Grid Impacts of PEV Charging Infrastructure

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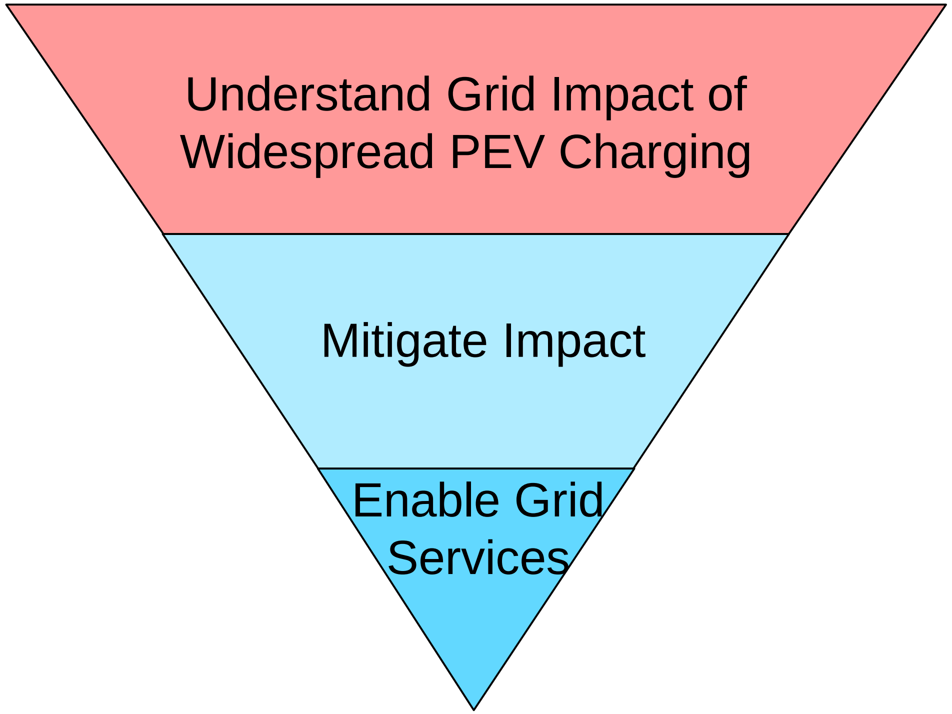
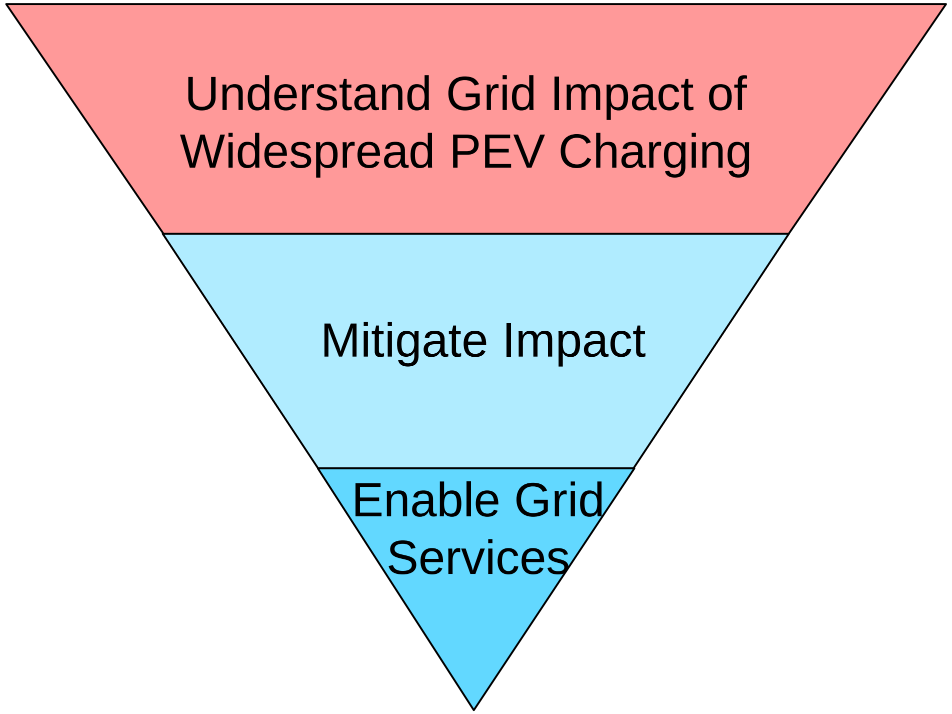
Why Vehicle/Grid Integration is Needed?



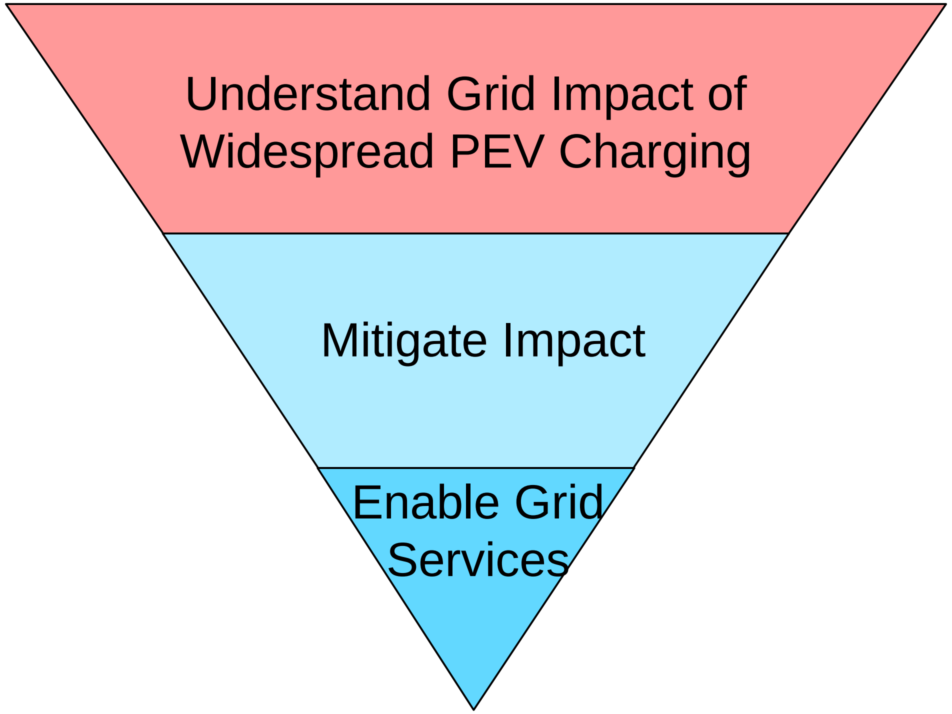
- Under what circumstances will PEV charging begin to cause grid problems?
  - PEV Penetration Level
  - Charge Rate
- What are the grid problems and cyber security risks?
- What is the best way to mitigate these grid problems?
- Can PEVs provide grid services?

