Optimal Location of Battery Electric Vehicle Charging Stations in Urban Areas: A New Approach

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1 Introduction

It is widely recognized that the development of a charging infrastructure is essential for the spread of battery electric vehicles (BEV). In order to support and promote the use of these vehicles, many governments are developing plans to deploy pilot networks of slow charging stations in urban areas. It is very important for the development of electrical mobility that the best possible locations are chosen for the stations, because this will favor the purchase of BEV. In most cases, the plans are choosing locations at popular parking places, such as city centers, shopping areas, train stations, and university campuses. These places are highly visible, however, the low parking time and high rotation rates often observed there could deliver an inadequate solution for the real daily charging needs of the users. In this paper, we propose an approach to the location of charging stations that takes into account these needs through the concept of personal charging coverage. The approach relies on a maximal demand coverage models for optimizing the location of charging stations. The amount of demand is defined in terms of the concept of BEV adoption potential.

Few authors have dealt with charging station location models (Kuby and Lim [1], Wang and Wang [2], Frade et al. [3], Bersani et al. [4]). They have addressed them either through classic location models or through flow interception models. The latter, convey a convenient solution for interurban areas and fast charging systems but are not suitable for the slow charging systems of urban areas, in which the recharging process is done in parking areas (nodes) and not along travel paths (arcs).

2 Personal Charging Coverage

The concept of personal charging coverage is defined as the amount of time a user (vehicle owner) has effective access to a charging station during a day. Potential charging locations are linked to parking places near the usual daily activities of the users. These activities are aggregated in three groups: at home, at work, and others (mainly shopping and recreation). These potential places are weighted according with the parking time spent in each one. Considering the particular combination of activities of each user, the total access time to charging stations is measured and compared with the minimum charging time needs (8 hours for a full charge of a typical commercially available BEV).

3 BEV Adoption Potential

Since charging stations are developed to supply and also promote a future demand, the target users have to be identified and differentiated according with their potential for using the charging stations. The concept of BEV adoption potential is defined as the likelihood of a given person purchasing a BEV, thus becoming a potential user of charging stations. This concept is estimated by a series of demographic variables (education level, income, car ownership, commute distance, age and gender) that are identified from a wide overview of previous studies, mainly state of preference type, related with the preference for BEV. The BEV potential of adoption is then calculated from the multiplication of the factors assigned to each demographic variable, according with defined threshold levels.

4 Stations Location Models

The aim of the charging station location models is to determine the location for a given number of charging stations that maximizes the amount of potential users with a minimum daily access time, large enough to cover their common charging needs. The number of new stations has to be previously decided according with the investment to be made on the development of the charging network. Different levels of investment (number of stations) imply different marginal benefits.

Two models are proposed: a model where both the personal charging coverage concept and the BEV adoption potential concept are taken into account, designated as complete model; and a model where the BEV adoption potential concept is not taken into account and the marginal benefits for each hour of coverage are constant, designated as basic model.

The data requirements for the complete model are: demand from a user living in zone *j* and working in zone *k* (which depends on household size and income, car ownership, and garage ownership) and the walking distances between zones. The zones should be small geographical units, as for example census blocks.

5 Preliminary model results

In order to compare the performance of the models among them and with a classic maximum coverage model, we present below a summary of the results obtained for 20 instances of a charging station location problem. Each instance was defined for an urban area of 1.5 x 1.5 km2 comprising 25 randomly-distributed zones, each zone being a possible location for a charging station. The population and employment in each zone was randomly-generated as well. The objective was to know the percentage of users that would have access to a station at least 8 hours a day. The number of stations to locate was 2, 3, or 4.

For the complete model, the results were: 51.7% (2 stations), 70.5% (3 stations), and 84.5% (4 stations). The equivalent figures for the basic model were: 49.8% (2), 67.2% (3), and 81.0% (4). Finally, with the classic model, the results were 49.1% (2), 66.5% (3), and 80.5% (4).

The complete model always found solutions equal to or better than the basic and the classic models. The coverage given by the complete model was, on average, 5.2, 6.0, and 4.9 percent larger than the coverage given by the classic model, respectively when there were 2, 3, and 4 stations to locate. In some cases, the differences in coverage were quite large – up to 32.1, 13.4, and 13.5 percent for 2, 3, and 4 stations. The solutions for the basic model were 1 percent better on average than the solutions for the classic model, and were obtained in a few seconds using the XPRESS optimizer (branch-and-cut) in a top-market PC. This is approximately the same time taken to calculate solutions for the classic model. In contrast, the solutions for the complete model took some minutes to compute. This clearly indicates that it may be necessary to resort to heuristics when dealing with real-world instances, which, even for a mid-size city, will involve hundreds of zones.

6 Conclusion

In this paper, we presented a new approach to the location of battery electric vehicle charging stations in urban areas. The approach relies on optimization models that allow determining where the stations should be located to maximize demand coverage taking into account the concepts of personal charging coverage and BEV adoption potential. Based on the results already obtained for a sample of randomly-generated instances, it appears that the approach can be very useful in practice, providing clearly better results than approaches grounded in classic location models.

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References

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