Project ID# ELT202

Charging Infrastructure Technologies: Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE)

Jesse Bennett

National Renewable Energy Lab (Lead Lab)

Matt Lave – Sandia National Laboratories

Don Scofield – Idaho National Laboratory

June 23, 2021 11:30:00

DOE Vehicle Technologies Program
2021 Annual Merit Review and Peer Evaluation Meeting

Overview

Timeline

- Project start date: October 2018
- Project end date: December 2021
- Percent complete: 84%

Barriers Addressed

- Identification of when and how electric vehicles at Scale will impact the grid.
- Determination of how electric vehicle load can 'move' throughout the grid under various control and infrastructure scenarios.
- A need to develop and enable reduced costs for electric charging infrastructure.

Budget

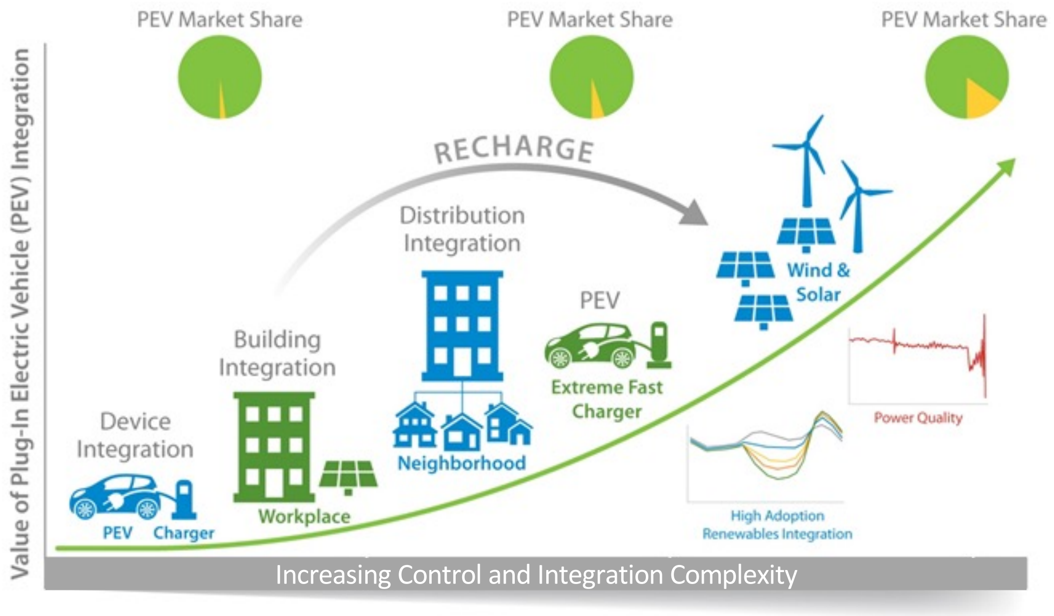
- Total project funding: $ 6.0 M
- DOE Share: $ 6.0 M
- Contractor Share: $ 0
- Fiscal Year 2019 Funding: $ 2.0 M
- Fiscal Year 2020 Funding: $ 2.0 M

Partners

- Idaho National Lab (INL)
- Sandia National Labs (SNL)
- National Renewable Energy Lab (NREL)
- Xcel Energy
- Southern Company
- INRIX
- EDF Renewables

Relevance

- **This project will:** Demonstrate the value of smart charge management to reduce the impact of Electric Vehicles at Scale.
- **Objective(s):** Assess management of Plug-in Electric Vehicle (PEV) charging at scale to avoid negative grid impacts, identify critical strategies and technologies, and enhance value for PEV / EVSE / grid stakeholders. Tasks include:
  - Regional charging load estimation
  - Quantify the effects of uncontrolled charging
  - Develop and evaluate the effectiveness of smart charge control strategies
  - Identify required constraints and mechanisms to implement high-value charge control strategies



Resources

4 Efforts → 3 Lab Approach

- Vehicle Load and Control (NREL)
- Vehicle Modelling and Control (INL)
- Grid Impacts Analysis Minneapolis (NREL)
- Grid Impacts Analysis Atlanta (Sandia)

NREL Team:

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INL Team:

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SNL Team:

Matt Lave
Birk Jones
William Vining
Summer Ferreira

Total Funding:
$6M over 3 years ($2M/yr)

NREL: $3M ($1M/yr)
INL: $1.5M ($0.5M/yr)
SNL: $1.5M ($0.5M/yr)