Vehicle/Grid Integration of Level 2 Charging



- Understand impact of *uncontrolled* Level 2 charging on the distribution feeder as PEV penetration increases
- Develop an aggregator control strategy to mitigate negative impacts
- Understand the cyber security risks associated with the control strategy
- Leverage control strategy to provide grid services

Vehicle/Grid Integration of Extreme Fast Charging (XFC)

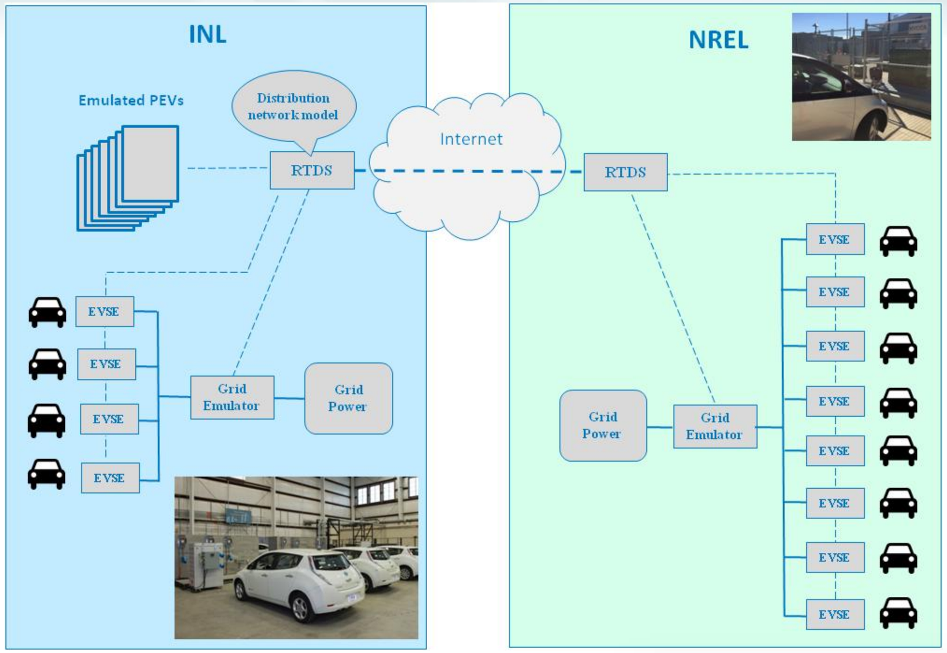


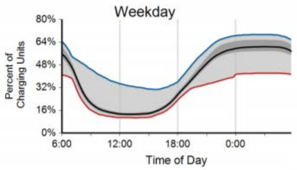
- Understand impact of XFC on the grid as PEV penetration and charge rates increase
- Investigate ways to mitigate XFC grid impacts:
    - On-site energy storage
    - Infrastructure upgrades
    - Controlling XFC
- Understand the cyber security risks associated with XFC
- Explore potential for XFC to provide grid services

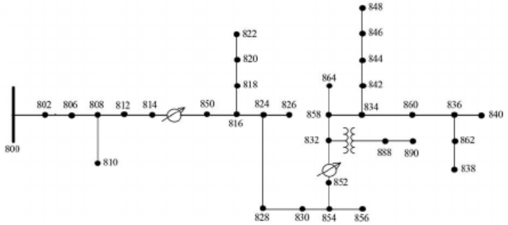
Grid Impacts of Level 2 Charging

Platform

- Key Elements
  - High fidelity distribution system model
    - IEEE 34-node distribution feeder.
  - High fidelity charging models for production PEVs.
  - PEV charging control strategy capable of control the charging of millions of PEVs.
- Key Capabilities
  - Investigate the impact of 100’s of thousands of PEVs charging on a distribution feeder or sub-transmison system.
  - Investigate benefits of controlling charging.
  - Investigate grid problems a hacker can cause if they are able to control the charging of PEVs (in parallel with GM0163).



