A Non-Linear, Zonal and Time-dependent Electric Vehicle Charging Pricing Framework for Multi Agent Transportation Simulation (MATSim)

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Abstract

Electric vehicles (EVs) are increasingly popular and becoming an important alternative to internal combustion engine vehicles (ICEVs) as they can cut down CO2 emission footprint and fossil fuel dependency. However, the large-scale adoption of EVs, which results in an increase in electricity demand due to EV charging, may impose important challenges to the stability of the power grid while generating excessive queuing at the charging stations. In addition to different solutions that have been proposed in the literature, pricing schemes such as non-linear, time-dependent or zonal pricing appear to be a promising control strategy to overcome the challenges associated with an increased penetration of electric vehicles. However, little research has incorporated these considerations into the transportation simulation frameworks. This paper, therefore, addresses this gap by introducing a framework that can account for zonal, non-linear and time-dependent charging pricing schemes for electric vehicles, and heterogeneity of charging behavior using multi agent transportation simulation (MATSim). The methodology is tested in the case of study of Montreal, Canada.

Keywords: Electric Vehicles (EVs), Non-linear pricing, Time-dependent pricing, MATSim.

Motivations

There are currently several public charging stations for electric vehicles (EVs) in Montreal, a majority of which are uncontrolled. In other words, when a plug-in hybrid or electric vehicle is plugged in, it immediately starts charging with its maximum possible power until the battery is fully charged, or until it is unplugged. Controlled charging, however, is gaining attention, in which EVs are somehow forced to change their charging behavior according to pricing policies. A time-dependent pricing system is an example of such approach. It refers to a situation in which the charging provider, which can be a distribution system operator, or an operator or aggregate of charging stations, adapts the price that must be paid by the end users (EV drivers) for charging their EVs during different times of the day. In other words, the charging prices can be adjusted based on changes in the operating conditions, such as higher electricity prices during times of high energy costs or peak hours to shift consumption to low demand periods of the day. However, since all EV owners receive the same signals, they tend to respond in the same way, which may result in the creation of new peaks when prices are low. In this way, non-linear pricing can come in handy. Non-linear pricing refers to a situation in which electric utilities (or aggregators) set a stepwise price for charging based on the charging duration, and electric vehicles select a charging profile that minimizes their individual charging costs (maximizes their individual profits).

Waraich 2013 considered different pricing schemes such as dump charging and dual tariff charging in MATSim, and implemented it for the city of Zurich as a case study. Afterward, using a price control signal, he analyzed the effects of different schemes and proposed the most efficient scheme for charging pricing [1]. On the other hand, Ghavami et al. in 2014 used a Bayesian extension of the widely studied Walrasian pricing, and applied it to their PEV charging model, while considering non-linear pricing functions instead of linear flat pricing function [2]. However, as mentioned previously, to the best of author knowledge, there is sparse literature on a framework that is able to consider both non-linear and time-dependent pricing and apply it to a large-scale scenario and verify it using a transportation simulation. In addition, we keep provision for a zonal pricing scheme (which applies different electricity prices at different zones of the city) in our framework, which is non-existent in literature. By introducing such a framework, the benefits of the current study can be divided in three categories; first, in terms of power grid, it will be possible to reduce energy production costs, increase grid stability and reduce CO2 emission footprint of electricity production, as by using this framework, the extra load on power grids will be controlled. Second, in terms of public charging station operators, it will reduce the operating costs of public charging stations. Finally, in terms of EV users, it will help to increase user satisfaction by controlling queues at charging stations.

Methodology

Using MATSim, different charging schemes have been considered in this study including: 1; linear flat pricing (which has been considered as a base scenario), 2; non-linear pricing that accounts for a different price for every 30-minute charging period, 3; time-dependent pricing that accounts for different electricity prices during peak and off-peak hours, and finally combined pricing that considers both time-dependent and non-linear pricing at the same time. Afterward, this framework has been applied to the Montreal-Scenario to verify the validity of the framework. There is provision for zonal pricing in our framework as well. However, we have kept it for our future research. The novelty of this paper is to apply pricing scheme in large scale mobility scenario, considering that the variation in charging behavior is affected by this pricing control.

Assumptions for the experiments

- The penetration of EVs is assumed to be 10%, while the higher percentages will be evaluated further.
- The minimum level of state of charge (SOC) is considered as 20kWh, meaning when an EV's soc reaches this level, the agents will search for a suitable charging station within 500 meters radius.
- To verify the validity of the framework, for now, the simulation has been run with 1% population of the Montreal scenario, with only 100 iterations.

Preliminary results

As an example, one of the results of the study has been shown. Figure 1 shows the amount of energy used during various times of the day and has been compared with the base scenario. As can be seen, the peak usage has been reduced.

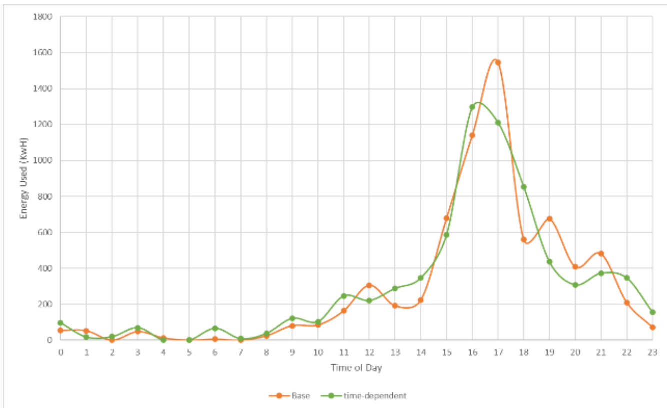

Figure 1: Energy used by EVs during various times of the day in base and time-dependent pricing schemes.

References

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