UC SANTA BARBARA

Electrical and Computer Engineering

Smart Infrastructure Systems Lab

Real-Time Electric Vehicle Smart Charging at Workplaces: A Real-World Case Study

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We study a real-time smart charging algorithm for electric vehicles (EVs) at a workplace parking lot in order to minimize electricity cost from time-of-use electricity rates and demand charges while ensuring that the owners of the EVs receive adequate levels of charge. Notably, due to real-world constraints, our algorithm is agnostic to both the state-of-charge and the departure time of the EVs and uses scenario generation to account for each EV's unknown future departure time as well as certainty equivalent control to account for the unknown EV arrivals in the future. Real-world charging data from a Google campus in California allows us to build realistic models of charging demand for each day of the week. We then compare various results from our smart charging algorithm to the status quo for a two-week period at a Google parking location.

EV Smart Charging at Large-Scale Facilities

- 2012: 120,000 EVs sold
- 2021: 120,000 EVs sold per week

Smart charging is increasingly critical for large-scale facilities (e.g., workplaces, apartment complexes, shopping centers, airports, fleet depots, etc.)

2022 Global EV Outlook, International Energy Agency (IEA)

SLAC & Google Datasets

Collaboration with the GISMO group at SLAC, have access to a large historical EV charging dataset:

- Workplaces throughout the Bay Area
- Most sessions exhibit typical workplace behavior
- 15-minute interval data for over 10,000 sessions
- Start times, end times, 15 minute avg. power delivered, total energy delivered, etc.

Opportunity to showcase the benefits of various smart charging strategies

Smart Charging Objectives

EV owner utility	$u_{OU}(e) = \sum_i \log(\sum_t e_i(t) + 1)$
Quick charge	$u_{QC}(e) = \sum_t \frac{T-t+1}{T} \sum_i e_i(t)$
Profit	$u_{PM}(e) = q \sum_t \sum_i e_i(t) - \sum_t p(t)\left(\sum_i e_i(t) + z(t)\right)$
Demand charges	$u_{DC}(e) = -\hat{p} \cdot \max_t \left(\sum_i e_i(t) + z(t)\right)$
Load flattening	$u_{LF}(e) = -\sum_t \left(\sum_i e_i(t) + z(t)\right)^2$
Equal sharing	$u_{ES}(e) = -\sum_{t,i} e_i(t)^2$
Energy demand	$u_{ED}(e) = -\sum_i \left(\lvert \sum_t e_i(t) - d_i \rvert\right)$

Offline Objective + Constraints

$$\max_e U(e) = \max_e \sum_{f=1}^{F} w_f u_f(e)$$

subject to:

$$\begin{aligned} &0 \le e_i(t) \le e_{max}, && \forall t, i \\ &e_i(t) = 0, && \forall t \notin [t_i^a, t_i^d] \\ &\sum_t e_i(t) \le d_i, && \forall i \\ &\sum_i e_i(t) \le e_{trans}, && \forall t \end{aligned}$$

Implementation Challenges

- Real-world systems with human users
- Operate in real-time without knowledge of future
- Adapt as more information is revealed
- Infrastructure constraints coupling all charging profiles
- Limited information from the EV
- Inaccurate information from the EV
  - 18.6% percentage error in user predicted departure times[1]

[1][Lee, Sharma, Low, '21] Research Tools for Smart EV Charging

Test Case 1: User Utility Maximization with TOU Rates

- Facility manager → maximize user utility under TOU electricity rates
- A large company campus who wants to provide free and effective charging for employees

$$U_1(e) = 15 u_{OU}(e) + u_{PM}(e) + 10^{-9}\left(u_{LF}(e) + u_{ES}(e)\right)$$

Test Case 1: Results

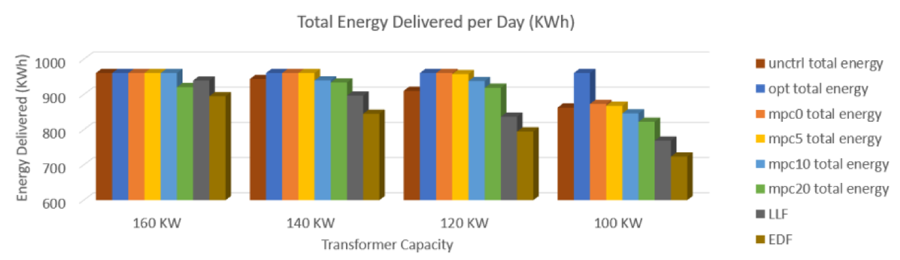


Figure: Total energy delivered for the various cases including Least-Laxity-First and Earliest-Deadline-First (both with perfect departure time knowledge) with varying transformer capacities.

