

# *Understanding and managing the impacts of PEVs on the electric grid*

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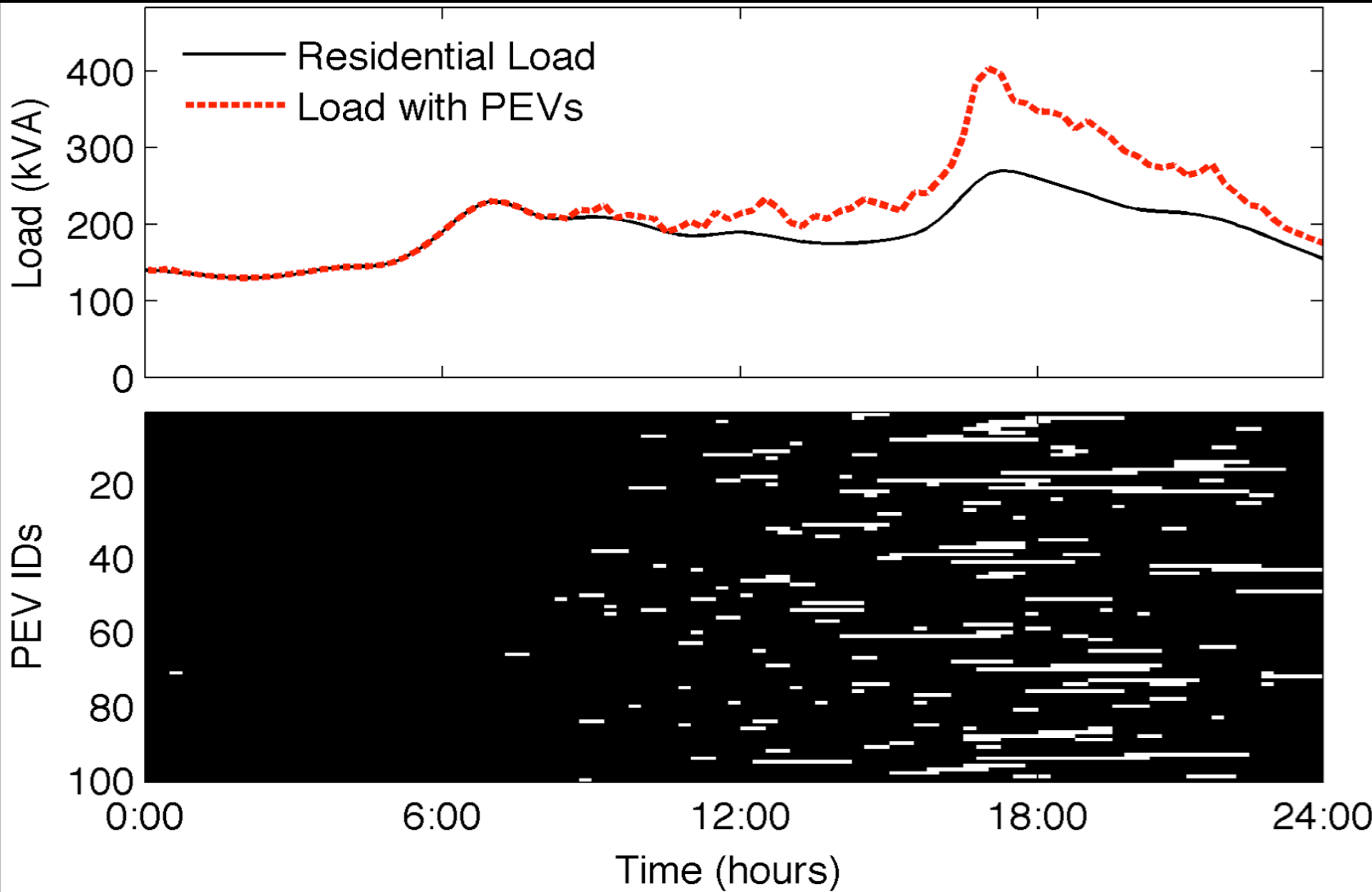
# The next ~30 minutes

- The PEV “problem”
- Cause & Effect
  - Adoption Heterogeneity
  - Infrastructure
- Charge Management
  - Problem with optimized approaches
  - The *Packetized Charging* approach
  - Results to date
  - Ongoing work

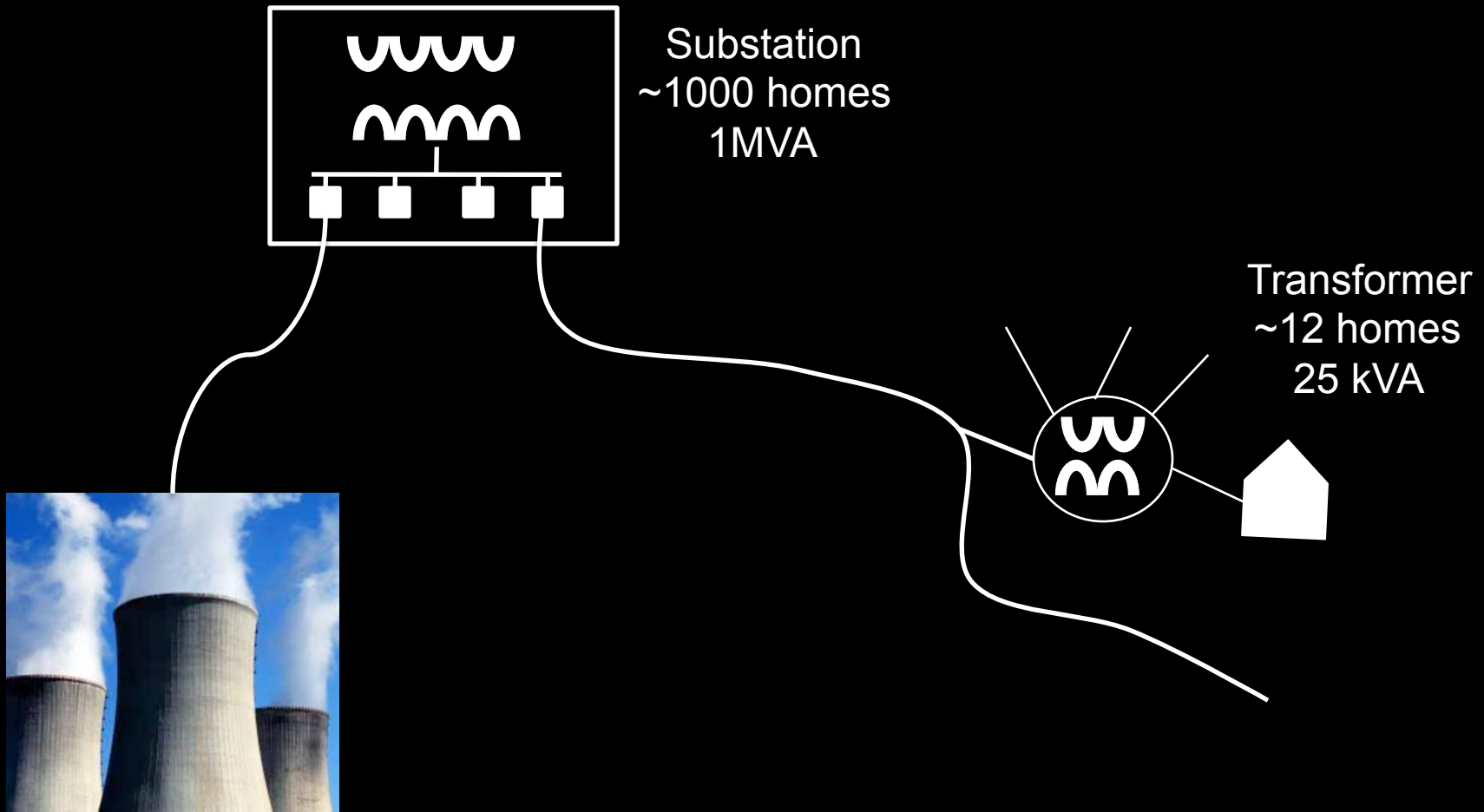
# The PEV Problem (!?)

