Spatio-Temporal Optimization of Bidirectional EV Charging Using Real-Time Traffic Flow Analysis and Stochastic Energy Modeling

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Abstract

Background

The increasing adoption of electric vehicles (EVs) drives demand for larger battery capacities and higher charging power, with the aim of minimizing disruptions during long-distance travel. As a result, modern EVs are now equipped with substantial battery capacities that could supply multiple households for several days [1]. As both the distribution grid operator and the energy supplier face constant challenges of accommodating this growing power demand, rising prices are a logical consequence. While expansion of the energy storage infrastructure is a cost-intensive endeavor, it seems obvious to integrate the significant capacity of individual EVs into the power grid and benefit from bidirectional charging (vehicle-to-grid, V2G) [2]. The majority of scientific efforts to date investigate the mitigation of power peaks when charging and discharging the EV in a manner conducive to power grid's resilience and associated carbon emission reductions. However, these studies often assume static scenarios like EVs being charged overnight at home or during the day at the workplace and thus rely too much on daily timetables.

Objectives

The novelty of this project lies in the additional consideration of the temporal and spatial components by tracing the traffic flow via cameras. Based on the analysis of real-time video data, predictions for individual cars reaching one of several destinations are improved. The analyzed traffic data is used as a method for feasible prediction of aggregated load profiles imposed by EVs in urban scenarios [3]. Such realistic load profiles are used to investigate mitigation strategies of power peaks [4].

Methods

It has been demonstrated that vehicles can be well detected through machine vision [5]. Vehicle tracking is implemented through real-time object detection models such as YOLO (You Only Look Once) and RT-DETR (Real-Time DEtection TRansformer) to continuously and accurately detect vehicles in the scene captured by cameras. After object detection, each vehicle is assigned a unique ID and its movement is tracked. Tracking techniques such as histogram-based tracking or Kalman filter are applied and compared.

A rule-based deduction is made from historic traffic data and daily deviating observations gained from traffic-flow analysis. Followingly, dynamic source-target matrices including intermediate stops is created. By integrating the prediction of EV arrivals, energy is allocated according to the probability of arrival to ensure power-peak free operation. Finally, functionality for future charging demands and storage availability is added. Based on this data, an Energy Management System provides bidirectional charging recommendations to ensure grid stability and avoid peak loads.

Results & Discussion

A stochastic environment based on Pyomo [6] has been set up to model different weather, traffic and PV production scenarios. The stochastics are added by the Pyomo plugin MPI-SPPY [7]. Decisions on the (dis)charging processes of stationary batteries, and dynamic energy prices, both for consumption and surplus feed-in represent a linea optimization problem and are solved by a IPOPT [8]. Possible PV generation and power demand is categorized into scenarios and weighted according to their probability and the best assignment for decision variables for all weighted scenarios is calculated. Preliminary optimization results demonstrate optimization of accumulated energy price and a smooth consumption curve at the distribution substation.

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Keywords: *Bidirectional Charging, Energy Flexibilities, Optimization*

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Biography

Dipl.-Ing. Paul Bauer earned a Diploma Engineer degree in Computer Engineering with a major in control theory from TU Wien. He worked at the Institute of Automation and Control Theory, now working towards a PhD at the Institute of Computer Technology. He is co-responsible for on-going research projects concerning the intelligent integration of electric vehicles into the smart grid and model-based control and probabilistic prediction approaches to the optimization of dynamic energy communities.