Milestones: All Labs

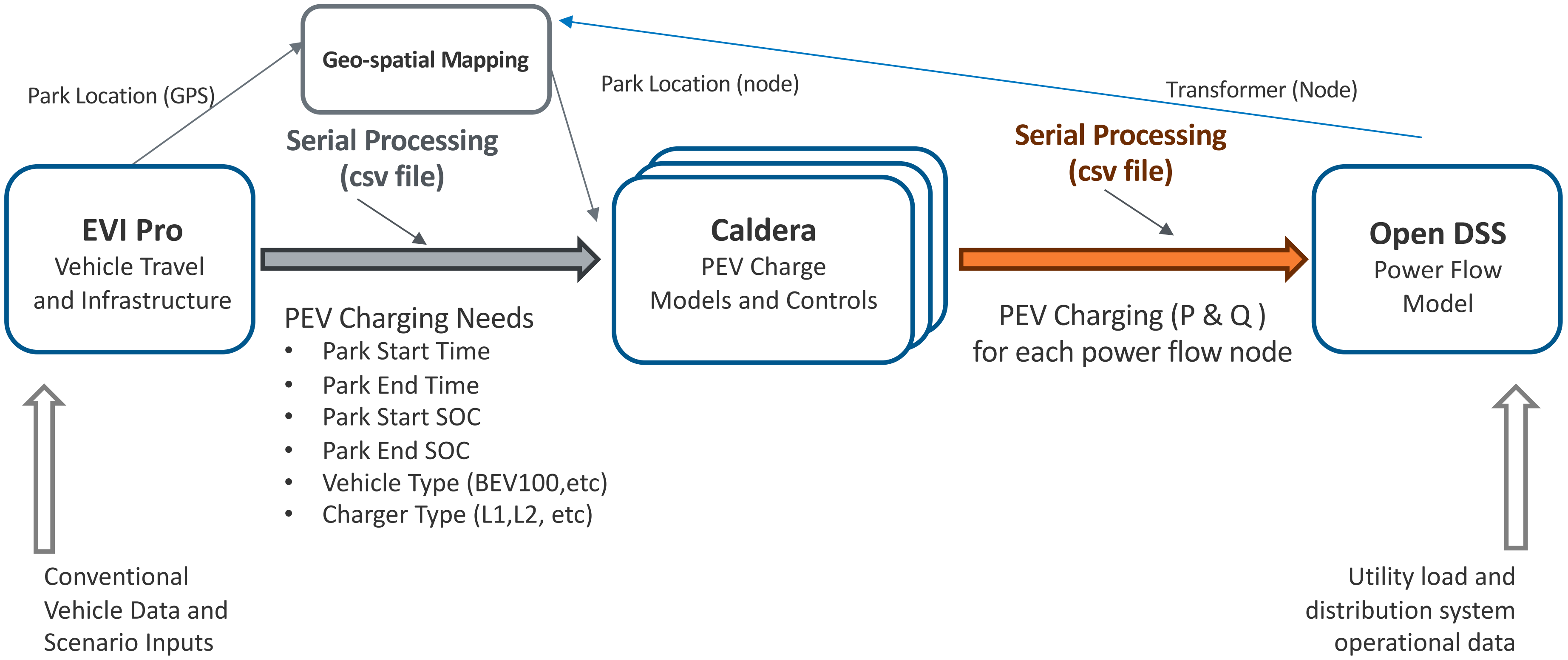
Milestone Name/Description	Task	Deadline	Milestone Type
Identify regions and establish utility partners for distribution system and PEVs at scale impact analysis.	1.1	12/31/2018	Quarterly Progress
Develop PEV charging load dataset for at least one of the two regions	2.1	3/31/2019	Quarterly Progress
OpenDSS-based Python tools for integrating PEVs into distribution feeder models	3.1.1 3.1.2	6/30/2019	Quarterly Progress
Conversion of EV charging stations at the NREL garage	9.1.1	9/29/2019	Quarterly Progress
Hosting capacity analysis quantifying uncontrolled charger capacity and infrastructure limitations at all nodes on 10 real distribution grid feeders	4.1.1	9/29/2019	Go/No-Go Milestone
Support hosting capacity analysis with aggregator model development for python toolkit.	5.1.1	9/29/2019	Go/No-Go Milestone
Develop the aggregator model developed from GM0085 in Python toolkit and integrate EVI-Pro dataset	5.2.1 5.2.2	12/31/2019	Quarterly Progress
Implementation of building load model into NREL garage control system to include building load forecasting in smart control	9.2.1	3/31/2020	Quarterly Progress
Distribution impact analysis including hosting capacity, distribution system upgrades, and costs performed for the smart control strategies identified	6.2.1	9/29/2020	Quarterly Progress
Quantify implementation costs of multiple smart charge management approaches	6.2.3	12/30/2020	Quarterly Progress
Impact of smart charging control strategies at smoothing temporal voltage and power draw profiles and reducing limits on hosting capacity demonstrated	6.2.1 6.2.2 6.2.3	12/30/2020	Go/No-Go Milestone
Transmission-level analysis showing EV charger impact to net load profiles and resulting modifications	6.2.2	3/31/2021	Quarterly Progress
Demonstration of the value of smart charging integration with other DER (PV, storage) to minimize cost and grid impacts	10.3.1 10.3.2	6/30/2021	Quarterly Progress
Resiliency analysis of smart charging control and value during extreme events which stress the grid	7.3.1	9/29/2021	Quarterly Progress
Develop joint journal publication(s) on smart charge strategies impact to the distribution system in Minneapolis and Atlanta.	10.3.1 10.3.2	12/31/2021	Annual Milestone

Year 3 Milestones will show:

1) Development of smart control strategies outside Caldera integrating DER
2) Distribution impact analysis of controlled charging on primary, secondary, and bulk electric systems
3) Qualification of smart charge implementation strategies and system requirements
4) Benefits of smart control strategies on distribution system upgrades and cost