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



# Heterogeneity of Adoption

## Examples:

- 1/2 of Teslas sold in CA (Bloomberg, 2014)
- 1/2 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 →

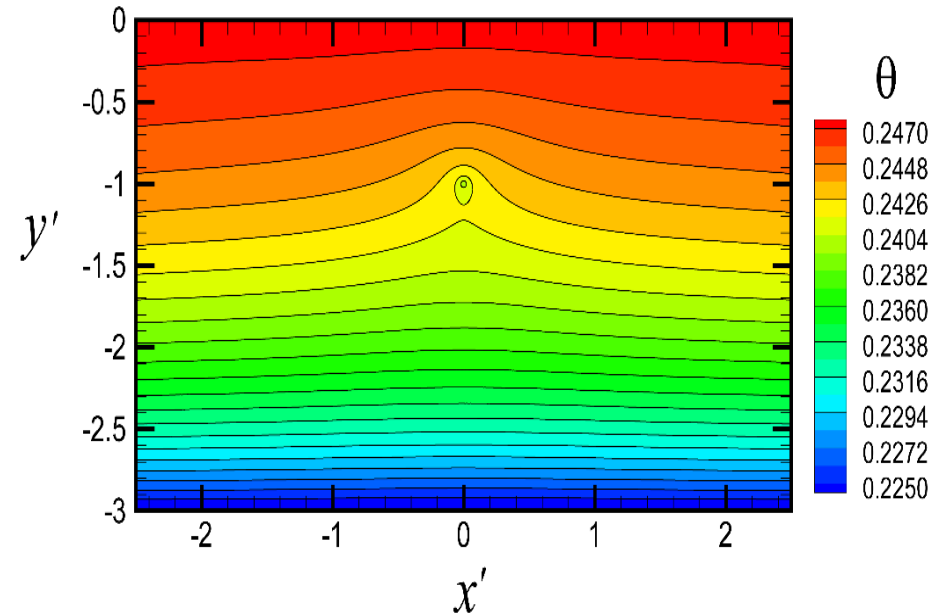
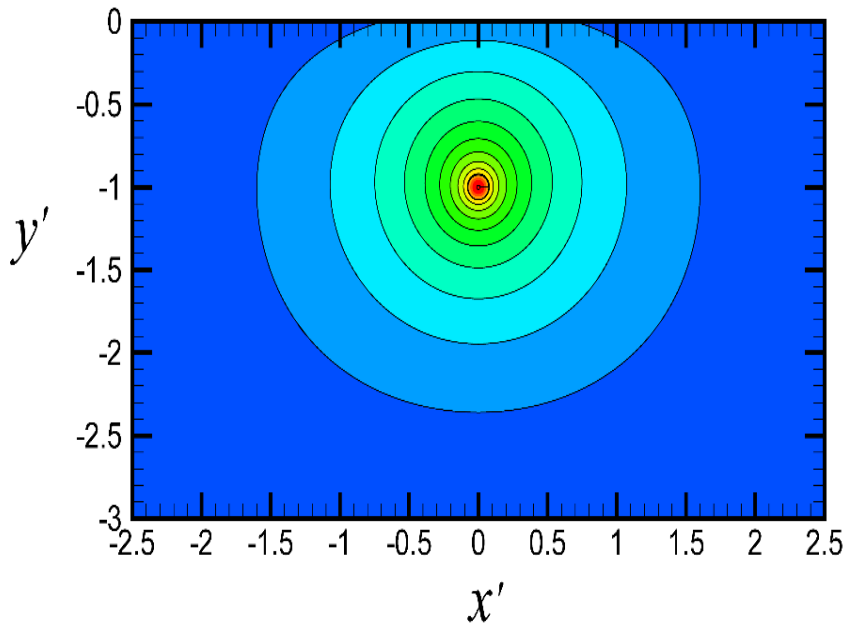
Accelerated Aging →

Or →





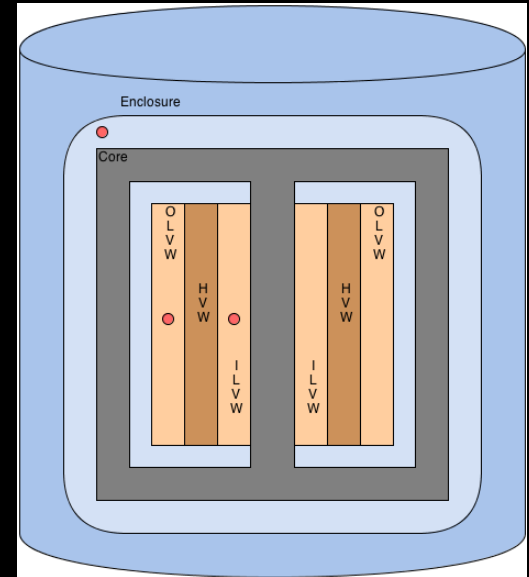
# Cable Aging



How does rainfall influence the aging of buried cables?

