Tariff Mechanism for fast EV charging station

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Overview

The energy transition in the transportation sector largely hinges on the shift from fossil fuel-powered vehicles to electric vehicles (EVs). Accommodating the increasing adoption of EVs necessitates the expansion of charging infrastructure, including diverse types of charging stations tailored to users' needs. One critical component is fast DC charging stations, designed to deliver high-power charging for minimal wait times. These stations are commonly located along highways to support long-distance travel and are essential for broader EV adoption. Yet, little of the literature focuses on proposing tariff mechanisms for this type of infrastructure.

Recently, EV charging stations have been equipped with adaptive power allocation capabilities, allowing individual chargers to dynamically adjust the charging power based on the station's grid connection limits. This functionality enables charging stations to efficiently utilize the available grid capacity, optimizing their operations and revenue even under constrained conditions. With power grids becoming increasingly saturated—such as in parts of the Netherlands, where maximum transmission capacity has already been reached—expanding grid connections is often not feasible. As a result, charging stations may need to limit the power they offer to vehicles. Traditionally, power allocation has relied on simple strategies like evenly splitting capacity among chargers or adhering to a first-come-first-serve principle. However, these approaches fail to consider user-specific charging needs. Our work aims to improve power distribution by assessing the urgency of charging for each EV owner and designing optimized tariffs accordingly.

In this study, we model a fast-charging station seeking to maximize revenue by offering a differentiated menu of prices and power rates and optimizing the number of charging points. The optimal pricing strategy accounts for consumer heterogeneity in time sensitivity to charging. Impatient users, who prioritize faster charging, are willing to pay a premium for higher power rates, while users with more flexible schedules prefer lower-cost options. By leveraging this diversity, our model enhances revenue generation while ensuring the efficient utilization of the station's limited grid capacity. This approach provides a practical framework for balancing user demands with infrastructure constraints.

Method

An analytical model is developed to determine the optimal pricing and power allocation strategy, as well as the optimal number of charging points at a fast-charging station. The model leverages queuing theory, particularly variations of the Erlang loss model, to account for the station’s limited queuing capacity. Initially, we consider a continuous distribution of consumer heterogeneity, where urgency parameters follow a standard distribution, resulting in a unique menu of prices and charging rates. Subsequently, we analyse a discrete setting with distinct consumer types and evaluate the advantages of offering differentiated menus for each type versus a unified pricing strategy. For this analysis, the multi-rate Erlang loss model is utilized. Numerical simulations are conducted to assess the sensitivity of the proposed model to key factors, including consumer heterogeneity, grid connection limitations, and arrival rates.

Results

Our findings reveal that for a continuous range of heterogeneous consumers, the optimal charging rate is the maximum power rate, constrained either by the vehicle's charging capacity or the grid connection. We further demonstrate that there exists a unique optimal price associated with this rate. Additionally, we establish that the optimal number of charging points corresponds to the closest integer—either rounded up or down—obtained by dividing the grid connection capacity by the maximum charging rate.
For the discrete case, where consumers are categorized by their urgency to charge, our results indicate that offering a single pricing menu is always the optimal strategy. If the arrival rate of less impatient consumers is relatively high compared to that of impatient consumers, and the disparity in urgency levels between the two types is small, it is advantageous to set a lower tariff to accommodate all consumer types. Conversely, when the impatient consumer

group dominates or urgency disparities are significant, it is more profitable to exclude less impatient consumers and implement a higher tariff for the impatient segment.

Conclusion

This study introduces a profit-maximizing tariff mechanism for fast-charging stations, offering practical insights into tariff design and station configuration under grid constraints. The proposed approach supports efficient power allocation, enhances revenue generation, and facilitates the sustainable scaling of EV infrastructure.