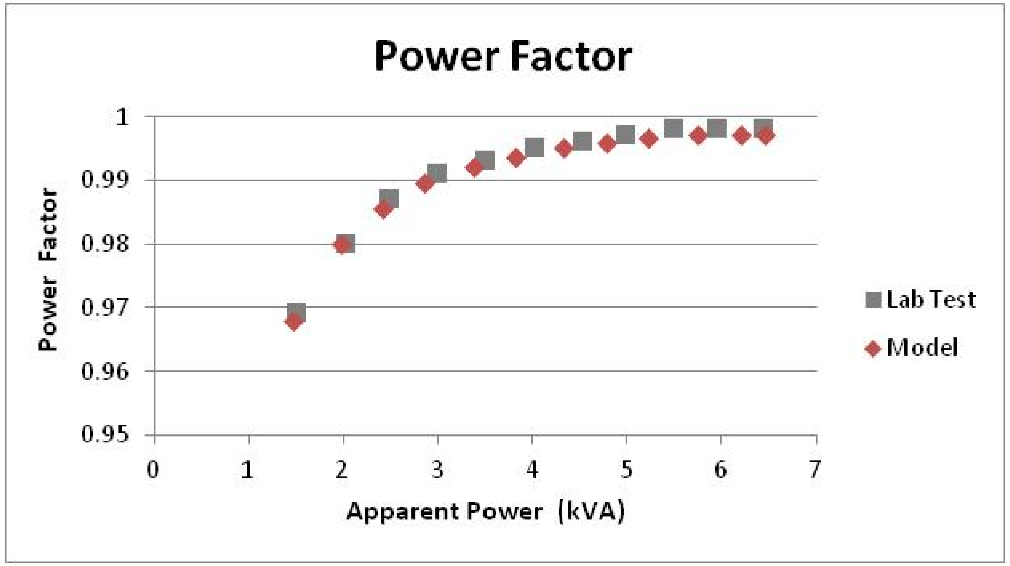


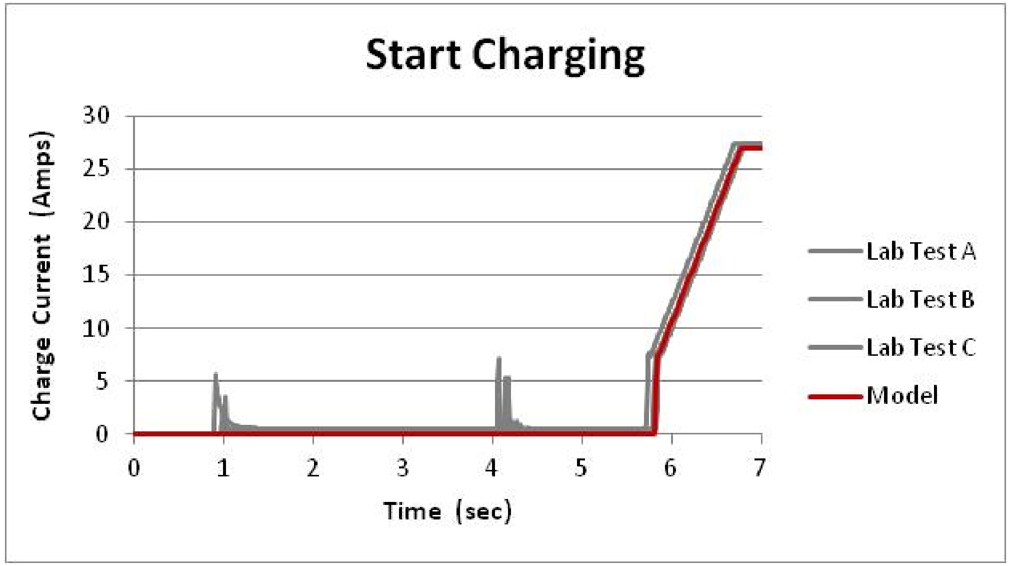


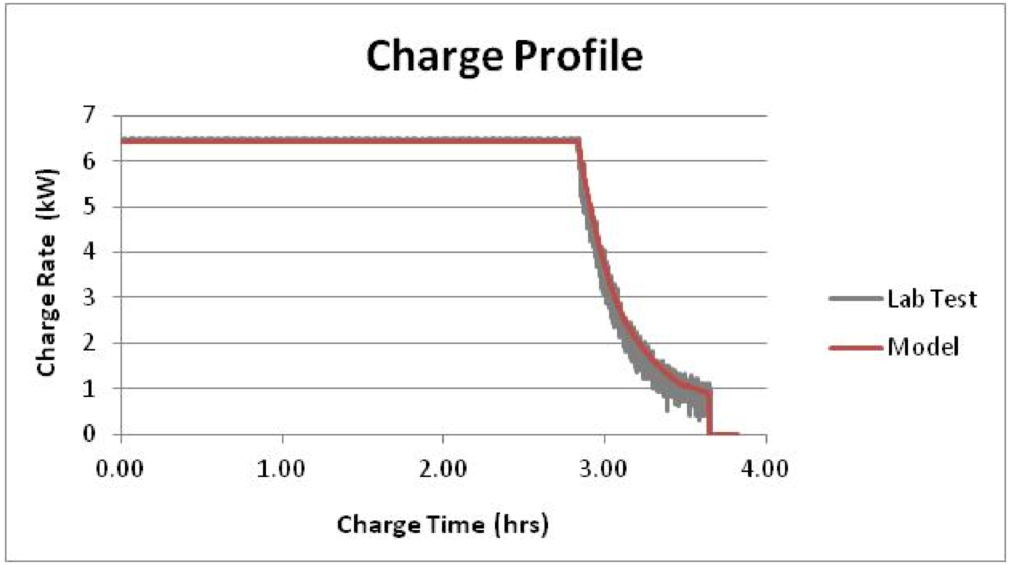
High Fidelity Level 2 Charging Models

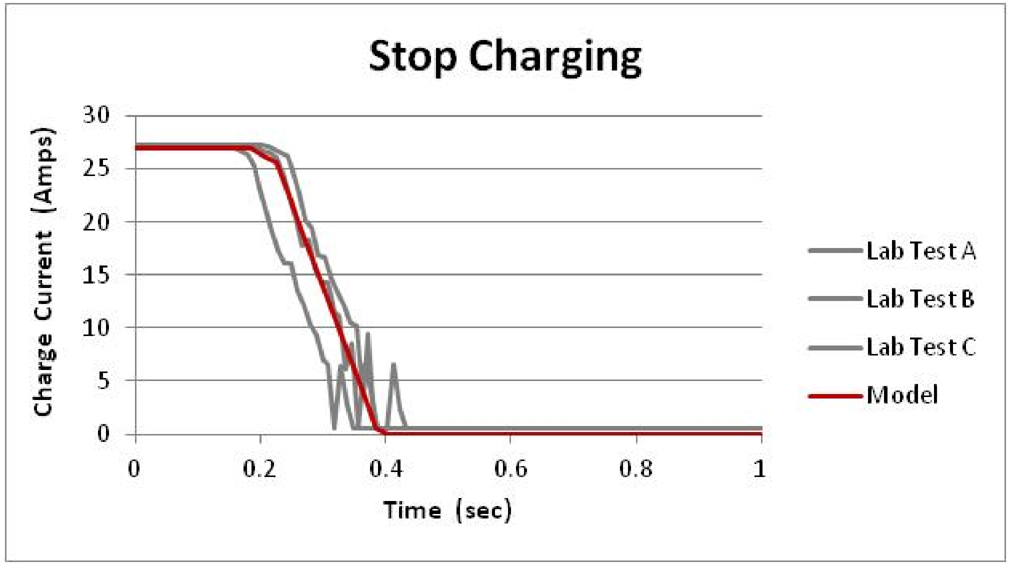
- Characterized the behavior of production PEVs as loads on the grid.
- Used this data to create high fidelity charging models for the: 2015 Leaf, 2016 Volt, 2013 Fusion.
- These charging models accurately captures how
  - Power factor changes with charge rate
  - Efficiency changes with charge rate
  - Max charge rate changes with battery SOC
  - The charging transitions from one charge rate to another charge rate
  - The charger power and current limits change with voltage

2015 Leaf Model Comparison with Lab Tests



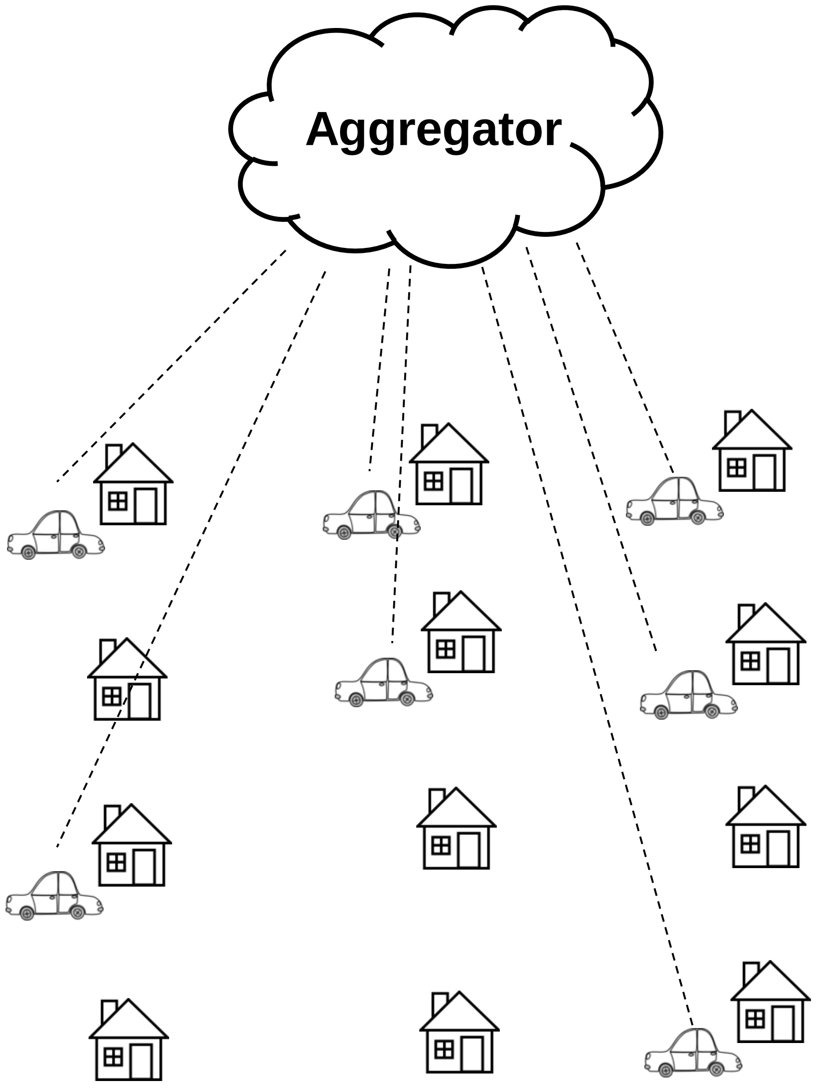






Level 2 Control Strategy Overview

- Control strategy was designed to be able to control the charging of millions of PEVs with minimal computational resources.
- Charging control strategy only controls the charging PEVs, not buildings.
- Uses a two-step optimization
  – The first step optimizes the total PEV charging energy for the next 15 minutes.
  – The second step allocates the charging total charging energy to the PEVs based on charging need.
- Benefits of two-step optimization
  – Size of optimization problem is independent of the number of PEVs
  – Is relatively small optimization problem
    - Inexpensive scalable solution
    - Help remove barriers to controlled PEV charging