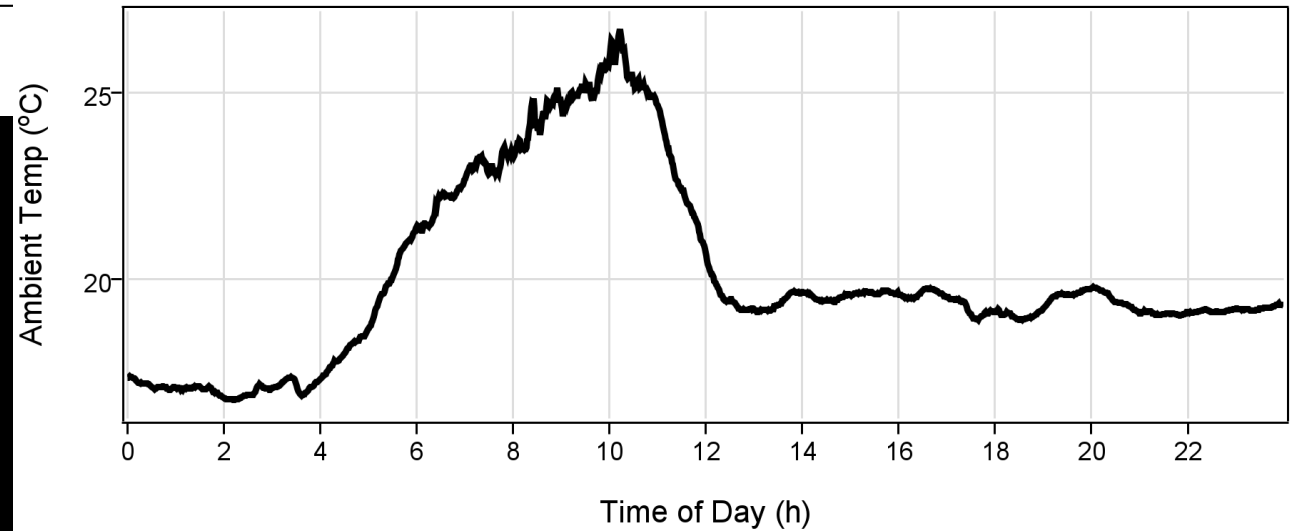
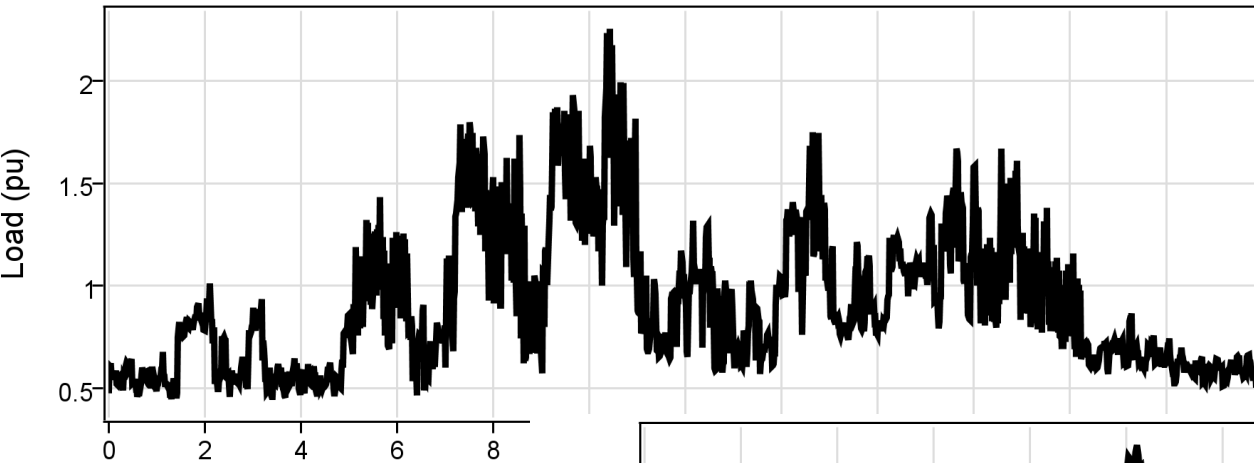
# Modeling Heating in Transformers

