Optimal Deployment of Charging Stations and Movable Charging Vehicles for Electric Vehicles

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Abstract. There is a broad consensus that popularizing electric vehicles is an important measure to save energy and reduce emission. However, unreasonable locations and deployment of charging stations obstruct the development of electric vehicles. We consider a novel solution that combine movable charging vehicles with charging stations, at which improving the service level and performance of the charging stations. Therefore, we introduce a new variant of location model, which involves movable charging vehicles. Based on the minimum budget cost, the charging stations and charging vehicles configuration were determined, including quantity and layout. The analysis and solution of the hypothetical example verifies the scientificity and feasibility of the method.

Keywords: Electric vehicles, Movable electric vehicles, Maximum covering model

1. Introduction

As the global population grows, so does the need for energy. Fossil fuels will continue to dominate the energy market, meeting 60 percent of the world's new energy demand and 80 percent of global energy supply by 2035. The rapid increase of automobile consumption makes the security of oil supply more serious. Meanwhile, environmental pollution has become more serious, and burning fossil

fuels in the industrial and transportation sectors is widely recognized as a major factor (Sabri et al.,2016). The development of electric vehicles seems to ease the above problems. In order to reduce the pressure of environmental pollution and resources, more and more countries begin to advocate the development of new energy vehicles (Shaukat et al., 2018; Zhang and Han, 2017). The development of new energy vehicles has become an irreversible trend (Garcia et al. 2017). In 2009, the United States launched a large-scale construction project for electric vehicle charging facilities, and plans to complete the construction of 11,210 charging stations in five pilots in three years. China plans to add 12,000 centralized charging stations and 4.8 million separate charging piles by 2020 to meet the charging needs of 5 million electric vehicles.

Although the technology of electric vehicles is increasingly mature, it is still difficult to promote electric vehicles. The biggest obstacle is the imperfection of the charging station network, resulting in low charging efficiency and inconvenience. An article by Johnson and Suskewicz (2009) in the Harvard Business Review also believes that to realize the transition from traditional energy economy to clean technology, technology alone is not enough, and business model, market and policy must be integrated into the thinking framework. The development of electric vehicles is also the same. It is necessary to replace the fuel vehicle system with the electric vehicle system, and the construction of the electric vehicles system is to establish a perfect and efficient network of charging stations. In a word, the construction of charging station service network is the key to the development of electric vehicles. How to plan the charging station service network to minimize costs and the highest level of

service is a problem that must be considered. However, this problem is different from previous network planning, such as high uncertainty in demand and service. Hosseini et al. (2015) believe that charging time is a key factor affecting the public's acceptance of electric vehicles. The layout of the charging station and the efficiency of the service determine the charging time.

In this paper, We aim to clarify the number and layout of the charging stations. We divide the charging station into movable charging stations (movable charging vehicles) and fixed location charging stations. The contribution of the paper is that we not only consider the cost and benefits of charging facility planning, but also focus on different types of charging deployment to increase the availability and flexibility of charging. In so doing, we examine the impact of various pertinent parameters on the optimal deployment, particularly movable charging vehicles.

2. Literature Review

At present, research on electric vehicles is mostly limited to the technical stage, and research is rarely carried out from the perspective of infrastructure construction and operation management. Schwoon (2007) asserted that the biggest obstacle lies in the imperfect facilities of charging stations.

As far as the location optimization and location model is concerned, the location problem of the charging stations is an NP-hard problem. Therefore, researchers tend to improve models and optimization algorithms. Sadeghi-Barzani et al. (2014) presented a Mixed-Integer Non-Linear (MINLP) optimization to solve the problem of location selection of fast charging stations.

Guo et al.(2015) used the multi-criteria decision making (MCDM) method to evaluate the selection criteria of charging stations and applied the fuzzy TOPSIS method to optimal site of charging satations from sustainability perspective. Extend the classical location model and design the algorithm to get the optimal network layout of the power station (Andrews et al. 2009). McPherson et al. (2011) compared several options for site selection and charging, and selected a location model to study the network planning problem of Australia's power station. Mak et al. (2013) Two types of robust location optimization models are used to study the location problem of electric steam exchange plants. One type of target is the lowest cost, and the other type is the highest service level. Schneider et al. (2017) used the methods of approximate dynamic programming and stochastic optimization to study the scale of electric vehicle charging and replacing stations and the number and mode optimization of daily battery charging. However, the layout of the charging station as part of the facility location should also include factor analysis of the location, such as the availability and flexibility of charging.

In addition to the quantitative research methods of modeling, the research mainly studies the influencing factors, standards and impacts on the grid of electric vehicle charging station network planning from a qualitative perspective.The construction cost of charging station is relatively high. Under the constraint of limited financial budget, how to improve the layout efficiency of charging station is particularly important. Wu et al.(2016) considered factors that affect the layout of charging stations, such as economic factors (construction cost, operation and maintenance cost, investment recovery cycle), technical feasibility (substation distance, power system influence, resource availability), service

effectiveness (transportation convenience, service capacity, service radius). Yagcitekin et al.(2016) based on queuing theory, the number of chargers, walking distance, distance between substations and parking areas, population and usage density, scalability and accessibility were studied. Zhang et al. (2016) proposed a decision-making framework that comprehensively considered the optimization models of the market, engineering and operations, and evaluates the profitability of the charging stations layout model. Simorgh et al.(2017) studied the optimal placement and sizing of electric vehicles, based on the goal of minimizing investment costs, connection cost, total cost of losses, and demand response.

