Understanding and managing the impacts of PEVs on the electric grid

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The next ~30 minutes

- The PEV “problem”

- Cause & Effect
  - Adoption Heterogeneity
  - Infrastructure

- Charge Management
  - Problem with optimized approaches
  - The *Packetized Charging* approach
  - Results to date
  - Ongoing work
The PEV Problem (!?)

- Models/data indicate PEV charging can put 2x load on neighborhood infrastructure
  - Level 2 Charging: \( \sim 5-7 \text{ kW} @ 4-5 \text{ hrs} = \sim 25 \text{ kWh} \)
  - My house \( \sim 18.5 \text{ kWh/day} \)

- Premise: Existing neighborhood and substation power distribution infrastructure will not handle significant PEV adoption rates without charge management (CM)
Pinch Points

Substation
~1000 homes
1MVA

Transformer
~12 homes
25 kVA
Heterogeneity of Adoption

Examples:

- ½ of Teslas sold in CA (Bloomberg, 2014)
- ½ of EVs are sold in 5 cities: SF, LA, Seattle, NY, Atlanta (GreenCar Reports, 2013)
- Fremont, CA has 2x the EVs as the county average (CleanTechnica, 2014)
- Neighborhood effect

Adoption influenced by income, education, politics, geography and incentives
Infrastructure

Cables and Transformers

Excess Current → Exceeding Rated Operation Temps → Accelerated Aging → Or →
How does rainfall influence the aging of buried cables?
Modeling Heating in Transformers

- Annex G is the IEEE standard (albeit complicated and intended for distribution transformers)
- A 25 kVA service transformer is a simple device
- GA uses real data to develop a simpler and customized model

\[ T_{HS}^* \approx f(L, T_D) = 0.178 + 0.000939L^2 - 0.0149T_D \]
Load Data
Model Fits

\[ T_{HS} \approx f(L, T_D) = 0.178 + 0.000939L^2 - 0.0149T_D \]
Why Charge Management?

Reduces stress on existing infrastructure.
Centralized & Optimized CM Approaches

- Utility collects data pertaining to all PEV customers’ needs
  - State of Charge (SOC)
  - Amount of charge needed
  - Expected arrival/departure times

- Using this data, an optimized charging schedule (vs. time or power) is developed for each PEV
  - Ensures ‘fairness’
  - Ensures resources are used most efficiently/safely
Issues as we see them

Provider side:
- Utilities may not want to deal with lots of data in real time
- Need approaches that prevents overload throughout system – distributed control

Customer side:
- User behavior is dynamic; advance scheduling may not work
- Users want simplicity
- Users want privacy
- What is ‘fair’?
Packetized Charging

- Treat EV charging as we do data – i.e., as discrete packets in a “net neutral” environment
- EV’s objective is then to receive the requisite number of packets to complete a charge – charging need not be continuous
Packetized Charge Management

- The distribution system can only provide a fixed number of power packets during each epoch.
- Task is to manage the demand in an egalitarian manner; i.e., fairness as a metric.
Limit

Load

# of PEVs charging

PEV ID

time (hrs)
Inspiration for Packetization

- Problem is analogous to that found in data communications – leverage those methods
- Problem is also analogous to other distributed participation control methods – leverage those too
What can we assume?

- Power distribution capacity will vary day to day
- PEV charging requirements will vary day to day and user to user
- PEV plug in/plug out times will vary day to day and user to user

PEV CM problem
- random supply *and* random demand
- robust (and simple) and fair CM techniques are needed that maintain anonymity
Random Demand Analogy

Problem: How does one share a single resource when the demand is distributed and random?

Objective: Want the overhead to be low.

Analogy: Medium Access Control (MAC) in random access, packet communication channels

- Examples: ALOHA, slotted-ALOHA, CSMA
Random Supply Analogy

Problem: Desire to control the number of active participants in a distributed random network

Objectives: Fairness and little communications

Analogy: Quality of Service (QoS) Control in wireless sensor networks using a distributed, automaton-based approach
Automaton-based design

- EV requests a charge during any particular epoch with probability $P_k$
  - $P_1 > P_2 > P_3$
- Successful requests moves EV to a higher automaton state
- Failed requests moves EV to a lower automaton state
- Controller accepts/denies requests blind to the identity of the requesting EV – privacy maintained
Let’s test with an experiment

- Can the packetized approach keep loads below limits?
- How much would one day of travel cost under packetized charging, relative to an “ideal” optimization scenario in which the operator has perfect information about travel patterns?
- Compare also to a very simple first-come-first served charging scenario

(Razaei, TSG 2014)
Assumptions

- 320 GM-Volt-like PHEVs
- 320 homes (i.e., 50% penetration).
- Level-2 charging
- Travel patterns from US survey data.
- 500 kVA load limit
- Customers are charged on a time-of-use (peak: $0.14/kWh / off-peak: $0.10/kWh) rate
- Use gasoline if batteries run low.
- Three methods: FCFS, Optimal, Packetized
Costs

Travel costs are similar, despite the unrealistic information requirements for optimal approach.
Green – Charging
Red – Charge mitigated
Blue – Charge not needed

Note: Higher ID cars are not getting full charge
All EVs charge when plugged in but at variable rates (0-6)
Again:
Green – Charging
Red – Charging mitigated

Note: Charging is randomly distributed across EVs
All Methods Work

But….

- Optimized case assumes all EV data is known in advance so that a fair and efficient charging schedule can be developed.
- The simple first-come, first-served (FCFS) approach requires no advanced data but results in customers not being treated fairly – LCLS!
- Packetized CM approaches the fairness and efficiency found in optimized schemes and has the simplicity and adaptability of FCFS.
Implementation

- Unidirectional and Localized
- Bidirectional and Aggregated
Uni-directional Implementation

- Listen only
- A EV will randomly listen to a broadcasted signal to ascertain whether they can take a ‘packet’
- Broadcast could be from the local service transformer and/or substation
- No data / requests are sent by EV
- Broadcast can be from multiple points
Bi-directional Implementation

Request to Charge / Clear to Charge

- A EV will randomly send a request to a local aggregator to ascertain whether a ‘packet’ can be supported

- Aggregator would have working knowledge of service transformer and substation loads and overall system capacity to support charge

- Similar to anonymous RTS/CTS* from wireless communications. No data is transferred.

*RTS/CTS – request to send / clear to send
Caveats

- Packetized charging does not guarantee everyone will receive the full charge desired.
- Users will need incentives to play fairly in this scheme based on chance (green zone) of service.
- Users with urgent needs should have the option to bypass approach if they are willing to pay the full rate (red zone).
- EV chargers could be equipped with an urgency dial that indicates the price/kWh for a given guarantee of service.
Ongoing Work

- Results to date are based on simulations
- Hoping to implement a pilot implementation in partnership with a start up and VT concerns
- Formalizing the analysis of the approach and considering other automaton actions
- Understanding consumer reaction to charge management and developing appropriate incentives
Questions & Feedback