- 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

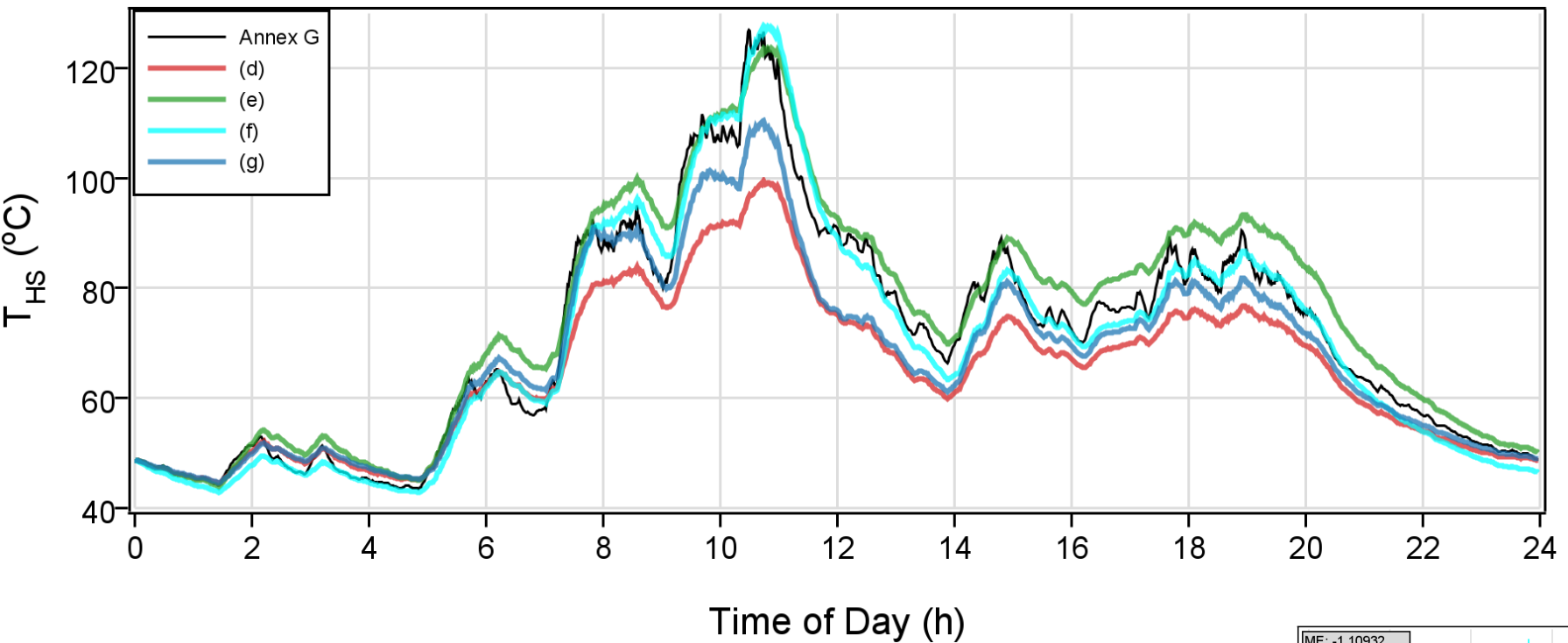


$$T_{HS} \approx f(L, T_D) = 0.178 + 0.000939L^2 - 0.0149T_D$$

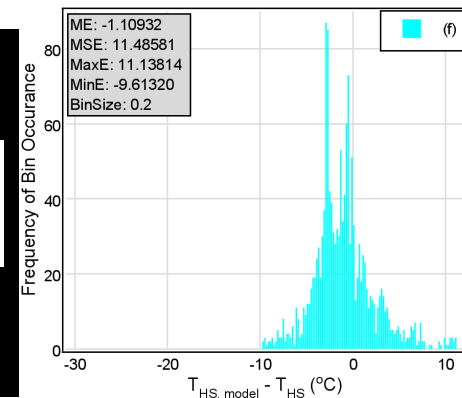
# Load Data

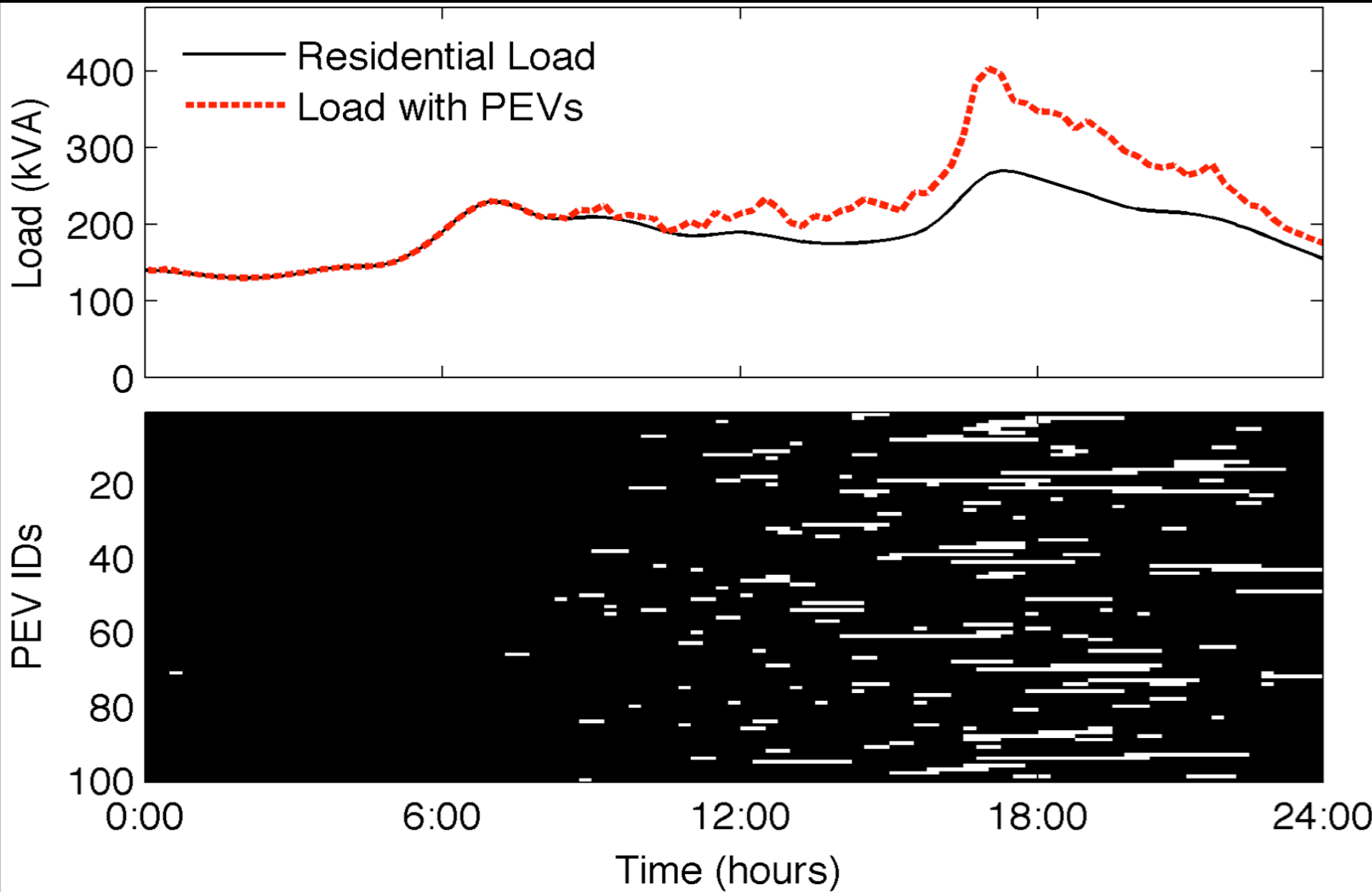


# Model Fits

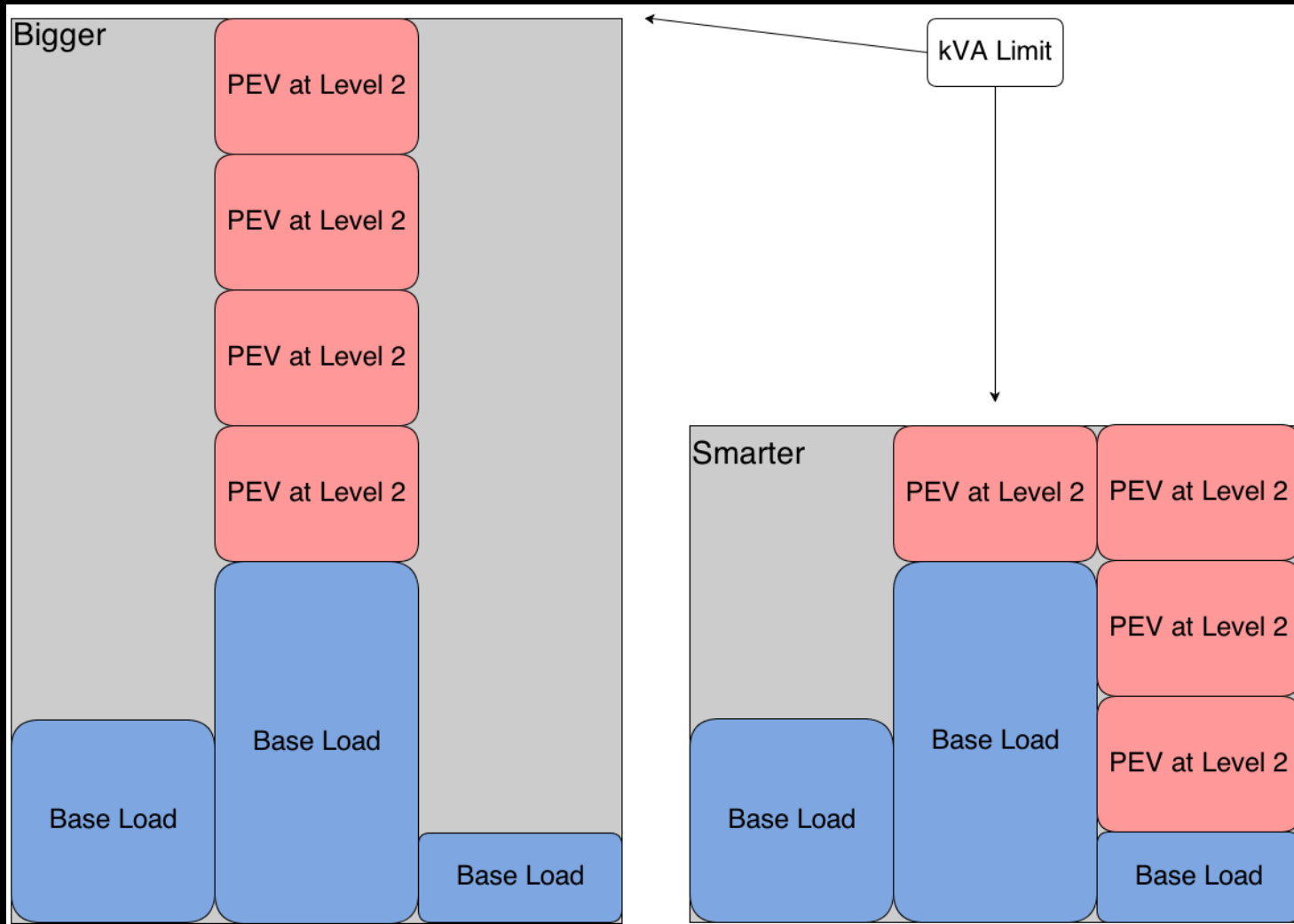


$$\dot{T}_{HS} \approx f(L, T_D) = 0.178 + 0.000939L^2 - 0.0149T_D$$





# 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'?



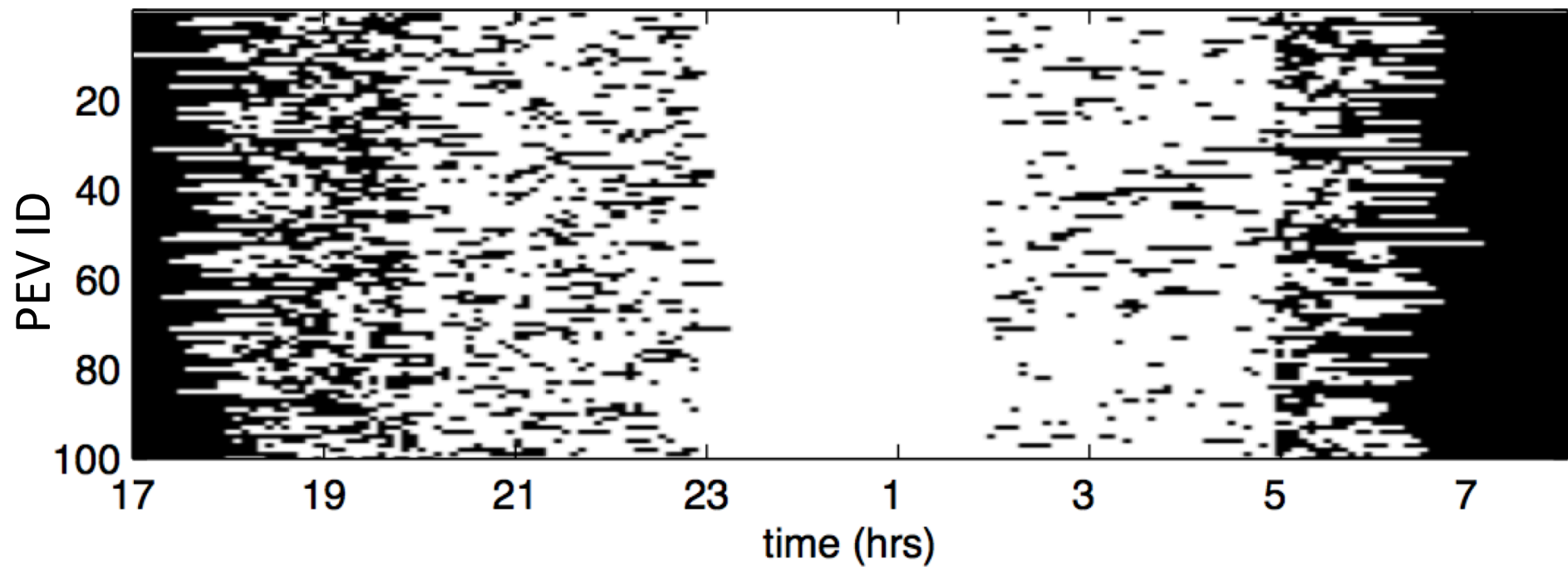


