x \) road.

Electric vehicle charging time; the value of the remaining charge at the moment of charging request, to the charging pile road energy consumption and electric car charging power decision:
\[ T_{char,x} = \frac{E_{d,x} + e^{-w_{y}t}}{P_{x}(t)} \]  
\( t \in [0, 24], x \in [1, i], y \in [1, j] \)

\( P_{x}(t) \) is the charging power of charging pile \( x \) at \( t \) moment.

User end of charging time; This calculation method to reach the electric vehicle charging pile and the charging pile last car at the end of charging the maximum, and after the electric energy and charging time as the electric vehicle charging end time:

\[ T_{end,x} = \max(t + T_{d,x}, T_{end,k}) + T_{char,x} \]  
\( t \) is the current moment, \( T_{end,x} \) is the charging end time of the last electric vehicle \( k \) charged to the charging pile \( x \).

The waiting time \([10]\) is determined by the charging end time of the last arriving electric vehicle of the charging post and the moment when the current vehicle reaches the charging post:

\[ T_{wait,x}(t) = \begin{cases} \end{cases} \begin{align*} & \text{end}_x - (t + T_{d,x}), t + T_{char} \leq \text{end}_x, \\ & 0, t + T_{d,x} \geq \text{end}_x \end{align*} \]  
\( t \in [0, 24], x \in [1, i], y \in [1, n(t)] \)

Time cost \( CT \) mainly includes: driving time on the road \( T_{d,x} \) charging waiting time \( T_{wait,x} \) power supplement time \( T_{char,x} \).

\[ CT_{x}(t) = T_{d,x} + T_{char,x} + T_{wait,x} \]  
\( t \in [0, 24], x \in [1, i], y \in [1, j] \)

Charging cost \( CP \) by the cost of electricity on the road and the user sends a charging request at the moment to be replenished charge charging composition:

\[ CP_{x} = J(t) \ast (ed_{x} + e^{-w_{y}t}) + J_{0} \ast ed_{x} \]  
\( t \in [0, 24], x \in [1, i], y \in [1, j] \)

Where \( CP \) is the cost of charging electric vehicle \( y \) to charging pile \( x \), \( J(t) \) is the price of electricity at time \( t \), and \( J_{0} \) is the price of last charging of electric vehicle.

Electric vehicle users choose to charge a comprehensive cost by the cost of costs and time costs constitute:

\[ W_{x}(t) = a \ast \frac{CP_{x}(t)}{\min CP_{x}(t)} + b \ast \frac{CT_{x}(t)}{\min CT_{x}(t)} \]  
\( t \in [0, 24], x \in [1, i], y \in [1, n(t)], a + b = 1 \)

\( W_{x} \) represents the total cost of charging users, \( a, b \), respectively, the cost of costs and time costs of the weight coefficient. User charge the lower the overall cost of higher customer satisfaction.

### 2.3 Charging pile model established

The charging characteristics of electric vehicle charging pile are characterized by charging pile number, charging pile coordinate, charging power and charging pile charging end time as follows:

\[ CS_{x} = (x, CS_{dx}, P_{x}, T_{end}), x \in [1, i] \]  
Where, \( x, i \), respectively, represent the number and number of charging pile; \( CS \), said charging pile coordinates, \( P_{x} \) charging pile charging power, \( T_{end} \) said charging end time.

Electric vehicle charging pile position coordinates and its corresponding one-to-one fixed value, this paper in order to facilitate the study of the layout of the manual settings:

\[ CS_{dx} = (X_{x}, Y_{x}), x \in [1, i] \]  
This article assumes that the charging pile to the electric car charging power \( P_{x}=50kw/h \) constant and convenient research, the market by the mainstream of the three kinds of charging research as follows:
\[
P_x = \begin{cases} 
27.3 - 41 \text{kw/h, slow} \\
41 - 131.2 \text{kw/h, normal} \\
131.2 - 262.4 \text{kw/h, fast}
\end{cases}
\]  
(15)

Charging pile charging end time charging terminal used to charge the last electric car charging end time:

\[T_{end_x} = T_{end_y}
\]  
(16)

\(T_{end_x}\) indicates the charging end charging time of the charging post \(x\), and real-time dynamic updating is performed from the charging ending time of the last electric vehicle to the charging post.

3. electric car user strategy analysis

3.1 User Cost Analysis

For EV users, the satisfaction of charging behavior of users is measured by time cost and cost cost. The lower the user charging time cost and the cost cost are, the higher the user satisfaction is. The composition of user costs is shown in Figure 1 below:

![Figure 1 user cost structure](image)

3.2 The user selects the evaluation index

The method of calculating the time cost and the cost cost for electric vehicle users is based on the analysis and calculation of the total cost cost and the time cost objective function.

The cost cost objective function is as follows:

\[
CP(t) = \sum_{t=0}^{24} \sum_{n(t)} CP_{yx}(t)
\]  
(17)

\(n(t)\) represents the number of electric vehicles in different time periods, and \(CP_{yx}(t)\) is the cost of choosing charging pile \(x\) for charging when the electric vehicle \(y\) is \(J(t)\) at a certain time under a certain scheduling strategy cost. The \(CP(t)\) can be transformed as follows:

\[
CP_{yx}(t) = f(Dy_{yx}) + f(e_w) \]  
(18)

\(f(Dy_{yx}) = (J_0 + J(t)) \times (Dy_{yx} \times 19.5 / 100)\)

\(f(e_w) = J(t) \times e_w\)

The user cost includes the on-street cost \(f(Dy_{yx})\) and the initial time power supplement \(f(e_w)\). The former is related to the distance between the electric vehicle and the selected charging pile, the latter has nothing to do with the selection of the charging pile. Therefore, the farther from the electric vehicle to the charging pile \(Dy_{yx}\), the higher the charging cost.