Approach: First, Understand PEVs at Scale with Unmanaged Charging

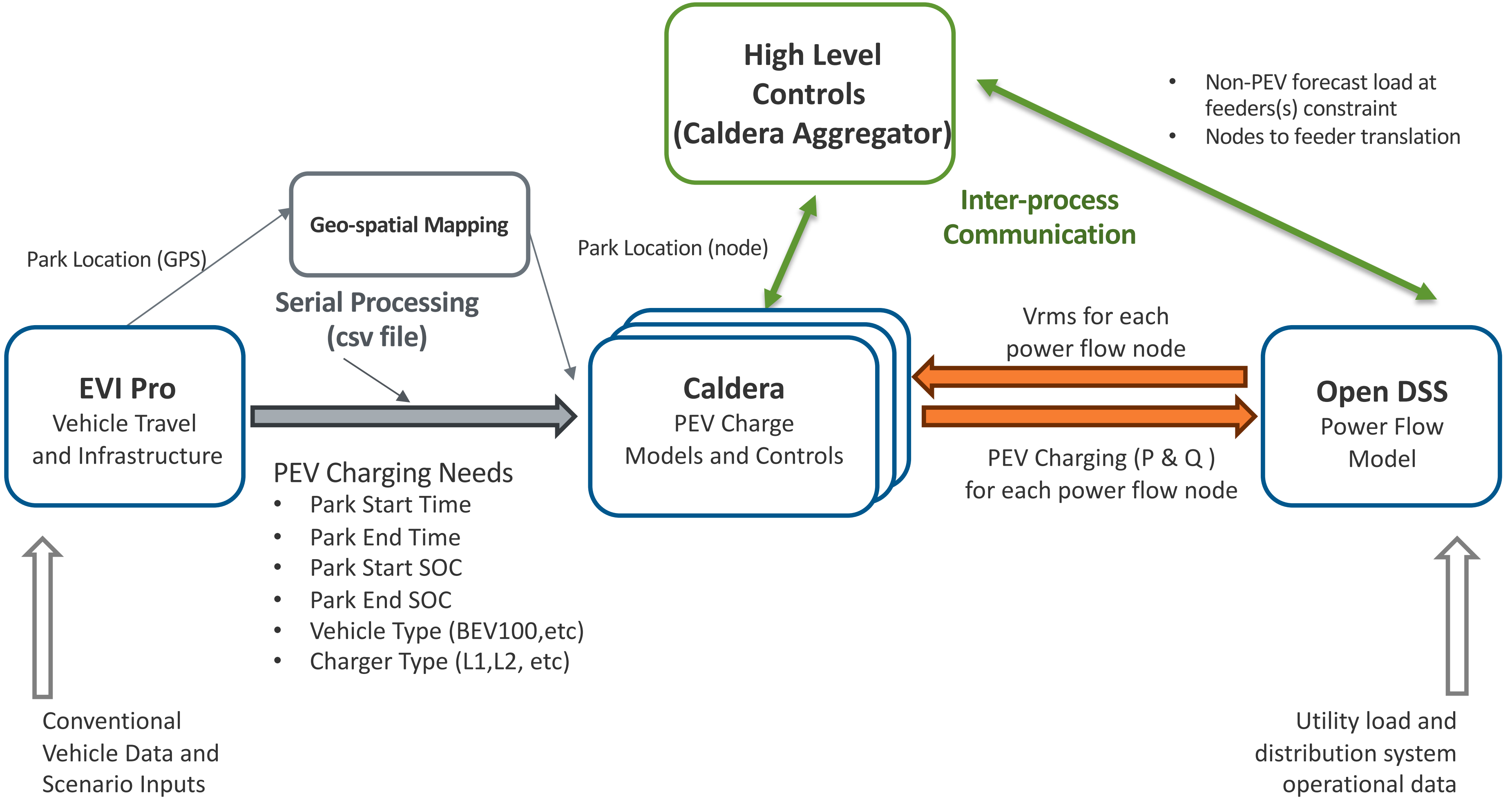
– No charge control flexibility



EVI Pro – Electric Vehicle Infrastructure Projection Tool
Open DSS – Open Distribution Simulation Software
SOC - State of Charge

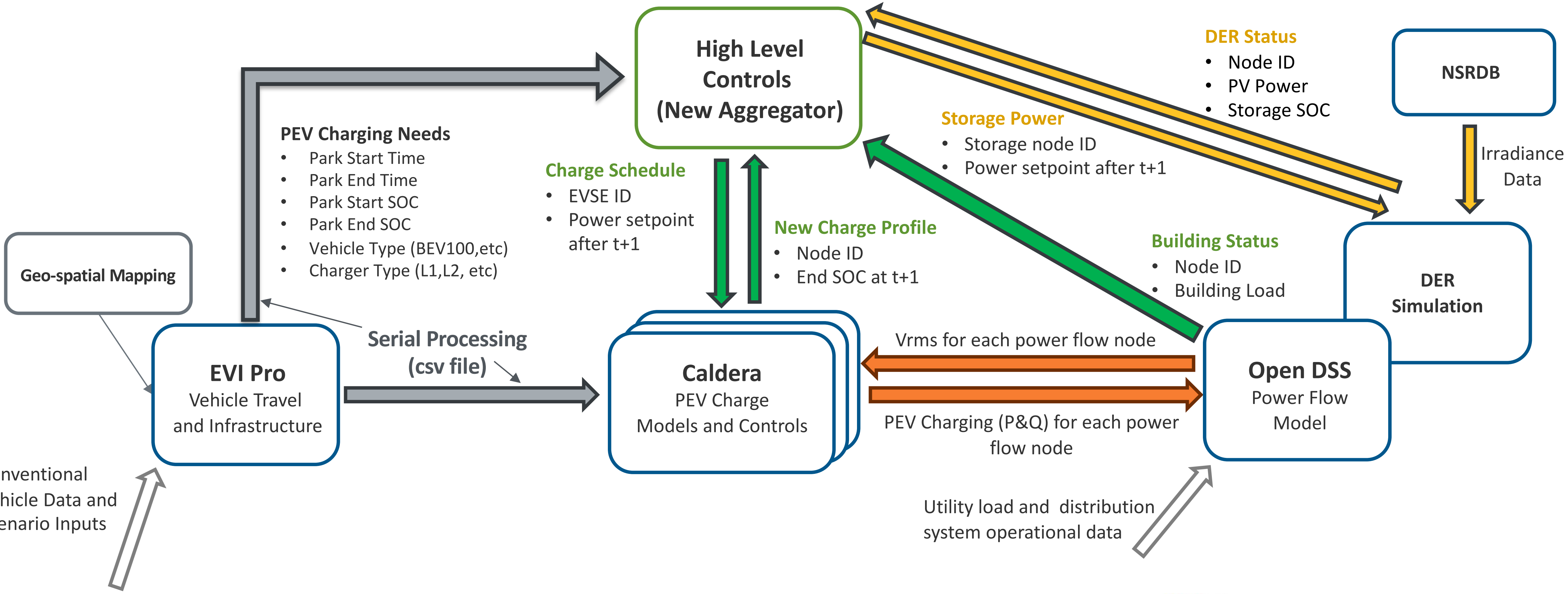
Approach: Next, Look at Managed Charging with Co-Simulation of PEV and Grid