# Packetized Charging

- 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



# 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

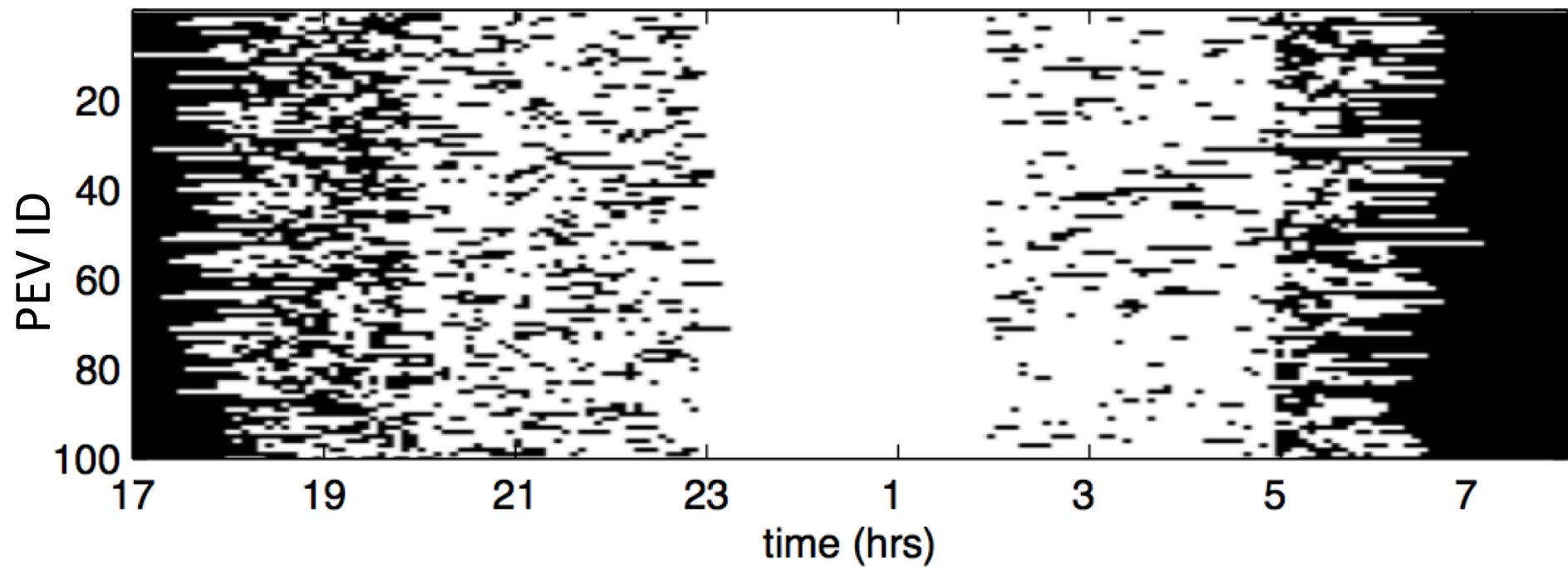
# Random Demand Analogy

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

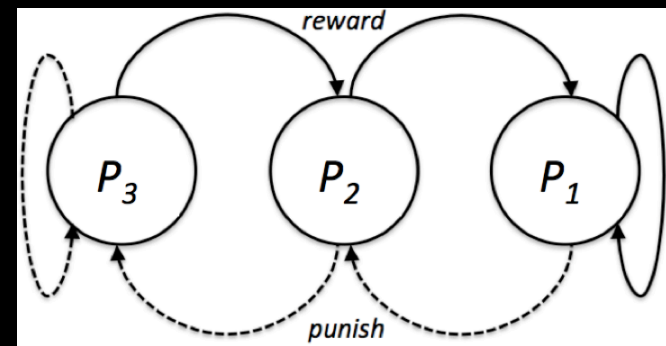
Problem: Desire to control the number of active participants in a distributed random network