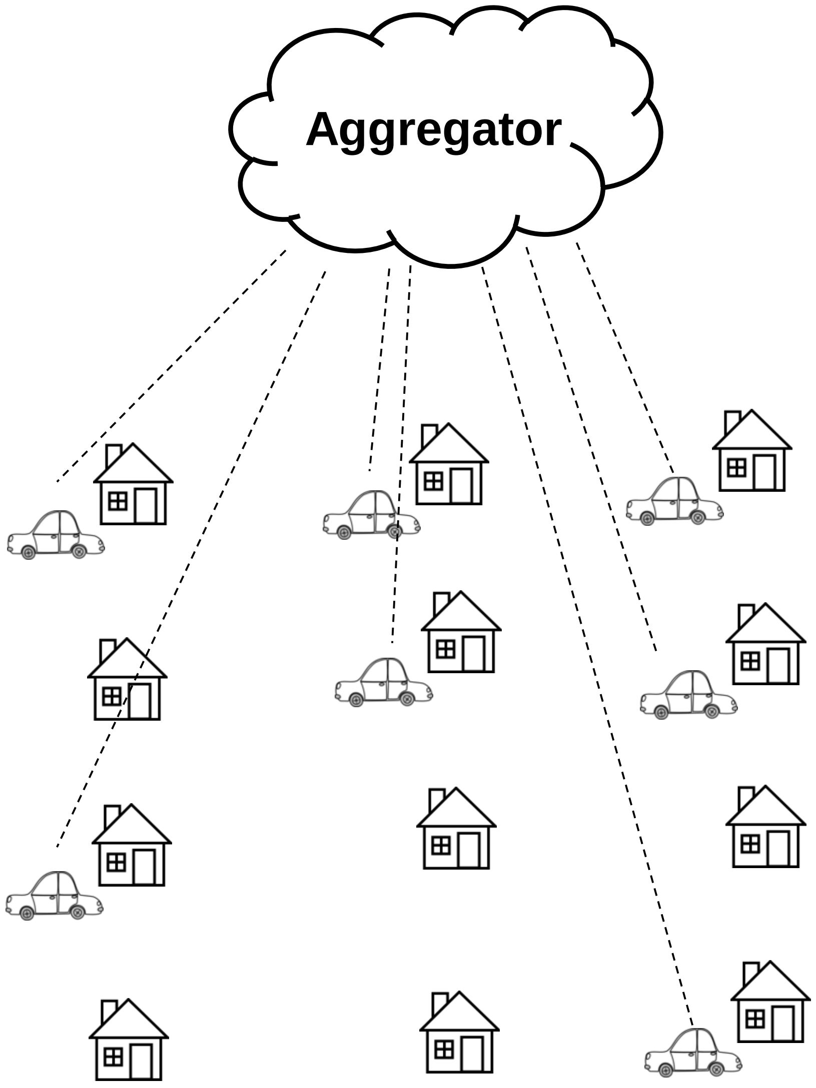
Fundamental Components of Level 2 Control Strategy

The Aggregator

- One Aggregator for entire distribution feeder
- Concerned with optimizing energy allocation during the day
  - Time step between 5 and 15 minutes
- Decides how much energy each PEV should draw during each time step to ensue:
  - User charging needs are met
  - Grid objectives are met (e.g. flatten duck curve, reduce peak)

The Front End Controller (FEC)

- One FEC per vehicle/EVSE
- Decides how to allocate energy over each time step in order to
  - Maximize charger efficiency
  - Maximize charger power quality
  - Provide grid services that require fast response (e.g. voltage support, frequency regulation)



Benefits of Level 2 Control Strategy

- The strategy has the following benefits:
  1. Ensures maximum charging efficiency and power quality
  2. Scalable to millions of PEVs
  3. Computationally efficient – a single PC can perform the calculations
  4. Ensure PEVs charging needs are met
  5. Not sensitive to internet latency – does not require fast communication between the PEVs and aggregator

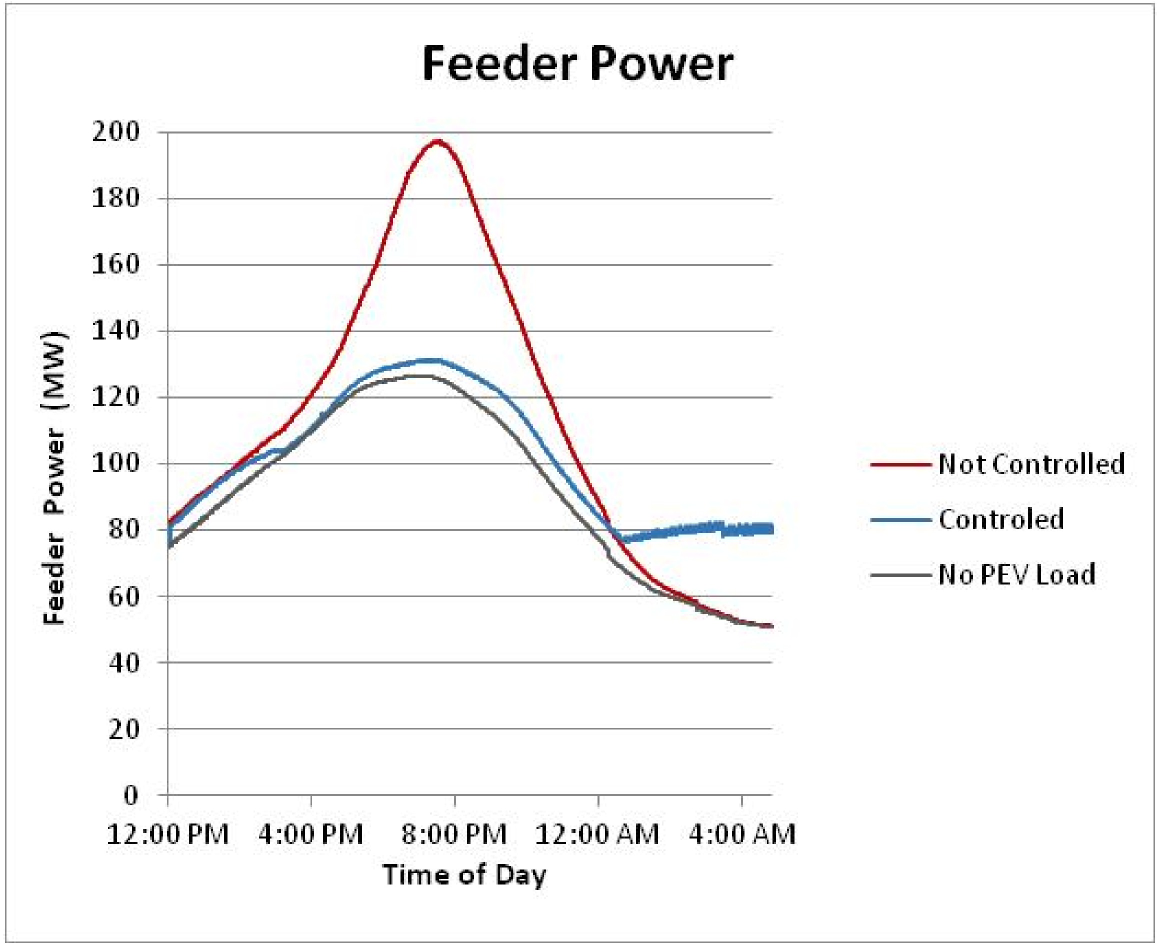
- Example of Aggregator Performance:
  - Optimal solution consistently found for 1,000,000 PEVs in 8 seconds on a desktop computer that is 7 years old.