– Charge control flexibility at a location



Approach: Finally, Look at Advanced Charge Controls with Co-simulation of PEV and Grid

– DER Integration
– Inter-EVSE communication



NSRDB – National Solar Radiation Database
DER – Distributed Energy Resource

Approach: Multi-Task, Multi-Year

Task	Year 1	Year 2	Year 3
1: Scoping, Requirements, and Industry Engagement	■	■	■
2: Develop PEV Charging Requirements	■	■	
3: PEV Charging and Distribution System Modeling	■		
4: Quantify the Impact of Uncontrolled Charging	■	■	
5: Refine Smart Charge Control Strategies (Caldera)	■	■	
6: Quantify Value of Smart Charging		■	■
7: Investigate "Resiliency" Scenario			■
8: Develop Smart Charge Strategies outside Caldera			■
9: Integration of Smart Charging with Building Loads	■	■	■
10: Integration of Site-Level DER with Smart Charging			■

Technical Accomplishments and Progress:

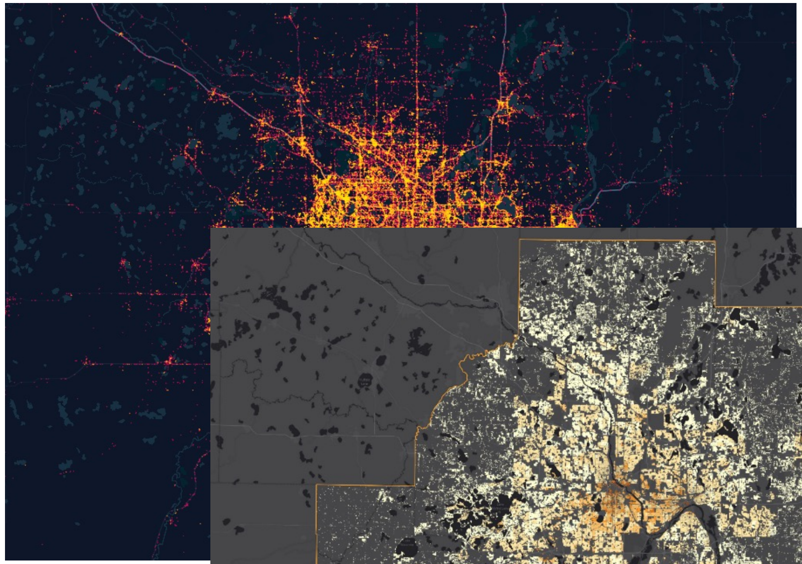
Task 1 - Scoping, Requirements, and Industry Engagement

- Feeder models for Minneapolis and Atlanta have been obtained, converted, and validated in OpenDSS.
- Team has regular meetings with Xcel Energy and Southern Company to share results and get feedback.

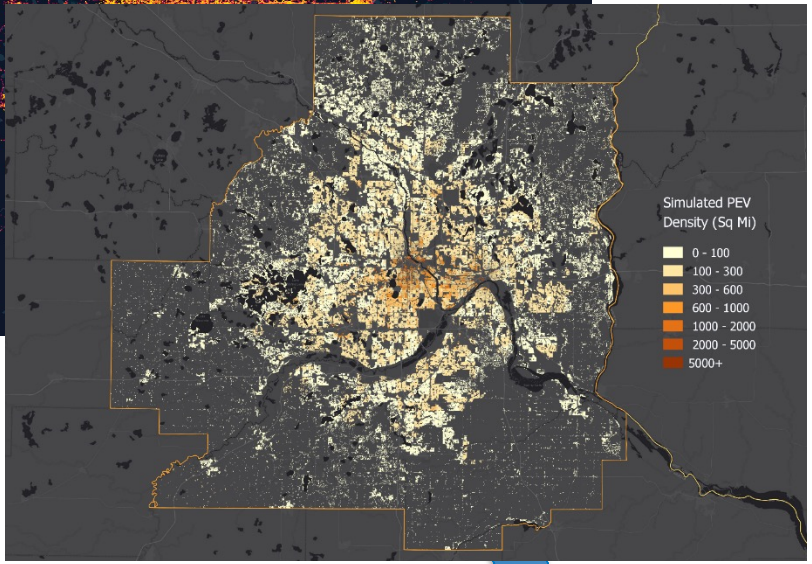
	Feeder	Description	# of customers on feeder	Peak Load [MW]
Minneapolis	1	Primarily residential and heavily loaded	2254	10.6
	2	Unbalanced, heavily residential and lightly loaded	283	1.4
	3	Long and evenly mixed customer types	1835	6.5
	4	Unbalanced and evenly mixed customer types	1558	5.9
	5	Heavily residential	2027	6.0
	6	Closer to downtown, highest EV density matches with highest EV counts-possible public charging location	2346	5.2
	7		986	4.8
	8		1322	6.4
	9	Feeder in the high EV density, 93% residential, suburban community	2507	8.7
	10	Commercial	1427	6.6
	11	Unbalanced, heavily residential	1977	5.4
	Total		**18,522**	**~ 67.5**
Atlanta	1	Residential	993	6.5
	2	Residential, some Commercial	662	7.6
	3	Industrial	3262	14.3
	4	Residential, some Commercial	1098	7.9
	5	Commercial, some Residential	1063	8.3
	6	Industrial	60	10.0
	7	Residential and Commercial	1323	9.9
	8	Residential and Commercial	2495	16.3
	9	Commercial	62	5.3
	10	Commercial, some Residential	3692	17.4
	Total		**14,710**	**~ 103.5**

Technical Accomplishments and Progress:

Task 2 - Develop PEV Charging Requirements

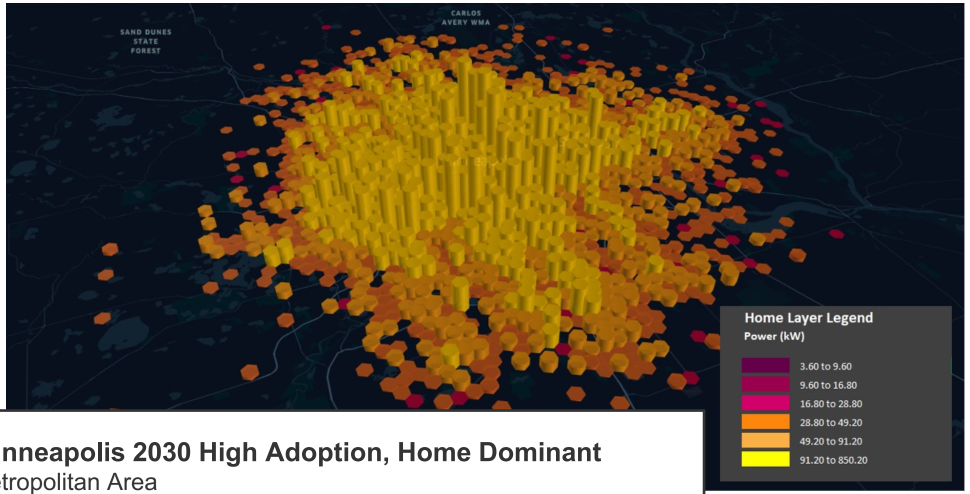


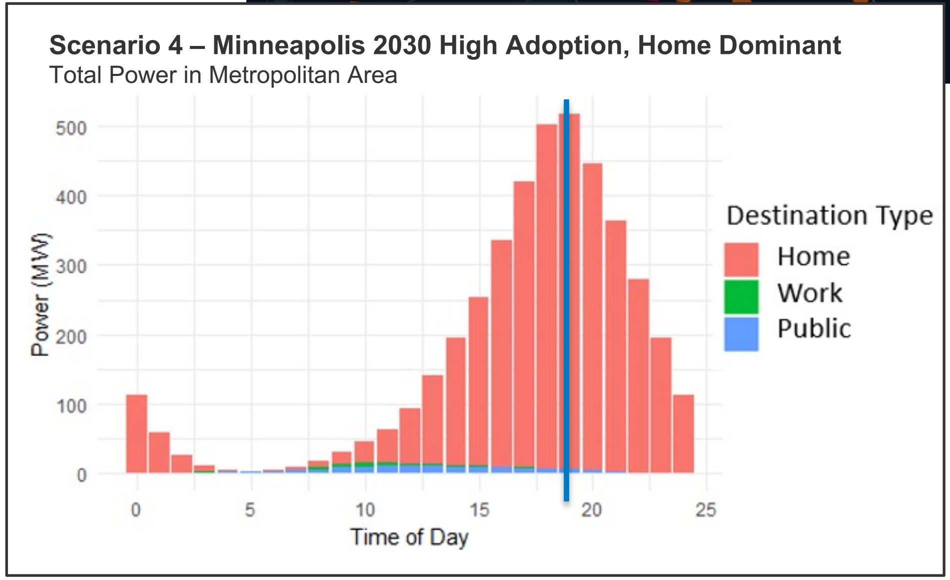
Travel Data



Land use and registration data

Spatial and temporal charging location is assigned from travel data





Technical Accomplishments and Progress:

Task 5 & 8 - Refine Smart Charge Control Strategies

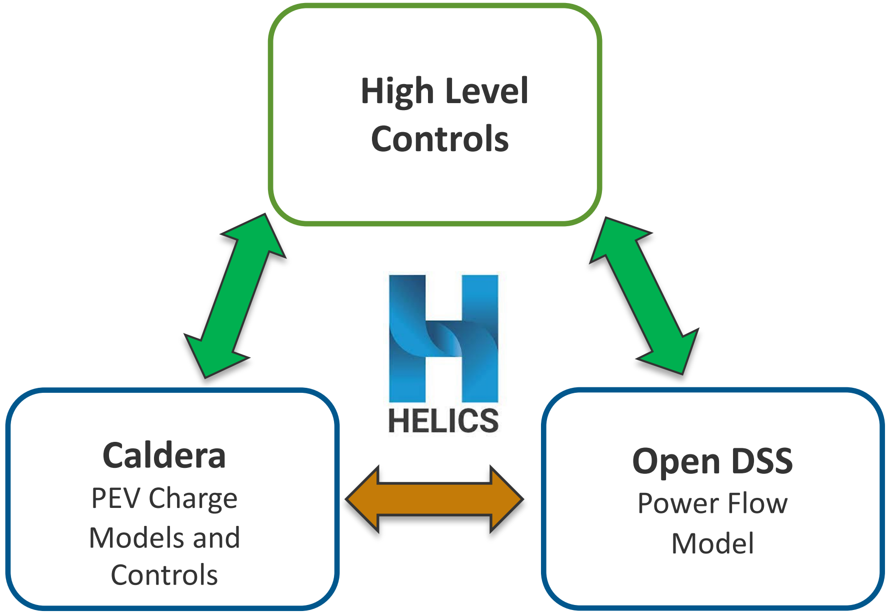
Strategy Name	Objective	Control Simulation	Grid Services
TOU Immediate	PEV driver responds to Time-of-Use incentives by charging at the beginning of TOU windows	Caldera	Price Signals
TOU Random	Decentralized control randomly distributes EV charging within vehicle dwell and TOU windows	Caldera	Price Signals, Capacity Deferral
Random Start	Decentralized control randomly distributes EV charging within vehicle dwell	Caldera	Capacity Deferral
Feeder Peak Avoidance	Centralized control shifts EV charging within vehicle dwell to minimize feeder peak	Caldera	Capacity Deferral
Volt/VAR	Decentralized control provides reactive power support based on local power quality	Caldera	Voltage Support
Volt/Watt	Decentralized control shifts EV charging real power within dwell to reduce nearby grid voltage concerns	Outside Caldera*	Demand Response, Voltage Support
BTM/DER	Decentralized control shifts EV charging within dwell to reduce behind-the-meter peak demand	Outside Caldera*	Demand Charge Mitigation, Max Renewables