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

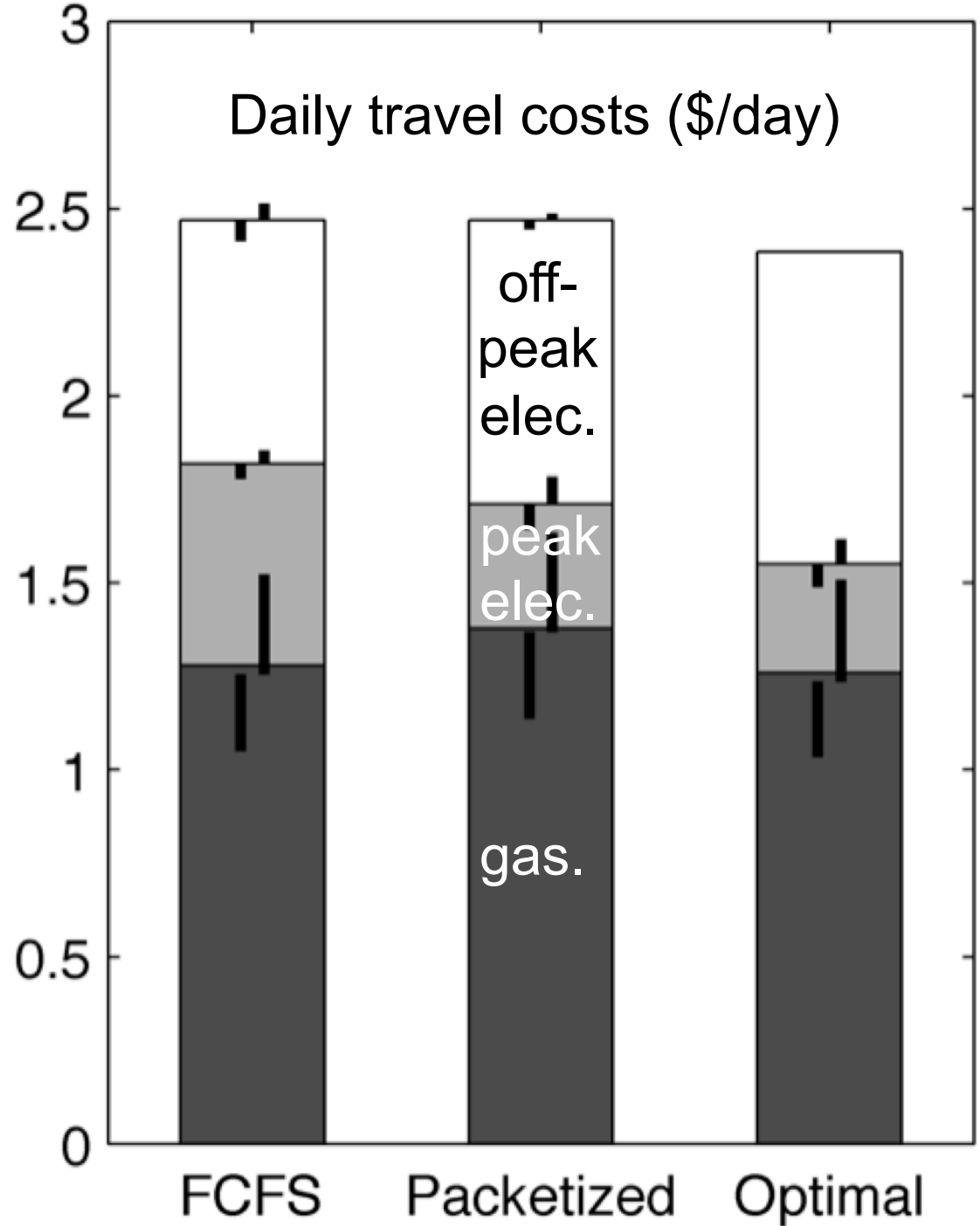
(Razaei, TSG 2014)

# 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.

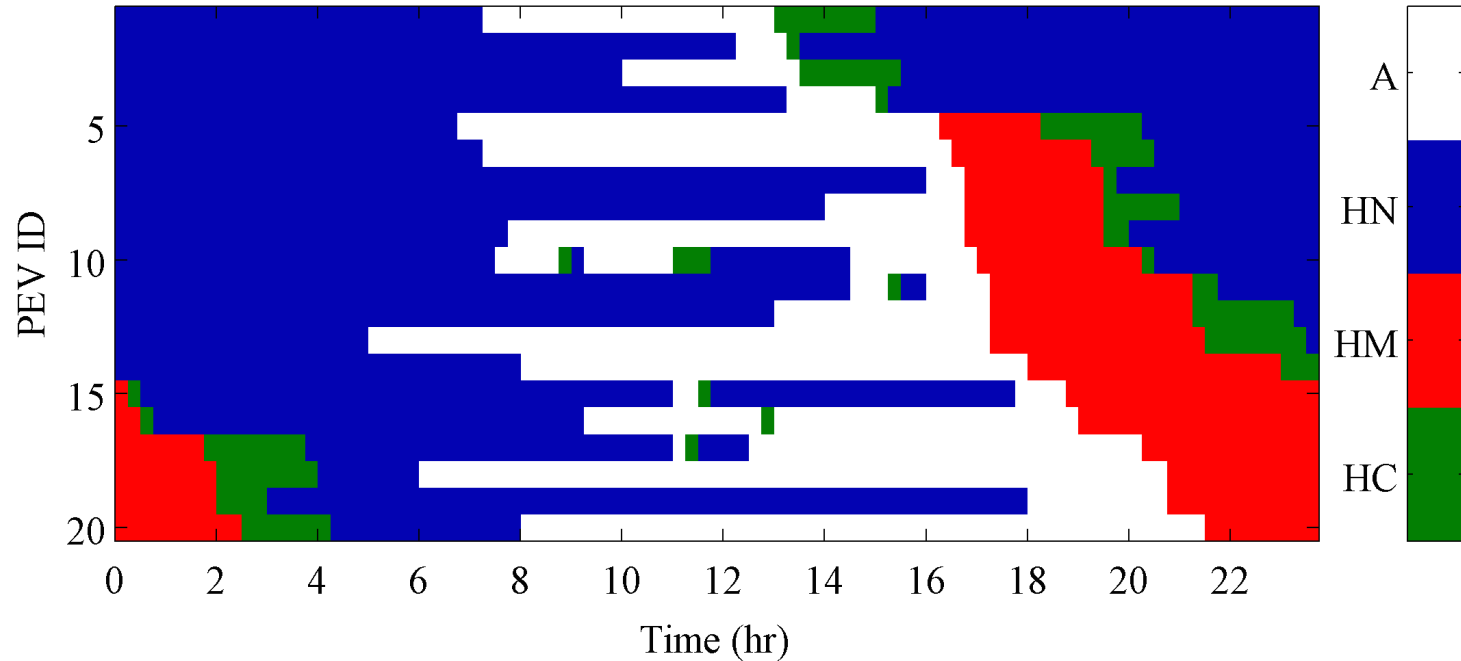
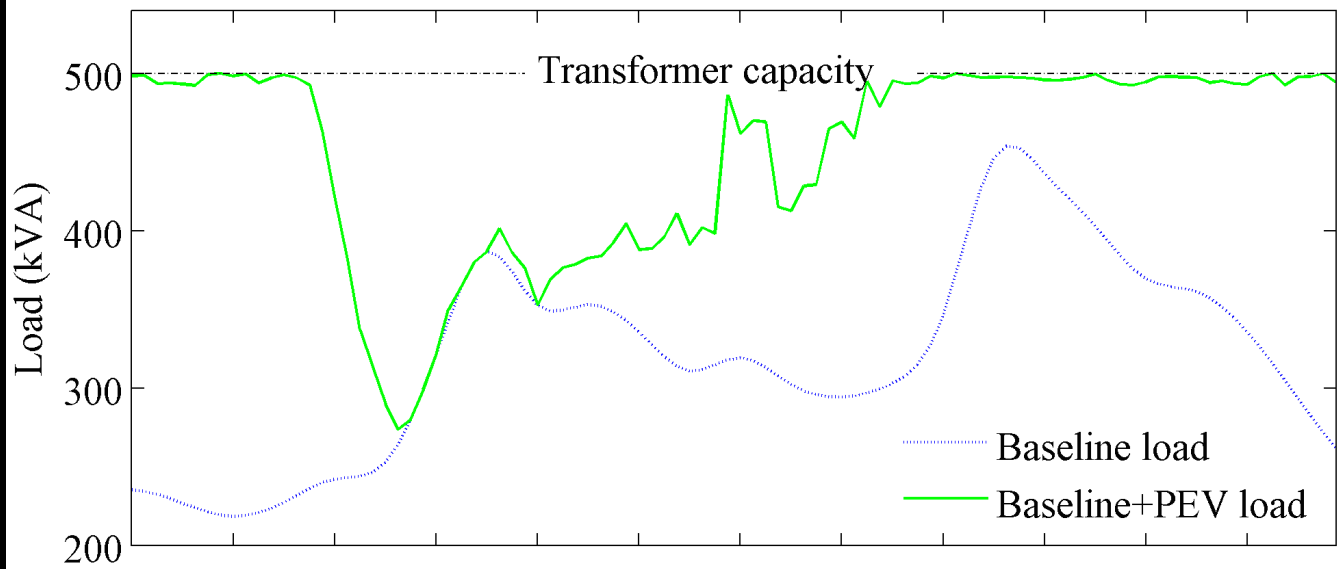