Scenario Description

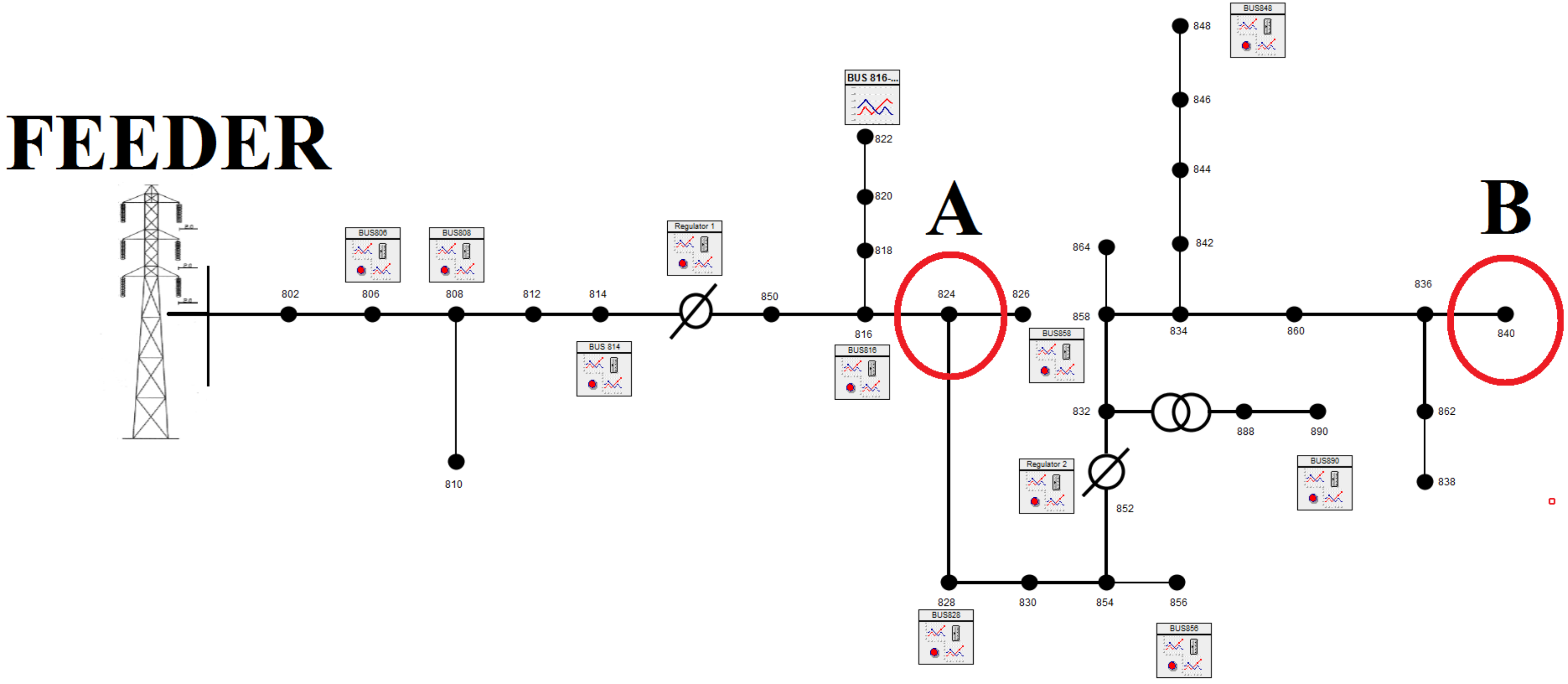
- System Composition
  - IEEE 34 node test feeder
  - 75,000 residential homes
  - 50% of the homes own a PEV (37,500 homes with a PEV)
  - 30,618 residential PEV charges during the day on the feeder
- PEV charging model
  - 2015 Nissan Leaf charging model
- PEV charging behavior data
  - aka. park start time, park end time, charge start time, charge energy, …
  - Derived from actual charging data of PEV owners in the PG&E service territory
    - Data collected during the EV Project
- Non PEV Load data
  - Used the typical residential PG&E load data for 2016
    - Downloaded from PG&E website
    - Selected the day with the highest peak load

Feeder Power

- Feeder Peak
  - No PEV charging = 127 MW
  - Controlled PEV charging = 132 MW
  - Uncontrolled PEV charging = 197 MW
- Uncontrolled Charging
  - Aligns the PEV peak with the non PEV peak load.
  - Increases the ramping and variation in load shape.
- Controlled Charging
  - Shifts PEV charging to the middle of the night during off peak hours.
  - Flattens the load shape.
    - Makes voltage support easier.
    - Requires less feeder capacity to serve load.