TOU – Time-of-Use

Technical Accomplishments and Progress:

Task 8 - Develop Smart Charge Strategies outside Caldera

- Implemented a co-simulation environment using the HELICS co-simulation framework to support DER integration
- The following three entities are co-simulated in the framework
  - OpenDSS distribution feeder power flow models
  - Caldera high fidelity PEV charging models
  - Control Strategies that can control PEV charging in Caldera or devices modeled in OpenDSS power flow model
- This co-simulation environment has been implemented, debugged and is currently being used in the project



Technical Accomplishments and Progress:

Task 6- Quantify Value of Charge Control Strategies

2030 High Home

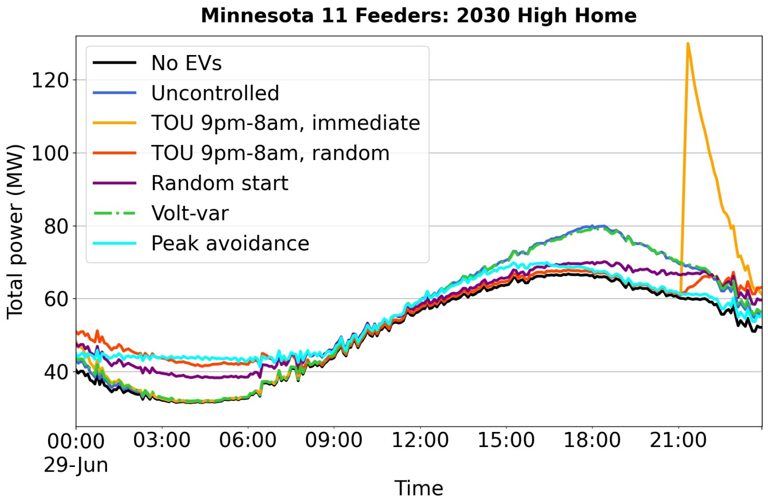
Region	Total EV Count	% EV Adoption*
Minn.	11,187	53%
Atlanta	5,974	30%

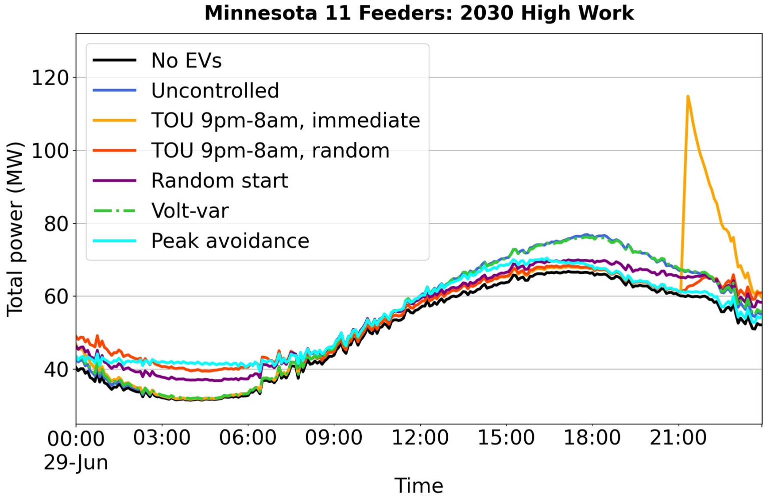
2030 High Work

Region	Total EV Count	EVs/Customer*
Minn.	9,987	42%
Atlanta	7,495	22%

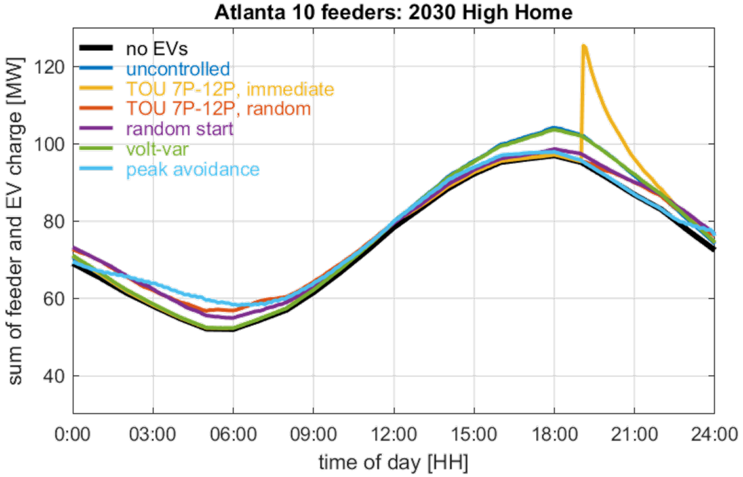
*Residential EV adoption assuming 1.8 vehicles per household