# FCFS

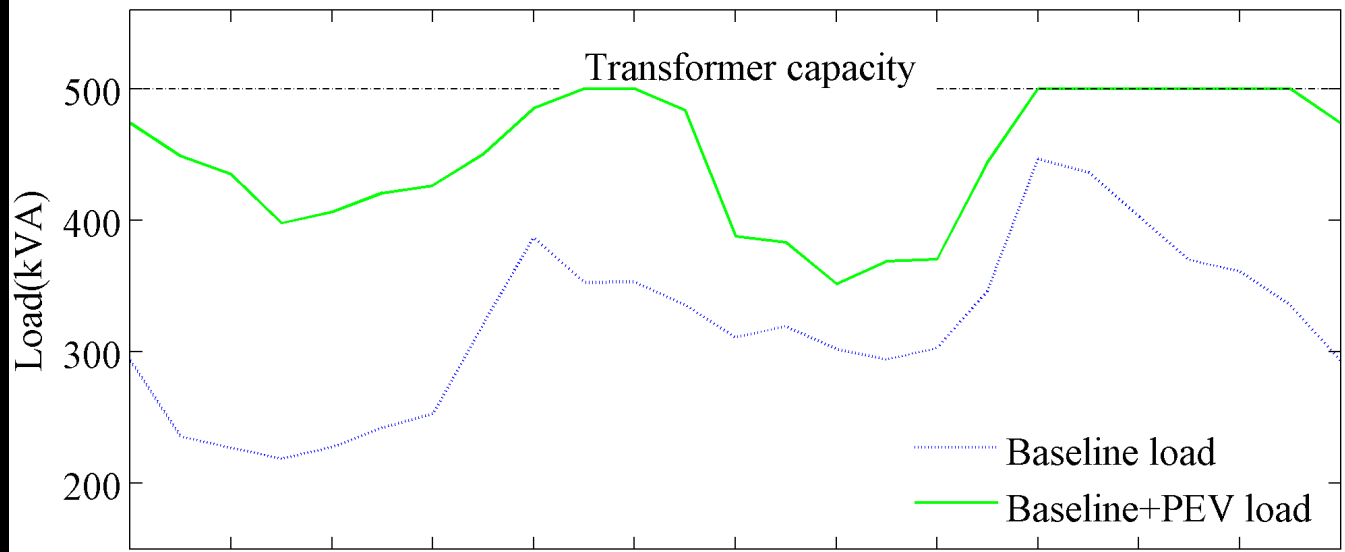
Charging pattern for 20 of the 320 EVs

Green – Charging  
Red – Charge mitigated  
Blue – Charge not needed

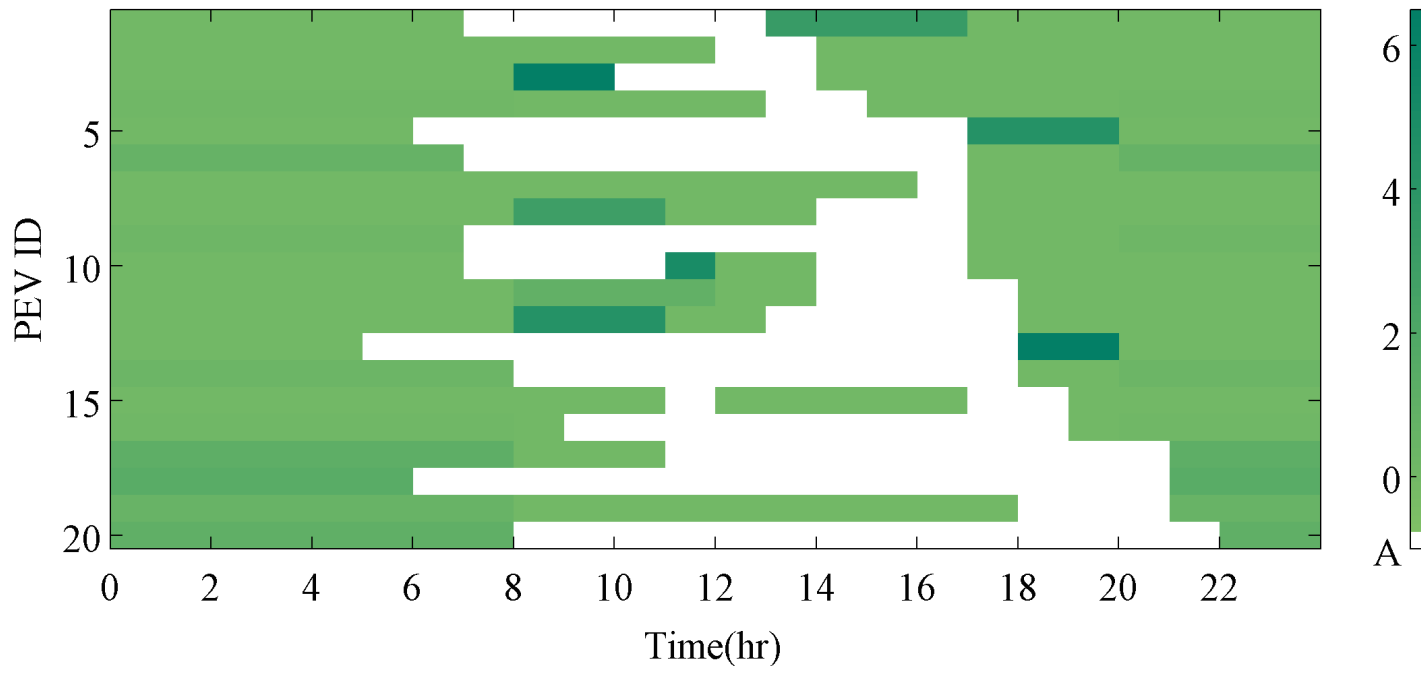
Note: Higher ID cars are not getting full charge