Test Case 1: Results

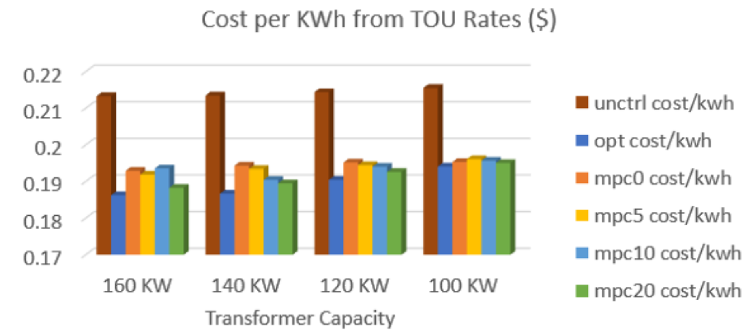


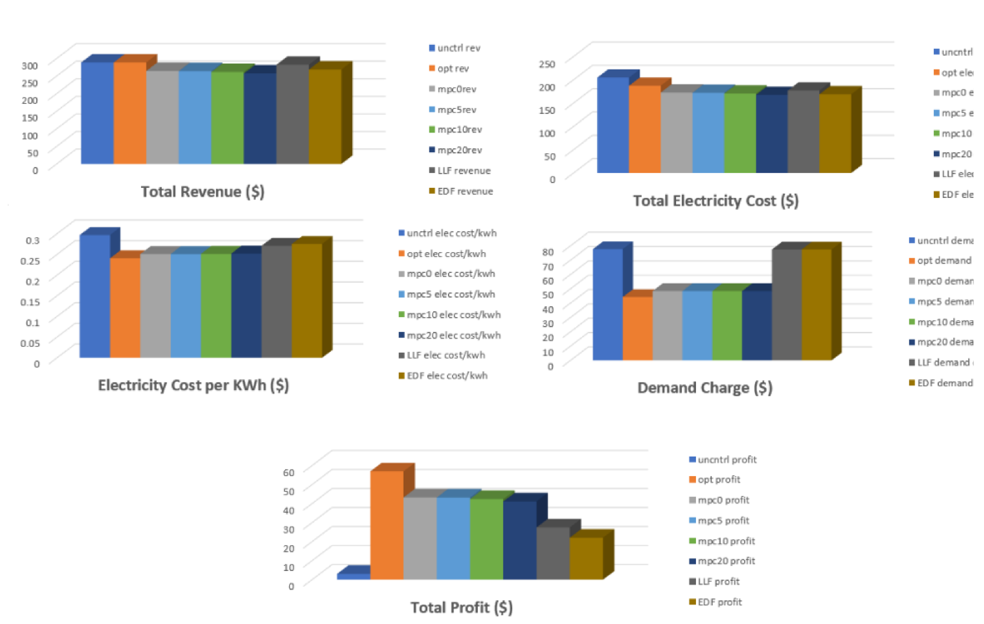
Figure: Cost per KWh from TOU rates for the uncontrolled, offline optimal, and 4 MPC test cases

Test Case 2: Profit Maximization with TOU Rates and Demand Charges

- Facility manager → maximize profit while delivering adequate energy to each customer
- For-profit third-party parking structure equipped with chargers and wants to minimize TOU electricity costs and demand charges

$$U_2(e) = 10\left(u_{PM}(e) + u_{DC}(e)\right) + u_{OU}(e) + 10^{-9}\left(u_{LF}(e) + u_{ES}(e)\right)$$

Test Case 2: Results



Test Case 2: Results

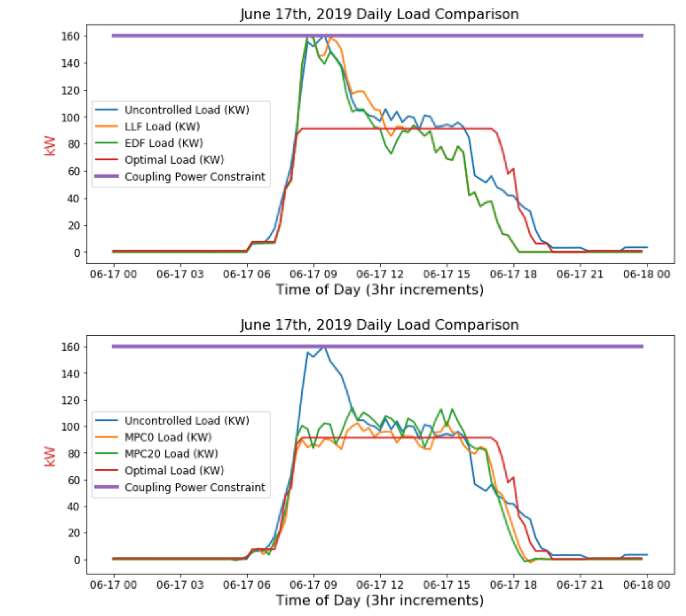


Figure: Daily loads of the charging facility for various charging strategies.