Overview of two research areas related to transportation and grid impacts

- Learned ride-hailing fleet control, load management
- Consensus charging overview
Presentation Overview

• Overview of two research areas related to **transportation and grid impacts**
  – Learned ride-hailing fleet control, load management
  – Consensus charging overview
• Integration into **broader AES simulation framework**
Ride Hailing Modeling, Managed Loads
Model Overview, Inputs and Outputs

- Battery size
- Fleet size
- Occupancy, etc.

- O-D locations
- Pickup times

- $/kWh by TOD

- Passenger pooling willingness

- Station power levels
- Locations, plugs, etc.
Model Overview, Inputs and Outputs

- Battery size
- Fleet size
- Occupancy, etc.
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- Station power levels
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Broad Outputs:
- Vehicle utilization
- Fleet performance
- Station economics
- ... and many more!

Highly Integrated Vehicle Ecosystem
Fleet Visualization (Austin, TX)

Trip Demand:
Ride Austin TNC Data

Animation Web link
HIVE 0.4.0+ Model Structure
Data-Driven Fleet Control

- Version: 0.1.0, heuristic based decision making
- Version: 0.4.0: Refactored HIVE in an “RL gym” to enable model training
- Exploring opportunities for improved performance beyond heuristics
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**State**
- Current & upcoming requests
- Current & upcoming prices to charge
- Fleet average SOC
- Fleet composition by state

**Agent**
“Fleet Manager”

**Environment**
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- % L2 vs DCFC
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- Request revenue – charging costs

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Sample Scenario, Downtown Chicago

- **Requests**: Two days of request data - one for training, one for test
- **Fleet**: 350 fleet vehicles with 50 kwh battery
- **Infrastructure**: 4 fast charging stations, 1 base with slow charging
- **Charging Costs**: variable by time of day, based on data from ComEd
- **Forecasting**: perfect for upcoming prices and requests
Results, RL-Trained Fleet Manager

Reward ($1000) vs. N training steps
Results, RL-Trained Fleet Manager, cont.
Future Work, HIVE

- Extended study over 10+ days of request data
- Expose fleet manager to more complicated rate structures (demand charges)
- Simulate more constrained scenarios – limited infrastructure, larger geographic area
- Expand scope of state/action space to include control of more than just charging
  - Fleet rebalancing
Consensus Charge Control
Background – Typical Control Hierarchies

A) No Control

All vehicles permitted to charge as demanded

B) Centralized Control

Centralized data acquisition from vehicles

Optimized charge profiles passed to EVs from centralized node
C) Consensus-based Distributed Control
Rather than communicating with a centralized node, vehicles communicate amongst each other to develop a charging profile through consensus.

Step 1: Communication among EVs

Node objective \( \text{minimize} \sum_{i \in V} f_i(x_i) \)

Where, \( f_i(x_i) = \text{min}. P_{ev,i} \)
\( P_{ev,i} \) - Charging profile for each EV

Step 2: Aggregate optimized charge profiles from individual EVs
**C) Consensus-based Distributed Control**

In addition to vehicles communicating amongst each other to optimize profiles at the station-level, additional communication amongst stations to consider grid supply/capacity

**Step 3: Communication among Charging Stations**

Node objective

\[
\text{minimize } \sum_{i \in V} f_i(x_i)
\]

Where, \( f_i(x_i) = \min \ P_{cs,i} \)

\( P_{cs,i} \) – Aggregated load profile at charging station

**Step 4: Aggregate optimized load profile from individual charging stations**

**Step 5: If \( P_{agg} \leq P_{lim} \), Stop. Else, repeat.**

\( P_{lim} \) = Grid supply/capacity constraint
Consensus Control: Parameters Assumed

Focus: Demand charge mitigation, by flattening the charging profile

Parameters:

- $E V_i$ is the vector specified by $(a_i, d_i, e_i, P_{\text{max},i})$
- $a_i$ is the arrival time of $E V_i$.
- $d_i$ is the departure time of $E V_i$.
- $e_i(t) = 0$ if $t < a_i$ or $t \geq d_i$
- $P_{\text{max},i}$ is the peak charging rate of $E V_i$.
- $r_i(t)$ is the instantaneous charging rate of $E V_i$. $r_i(t) = 0$ if $t < a_i$ or $t \geq d_i$.
- $P_{\text{cs}}(t)$ is the instantaneous aggregated power at charging station

Approach: ADMM based distributed control
Consensus Control: Performance Evaluation, cont.

**Peak Power vs. No. of Vehicles**

- **24h Horizon No Control**
- **24h Horizon Central**
- **24h Horizon Hierarchical w consensus**

**Peak Power vs. No. of Vehicles**

- **Real-time No Control**
- **Real-time Central**
- **Real-time Hierarchical w consensus**
Consensus Control: Performance Evaluation, cont.

Comparison for 24h Horizon

Comparison for Real-time

% Peak Reduction

No. of Vehicles

24h Horizon % reduction Central

24h Horizon % reduction Hierarchical w consensus

Real-time % reduction Central

Real-time % reduction Hierarchical w consensus
Consensus Control: Performance Evaluation, cont.

Solution time (24h Horizon)

Solution time (Real-time)
Transportation Topics, AES Simulation Framework
**HIVE: “Plug” control**

- HIVE has no formal charge control, but can load shift by controlling when vehicles are sent to charge
- Fleetwide charging peaks are controlled through strategic dispatch & charge instructions
- Main incentive is to recharge vehicles quickly so additional passengers may be served

No grid feedback, static decision-making
Load Shifting Strategy, Comparison

**HIVE: “Plug” control**
- HIVE has no formal charge control, but can load shift by controlling when vehicles are sent to charge.
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**Consensus: “Charge” control**
- Consensus control can affect the charging rate during an event, but has no control over plug-in / plug-out times.
- Charging peaks are controlled within the confines of a dwell. Greater dwell time correlated with greater flexibility.
- Likely to be best integrated at fleet depots where vehicles have long overnight stays.

### Graphs

**No grid feedback, static decision-making**

**Direct integration with AES framework**
Proposed Electric Vehicle-Grid Integration Framework

**Electric Vehicles**
- Optimized charge schedule
- Optimized charging cost
- Cost incentive for wait times
- Arrival and departure time
- Start and end SOC
- Energy requirement
- Vehicle parameters
- Connected charger details
- Desired charging cost
- Maximum allowable charging delay

**Grid**
- Optimized load profile
- Grid constraints
- Electricity price
- Additional load data

**AES Simulation Framework (Distribution Grid)**

**Buildings**
- Controllable loads
- Uncontrollable loads

**Renewables & Storage**
- Generation
- Storage values

**Electric Vehicle-Grid Integration Using Distributed Control**
- Optimized charge schedule for
  - Demand charge mitigation
  - Operating cost reduction
  - Charging stations integrated with building & renewables
- Quantify communication requirements
- Enable peer-to-peer transactions for price negotiation

**DER**
- Generation
- Storage values
Thanks! Questions?

This work was funded by the US Department of Energy Vehicle Technologies Office.
### Consensus Control: Performance Evaluation

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