Accenture (2011) has pointed out through consumer surveys that convenient charging and battery life are the most critical factors in motivating consumers to purchase electric vehicles. Amoroso and Cappuccino (2011) propose different charges for different charging efficiencies to coordinate the relationship between charging efficiency and charging rate. Nurre et al. (2014) studied the decision to change the number of rechargeable batteries in a substation rechargeable battery and a substation. Avci et al. (2013) studied Better Place's power-changing mode (charging by mileage, instead of selling batteries or charging service). Since this paper does not cover the research of electric vehicle batteries, it will not be described too much.

The selection of charging stations and other general facilities is obviously different in many aspects. The factors involved are more and more complex, such as the location and scale of the replacement of power stations and the scheduling and inventory of batteries. In our paper, we develop a model with movable charging vehicles and cross-check our analytic results with hypothetical example.

Different from previous literature research, the charging stations only exist in static form. We consider the moveble charging vehicles, enrich the way of charging and broaden the research perspective.

3.Model Formulation, Hypotheses and Results

In this section, we formulate the maximum covering laoction model with moveble charging vehicles. This basic model originally proposed by Church and ReVelle(1974). In this model, we consider the charging station to be the most capable within a limited budget. We assume that the budget for building charging facilities (no-movable charging stations and movable charging vehicles) is B_0, the cost of the charging station and the charging vehicles is p_1 and p_2 per unit, and quantity is is q_1 and q_2. In addition , we define the following additional notation:

$$i \quad --\text{demand node } i$$

$$j \quad --\text{charging stations candidate node } j$$

$$h_i \quad --\text{demand at node } i$$

$$a_{ij} = \begin{cases} 1 & \text{if demand node } i \text{ is met by facility node } j \\ 0 & \text{if not} \end{cases}$$

$$Z_i = \begin{cases} 1 & \text{if node } i \text{ is covered} \\ 0 & \text{if not} \end{cases}$$

$$X_j = \begin{cases} 1 & \text{if the facility is layout at node } j \\ 0 & \text{if not} \end{cases}$$

Decision variables are Z_i, X_j, q_1, q_2

Different from other literatures, We considered the daily service capacity of the movable charging vehicle, which depending on the time t hours available for charging each vehicle, the maximum electrical capacity E, and the electrical

energy consumed e per service.Therefore, the service capacity of the movable charging Vehicle is

$$\Delta = \min \left\{ \frac{24}{t}, \frac{E}{e} \right\}$$

Minimum utility indicates that the service performance of a movable charging vehicle depends on the minimum number of times that can be used for charging per day.

The maximum covering location model with movable charging vehicles as follows:

$$\text{MAXIMIZE} \qquad \sum_i h_i Z_i + \Delta q_2 \qquad\qquad (1)$$

$$\text{SUBJECT TO:} \qquad Z_i \leq \sum_j a_{ij} X_j \qquad \forall\, i \qquad (2)$$

$$\sum_j X_j \leq q_1 \qquad\qquad (3)$$

$$p_1 q_1 + p_2 q_2 \leq B_0 \qquad\qquad (4)$$

$$X_j = 0,1 \qquad \forall\, j \qquad (5)$$

$$Z_i = 0,1 \qquad \forall i \qquad (6)$$

$$p_1, p_2, q_1, q_2 \in N+ \qquad\qquad (7)$$

The objective function (1) maximizes the service performance. Constraints (2) state that demand at node i cannot be covered unless at least one of charging station cover node i is select. Constraint (3) means that layout of the non-movable charging stations cannot be more than q_1. Constraint (4) means that the cost of building non-movable charging stations and movable charging vehicles is less than the budget. Finally, constraints (5) and (6) are the integrality constraints on the decision variables. Constraint (7) indicates that both the number and price

of charging stations are positive integers, which is in line with the objective situation.

To illustrate the mechanics and the utility of the maximum covering lacation model with movable vehicles problem, we employ for numerical examples the following hypothetical parameter values and network shown in Table 1 and Figure 2. Figure 2 of the network we refer to Daskin (1997), and the charging station covers distance of 11.

Table 1. Base case parameters for numeric example

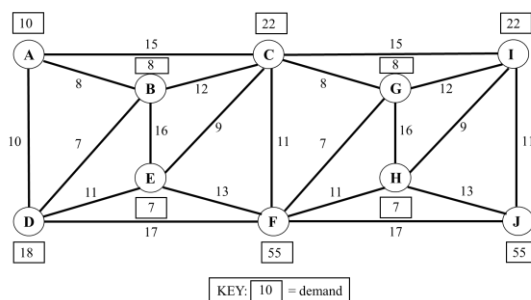| Paramter	B_0	t	E	e	p_1	p_2	$q_1(\max)$	$q_2(\max)$
Value	640	0.3	1000	20	100	80	3	8

Fig. 2. network

The optimal solution is found after the numerical example is solved. The resulting solution is

$$X_C = 1 , X_I = 1$$

$$Z_C = 1 , Z_E = 1, Z_F = 1 , Z_G = 1 , Z_H = 1 , Z_I = 1, Z_J = 1$$

$$q_1 = 2, q_2 = 5$$

and the objective function equals 426. It can be found that, with limited budget, the movable charging vehicles can improve the performance of charging stations and can fully meet the requirements of the uncovered node. For example, the total demand of 36 for A, B, and D can be fully met by a movable charging vehicle.

4. Conclusion

The research on the deployment of charging stations is continually trending towards real-world simulation and improving the efficiency of charging. Based on budget constraints and   movable charging vehicles, this paper optimizes the deployment of charging stations, including location and quantity of the purchase. We found that the movable charging vehicles not only have higher flexibility, but also can improve the service performance of the charging station and reduce the budget. For convenience, we only consider movable charging vehicles to meet all needs to the maximum, which is ideal. Therefore, we need to further refine the performance of the movable charging vehicles in the future.

Acknowledgments

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