The objective function of time cost is:
\[ CT(t) = \sum_{t=0}^{24} \sum_{y=1}^{n(t)} CT_{xy}(t) \] (19)

\[ t \in [0,24], x \in [1,i], y \in [1,n(t)] \]

\( CT \) is the time cost of charging the charging pile \( x \) in the electric car under a certain choice scheme of the user. \( CT \) can do the following changes:

\[ CT_{xy}(t) = g(Dis_{xy}) + g(Twait_{xy}) + g(e_{-w_y}) \]

\[ g(Dis_{xy}) = \frac{Dis_{xy}}{v} + \frac{19.5Dis_{xy}}{100P_x} \]

\[ g(Twait_{xy}) = Twait_{xy} \]

\[ g(e_{-w_y}) = \frac{e_{-w_y}}{P_x} \]

\[ t \in [0,24], x \in [1,i], y \in [1,n(t)] \]

\( g(Dis_{xy}) \) represents a function related to the distance \( Dis \) from the electric vehicle \( y \) to the charging pile \( x \), \( g(Twait_{xy}) \) represents a function related to the charging latency of the electric vehicle, and \( g(e_{-w}) \) represents a function related to the initial charge of the electric vehicle. Since each charging pile has the same charging power at the same time, \( g(e_{-w}) \) is independent of charging pile selection. The user's time cost \( Dis \) is determined by \( Twait \). The user time cost is proportional to the distance from the electric car to the charging pile and the charging waiting time.

4. program simulation analysis

4.1 MATLAB simulation process

![Diagram](image)

In Figure 2 above, the selection and comparison process of the entire user selection strategy is described, and the simulation results are compared with the results of four different decision-making methods.

4.2 Simulation Results

In this paper, 16 charging piles are selected as the research object to simulate the user's travel patterns at different periods of time, leading to 30 users for 0-4h, 10 users for 4h-6h, 20 users for 6-9h, 40 users...
for 9-16h, 20 users for 16h-22h; 22h-24h cited 20 users, only consider the single constant power charge of the case, the four kinds of user selection strategy simulation.

According to the four kinds of user selection schemes described in this article, the number of EVs selected to charge each charging pile within 24 hours is calculated respectively. After carrying on the emulation of four kinds of different schemes, the overall distribution of 4 kinds of vehicles of different schemes is shown as in Figure 3 below:

![Figure 3](image)

**Figure 3** (a) the shortest path (b) the total time consumption of at least (c) the user the least cost (d) shortest waiting time

Since the number of vehicles put in each time period is not the same within 24 hours, the number of vehicles is not evenly distributed on the time axis, that is, the number of vehicles in charging piles varies from one distribution to another. The variance of the number of vehicles for each scenario is shown in Figure 4 below:

![Figure 4](image)

**Figure 4** Variance distribution of the four strategies

Since the integrated strategy is to combine the variance between the two, in order to facilitate the study, this paper selected $a = 1$ for simulation analysis.

For the day when the peak use of electric vehicles, the following two selected periods, $t = 11$ and $t = 12$, combined with the overall distribution of the law for analysis:

![Figure 5](image)

**Figure 5** (a) User selection distribution at $t=11$ (b) User selection distribution at $t=12$

From the simulation results in Figure 5 we can see: The first (a) scheduling (shortest path), the distribution of electric vehicles is fragmented, because this scheduling method only considers the driving distance factor of the charging pile scheduling, while ignoring the user time costs, as well as the charging pile operating conditions, did not show a good time effect, do not have the regularity. At
t=11, the number of electric vehicles that choose charging post 2 for charging reaches 8, and when
t=12, the number of charging vehicles that choose charging post 2 and 14 reaches 6, which greatly
increases the waiting time for user charging Cost, and lead to overcharged operation of the charging
pile in areas where the distribution of traffic volume is relatively intensive, increasing the charging
pressure of the charging pile.

The third (c) scheduling (the smallest user integrated cost), although the number of electric vehicles
at various times the distribution of scattered, but its effect is better than the first scheduling. At t=11,
the number of vehicles supplemented by electric charging pile with number 2 is 7, and the distribution
is even when t=12. According to the overall distribution, the number of vehicles served by a single
charging pile is less than that of the first scheduling method under the scheduling cost with the lowest
total cost.

The second (b) scheduling method (the total time consuming), Show a more even distribution at
t=11 and t=12. At t=11, compared with the first and the third scheduling schemes, the number of
vehicles in charging station No.2 is reduced. At t=12, the number of vehicles charged by each charging
station does not exceed 5 vehicles. Compared with the shortest path scheduling scheme, The status of
the charging posts 1,2 and 14 has been improved. Charging pile is a reasonable distribution of use.

User costs include cost and time costs. According to these two evaluation indexes, the correlation
values of the four scheduling methods are respectively calculated, the result is shown in Figure 6
below:
of the four user strategies of the electric vehicle users with the above design, the advantages and disadvantages of the three schemes of lowest cost cost, lowest time cost and lowest comprehensive cost are obtained. The optimal choice of the key needs of users, for the general case, comprehensive cost options for the user has a good guiding significance.

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