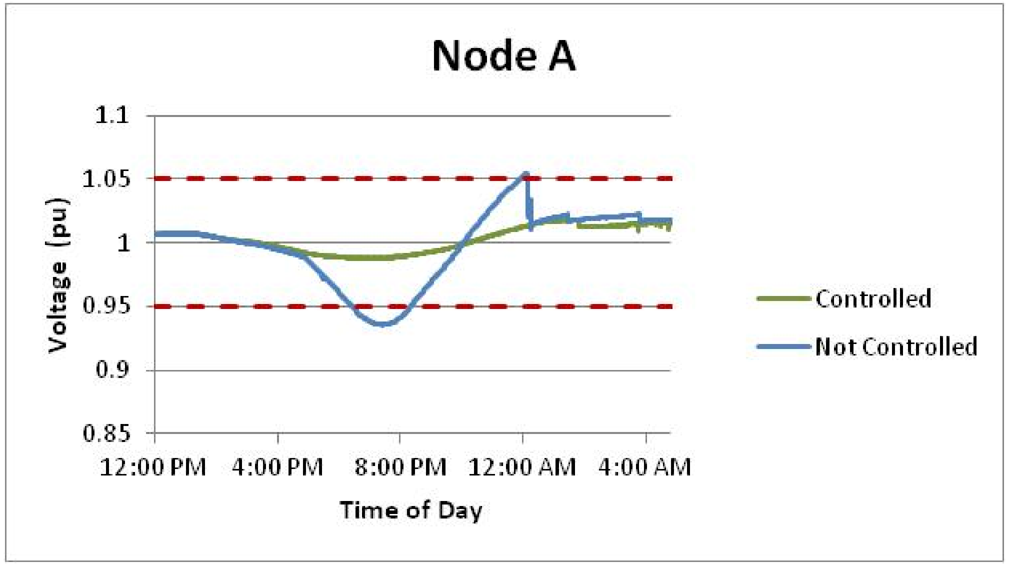


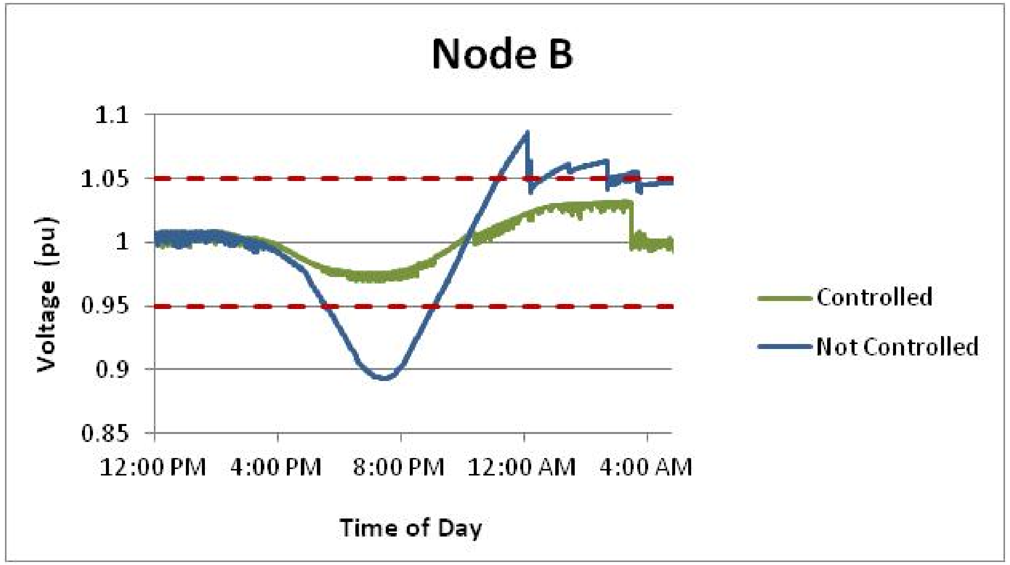
IEEE 34 Node Distribution Grid



Feeder Voltage

- Node A has less variation in voltage than Node B
  - Node A is closer to the feeder substation than Node B.
- Voltage profile is flatter when the PEV charging is controlled.
- The voltage is always within 5% of nominal voltage when the PEV charging is controlled.
- The voltage is not always within 5% of nominal voltage when the PEV charring is not controlled.
- Controlling the charging of PEVs on residential feeders helps to support feeder voltage.





Grid Impacts of 50 kW DC Fast Charging

Problem Statement

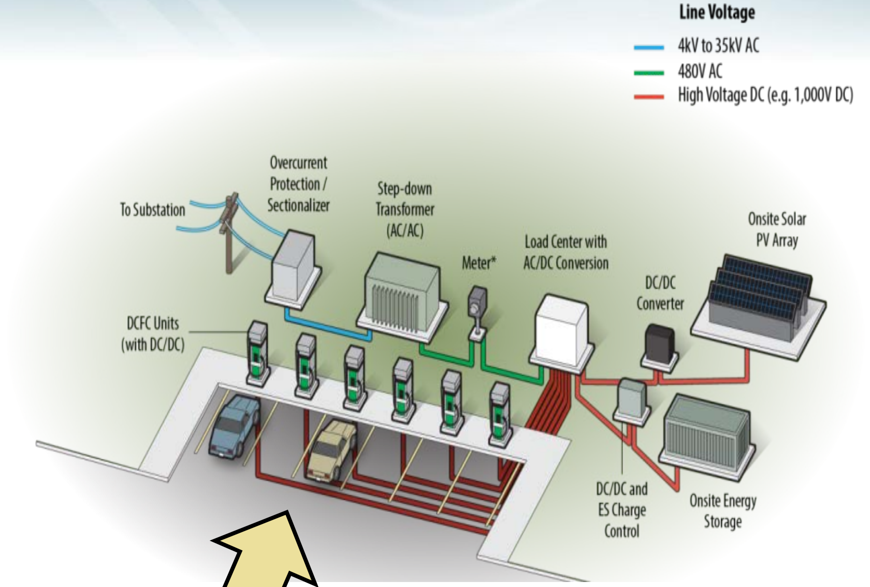
- DCFC (50kW) and XFC (350+kW) loads are intermittent, with high peaks and short duration, and are unlike other loads on the grid
- Prolific fast charging has the potential to create capacity and stability issues on local distribution networks and sub-transmission grids

Objective: Understand and mitigate these issues and identifying tipping points in DCFC and XFC penetration levels where issues arise

High-fidelity XFC characterization

In EVIL and RTPEL labs:

1. Proof-of-concept conducted using data-driven model of 50-kW DCFC
2. Capture characterization data from XFC units from partners (JRC prototype XFC data; manufacturers)
   – Charging behavior at various power levels (350kW, 150kW, 50kW)
3. Develop XFC models and implement in DRTS
4. Procure XFC unit(s) for HIL model validation



2,000+ kW

HIL emulation allows rapid evaluation of multiple parameters:

- Use cases (e.g. rural corridor charging; urban charging for MUD residents or shared mobility services)
- PEV penetration
- With / without onsite ESS

