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Electrical Vehicle Charging Infrastructure Design and Operations

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Introduction

As global warming and air pollution increasingly attract worldwide concerns, CO_2 efficient electric vehicles (EV) will gradually replace fossil fuel vehicles in the transportation sector. For example, the California government has set a very ambitious goal of 5 million zero emission vehicles (ZEV) by 2030. However, this transition process may take a long period of time and face several challenges. The lack of public charging infrastructure is one barrier to EV adoption in long-distance transportation. In California, 70,000 public and shared chargers have been installed by January 2021, whereas 700,000 chargers are needed to support 5 million ZEVs on the road. This gap motivates the government, industry practitioners, and academia to collaborate and find an economically sustainable solution for charging station development. In addition, the charging-incurred power demands and duration may significantly lower the delivered voltage in the power grid and increase travel expenses. Such drawbacks will degrade the appliance function, render safety issues in the power grid, and worsen traffic congestion. The proposed project aims to achieve a satisfactory solution to recover the voltage drop through PV inverters, develop a computationally efficient charging scheduling method, and design charging stations through infrastructure optimization.

Study Methods

This research integrates EV charging scheduling and infrastructure design as a two-stage optimization problem. This framework takes various input parameters into account, such as charging demands and allowable waiting time from the California State University, Long Beach (CSULB) campus, time-of-use electricity price, net surplus compensate rate, battery price, charging service fee, local weather short-term forecast, and solar panel cost, to formulate the optimization problem and simulation testbed. Two approaches for EV charging power dispatch are developed, including the robust model predictive control (MPC) and empirical rule. Although MPC has the potential to offer better service quality and profitability, its practical performance is subject to model accuracy and external uncertainty. In addition, MPC's computational time is substantially longer than that of the empirical rule. Therefore, this research adopts the empirical rule approach to solve the year-long optimal scheduling problem repeatedly under different infrastructure designs. Instead of enumerating all possible design combinations, this research follows the response surface methodology to build a quadratic function of the charging station's operational revenue over ten years. Consequently, the charging station's infrastructure, such as the number of chargers, the capacity of PV panels, and the size of the battery are smartly sampled, optimized on the surface function, and finally converged to the most profitable design.

Optimization-based scheduling and infrastructure design can improve a charging station's profitability and service quality.

Findings

This research shows that:

- Solar panels used for the charging station power supply can reduce operational cost while making transportation greener.
- The algorithm facilitates charging stations to meet customers' demands in charging power and wait time. The rule-based method is more efficient than the robust model predictive control, and its resulting scheduling solution is more profitable.
- The response surface methodology (RSM) is better integrated with the rule-based scheduling approach for infrastructure optimization, whereas the robust MPC can be used for validation or policy improvement.
- The battery energy storage system may not be economically efficient due to its high cost and net surplus compensation rate issued by the utility.
- Even though MPC is a promising way for EV charging power to be dispatched, its practical performance is highly restricted by model accuracy and external uncertainty, such as weather changes and unexpected service requests.

Policy Recommendations

This research highlights several key recommendations for improving an EV charging station's service and profitability. (1) Incentivizing charging station owners to update their facilities with PV panels and battery energy storage systems can help reduce their reliance on grid electricity and increase long-term revenue. (2) Reducing the cost of battery energy storage systems is essential to further improve the integrated charging station's profitability. (3) A centralized power dispatch system should be deployed in the charging station to improve the charging service quality and optimize the use of available resources. (4) Finally, integrating short-term weather forecasts with the solar power prediction can enhance the accuracy of EV charging scheduling and improve the overall efficiency of the charging station.

About the Authors

Dr. Yu Yang currently is an Assistant Professor at CSULB. His research interests include data-driven modeling, advanced process control, machine learning, and global optimization under uncertainty.

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To Learn More

For more details about the study, download the full report at transweb.sjsu.edu/research/2240

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