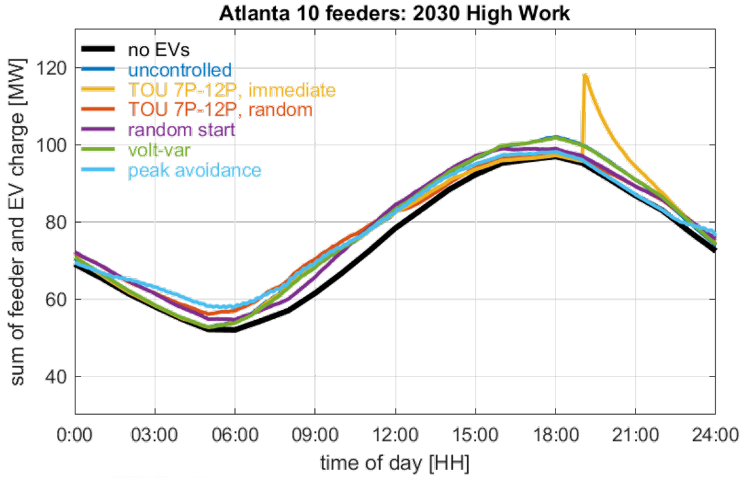
Minneapolis



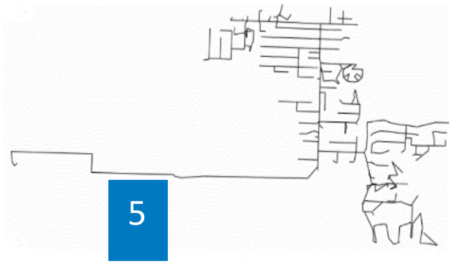


Atlanta

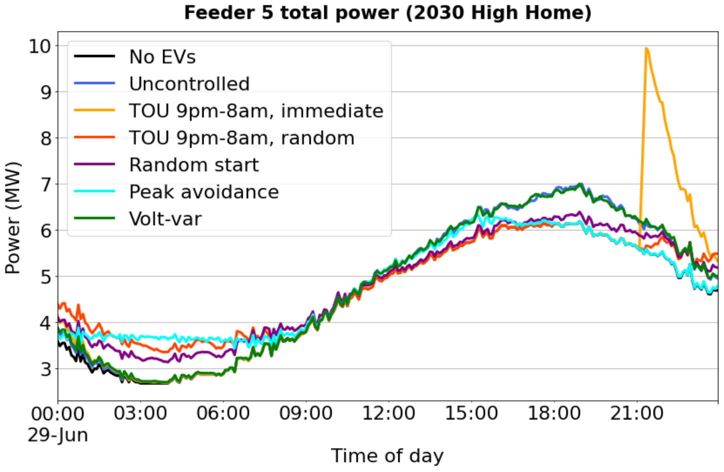


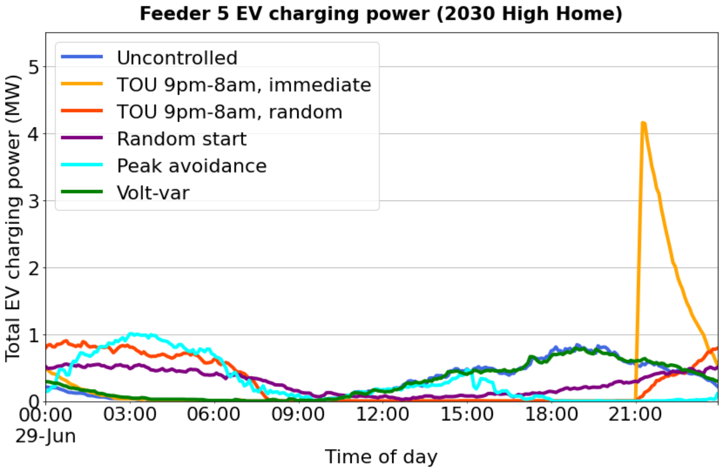


Minneapolis Feeder 5 (Heavily Residential)