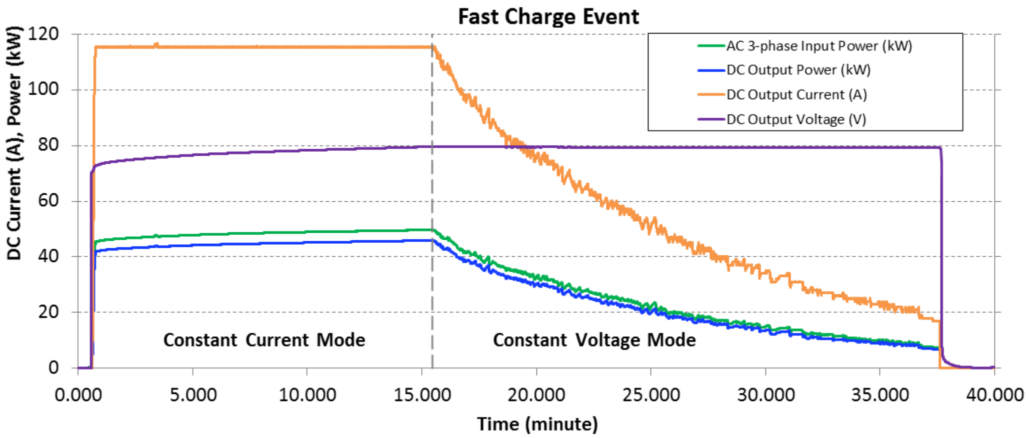
50 kW

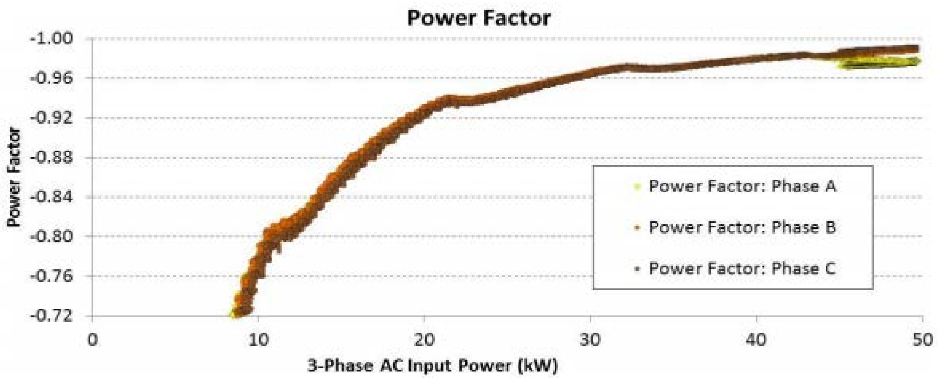
350 kW

Frequency Distribution Simulation

800 DCFCs @46kW on a 100-MW Distribution Grid

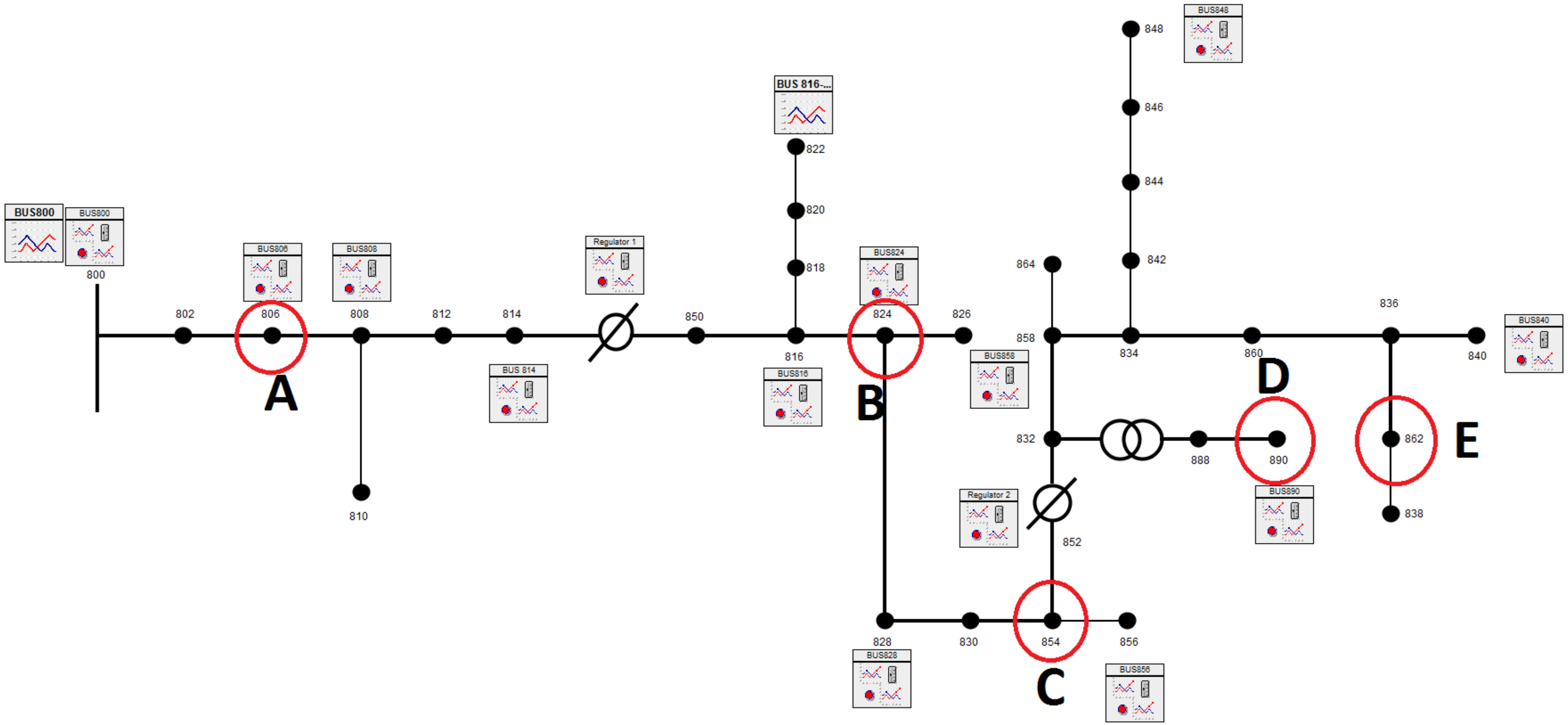
- Considered peak time (6:00 pm), with all PEV charging at the same time
- PEV distributed on all 34 nodes
- After 15 min, all users disconnect after reaching high SOC (when charging switches from Constant Current to Constant Voltage mode)
- Charger mapped according the following profile:
  - rising power: 7.4 kW/s,
  - turnoff time: 0.1s