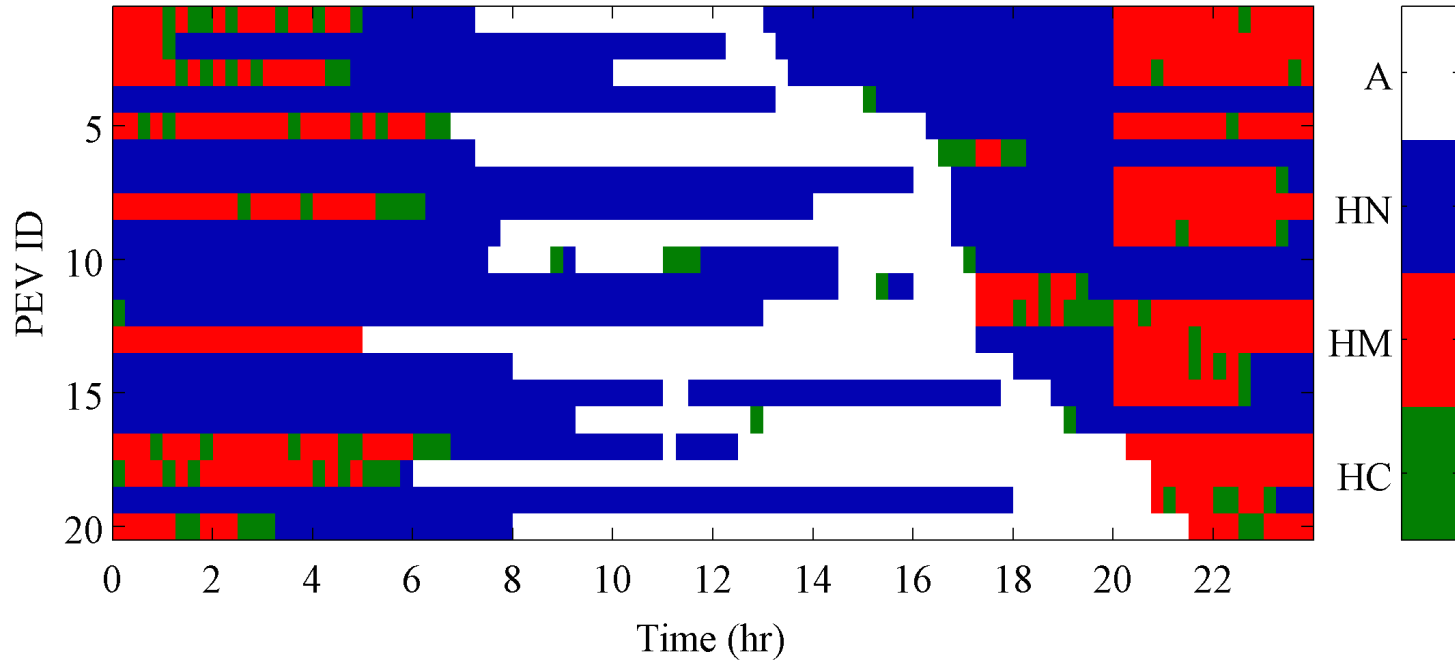
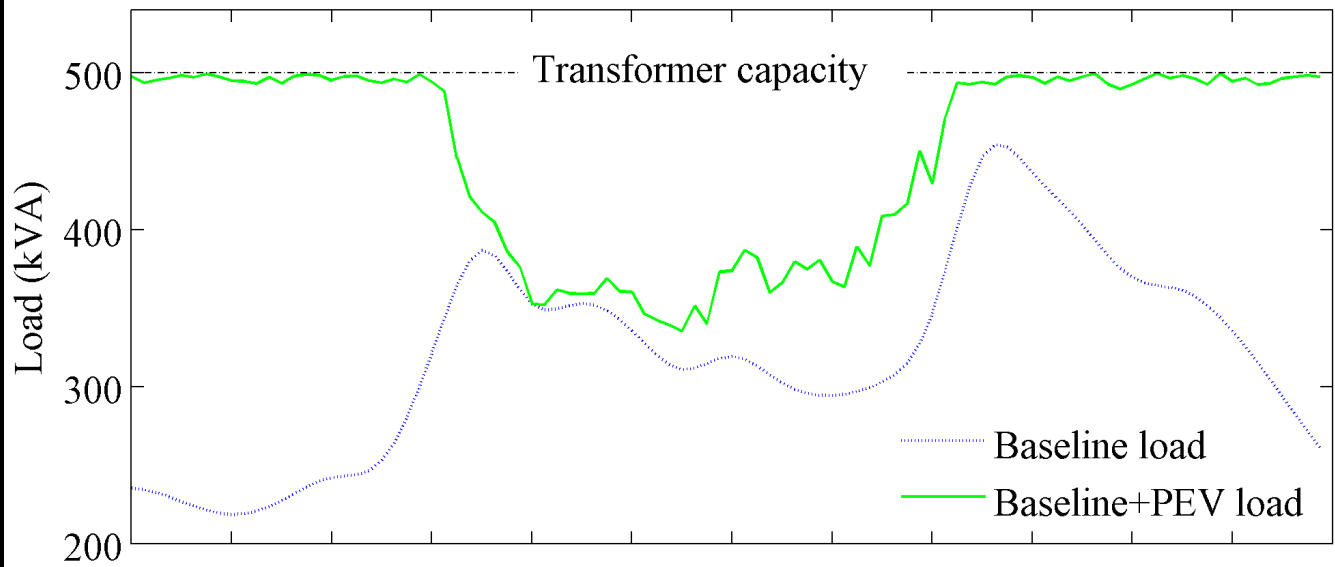
# Optimized



All EVs charge when plugged in but at variable rates (0-6)



# Packetized



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