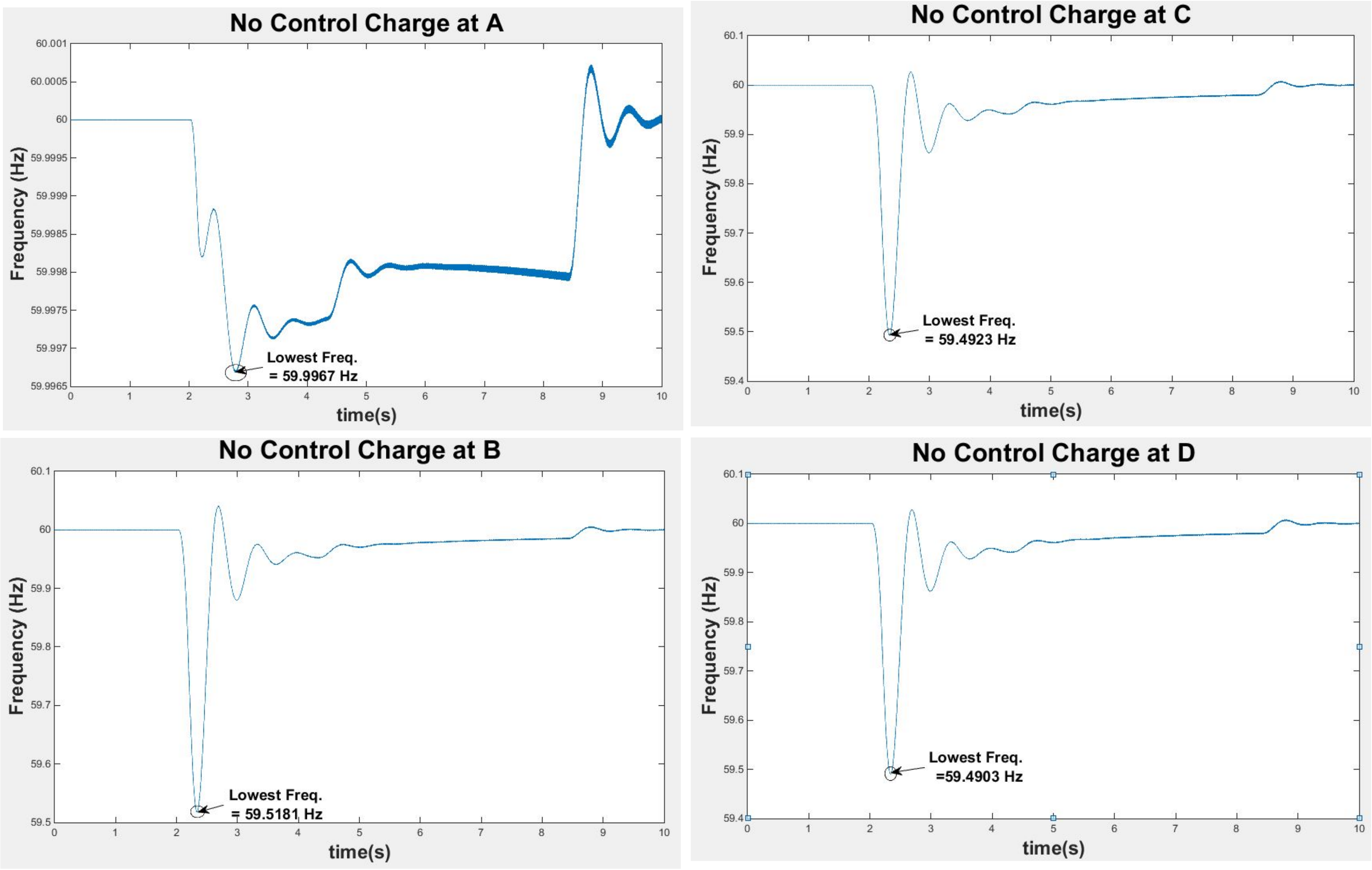
IEEE 34-nodes – 100 MW Distribution Grid

5 Nodes monitored: A, B, C, D and E for frequency response propagation
Each Node with ~18 PEV-DCFC @ 46 kW each



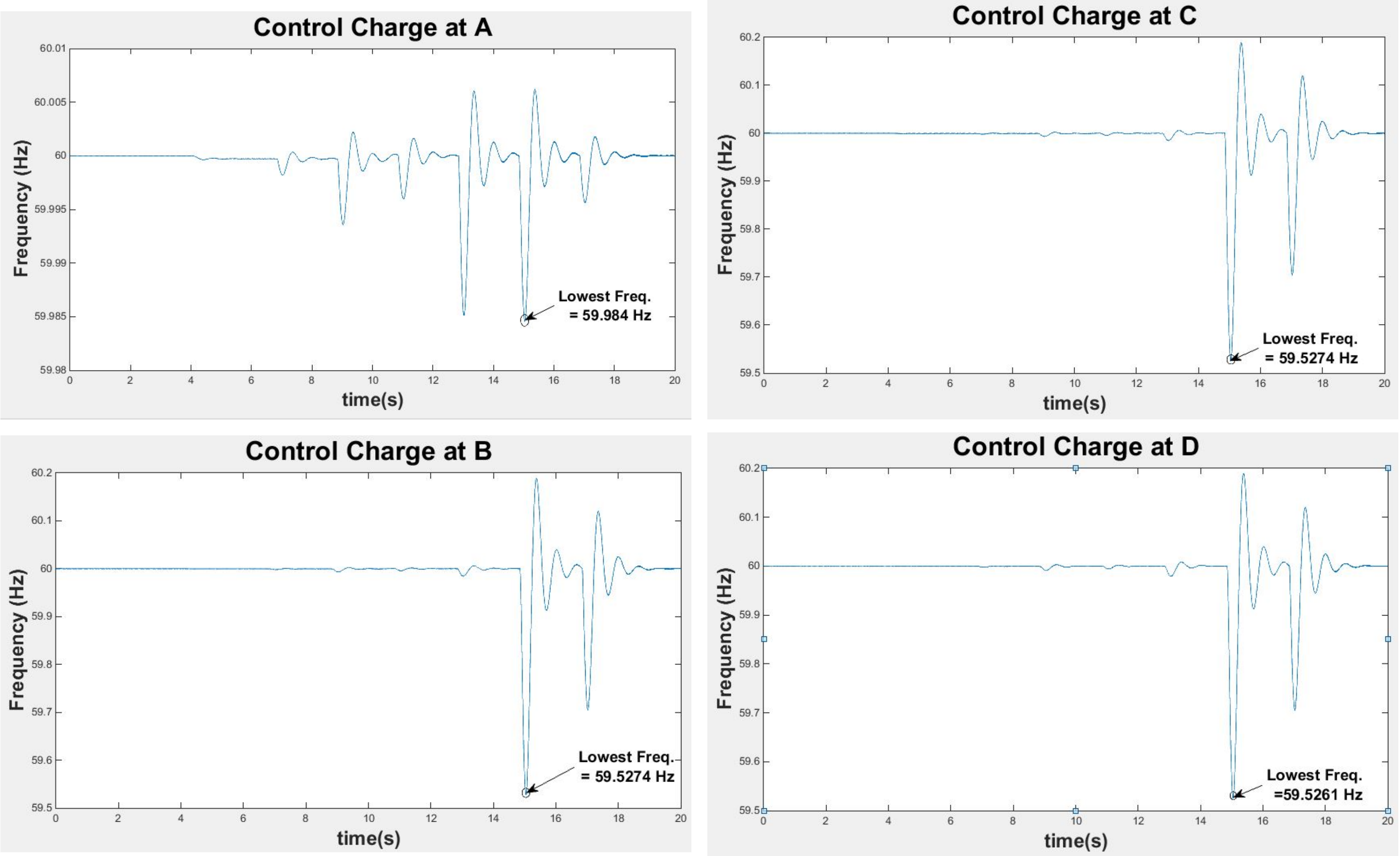
Charging Not Controlled

- Minimum Frequency
  - Node A = 59.99 Hz
  - Node B = 59.52 Hz
  - Node C = 59.49 Hz
  - Node D = 59.49 Hz



Charging Controlled

- Minimum Frequency
  - Node A = 59.98 Hz
  - Node B = 59.53 Hz
  - Node C = 59.53 Hz
  - Node D = 59.53 Hz
- Frequency always above 59.5 Hz and below 60.2 Hz.



Key takeaways

1) HIL-based impact analysis of DCFC and XFC on the grid
   – (1% - 100% penetration)
2) Real-world charging and discharging patterns at community and regional level integrated into the real-time analysis
3) Provision of Grid support by controlling charging
4) Leveraging existing Front-End-Controller methodology from FCTO and GM0085 (AC Level 2 charging)

Questions