Feeder-Wide Analysis

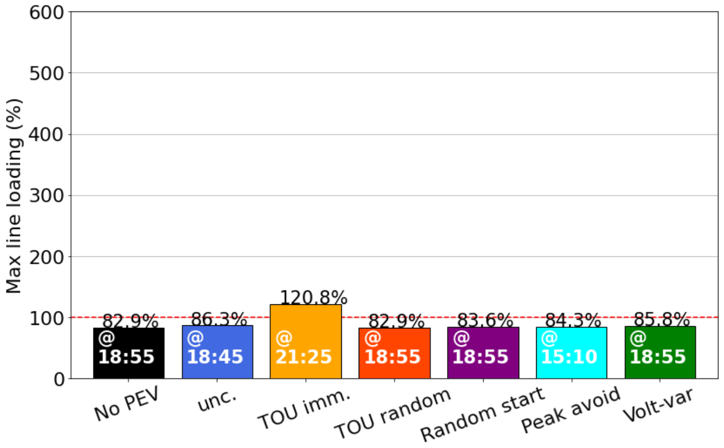


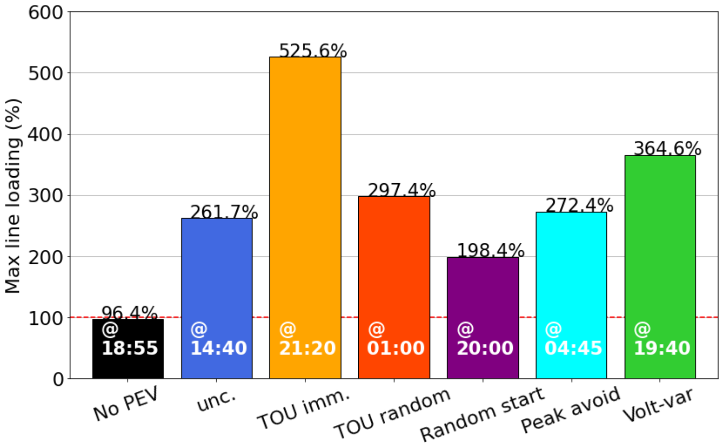


Primary

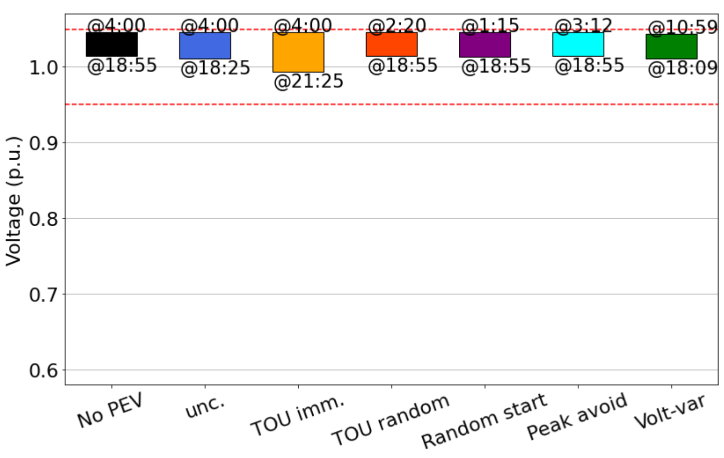
Secondary

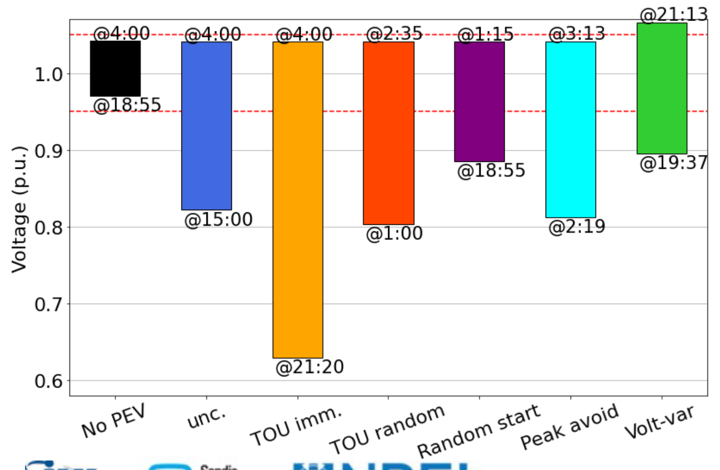
Worst case line loading





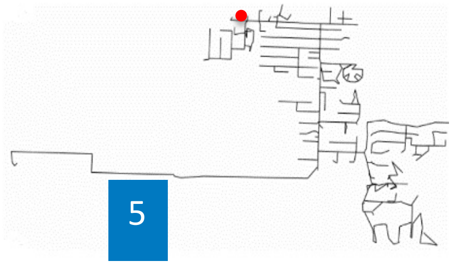
Min and max voltage range



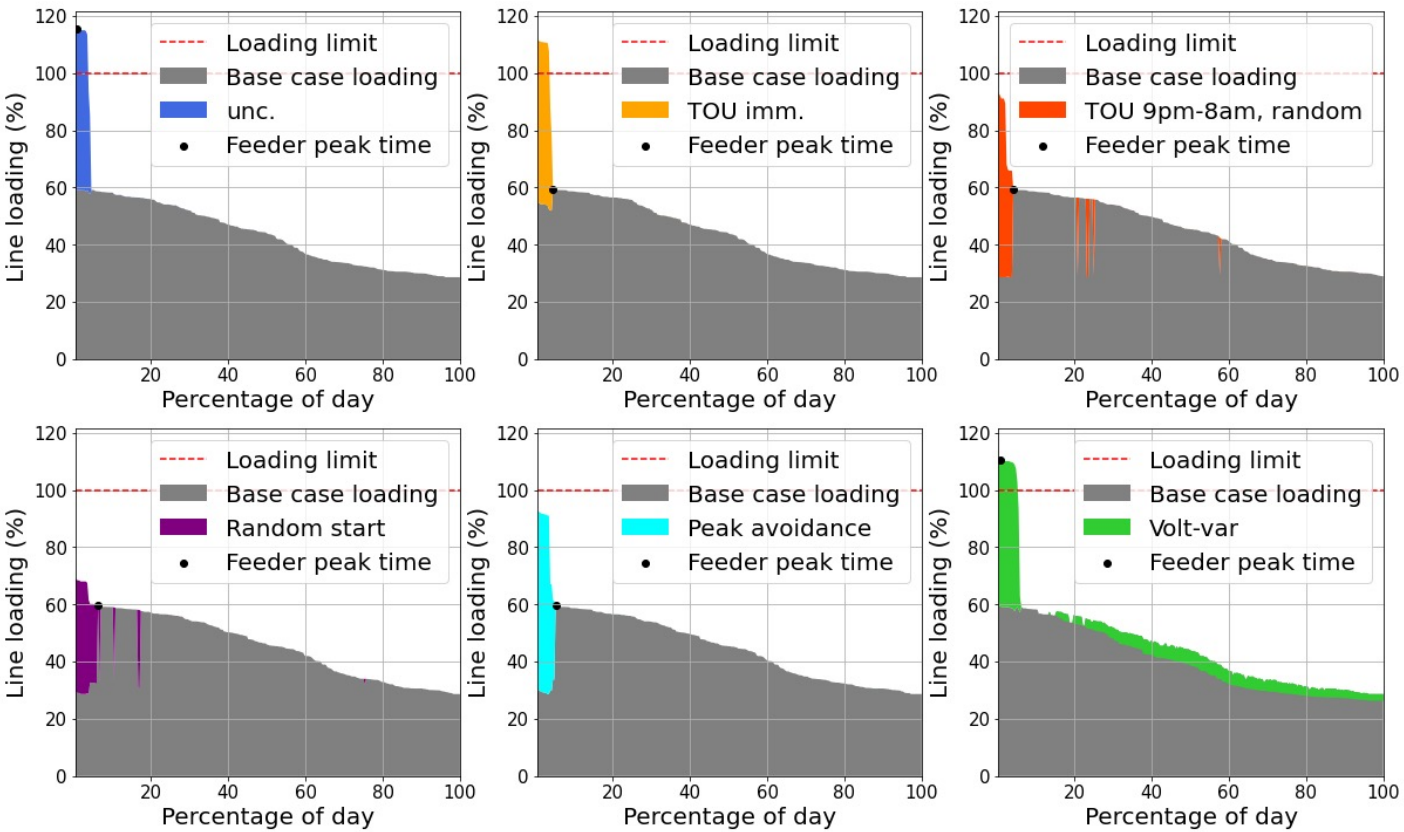


2030 High Home

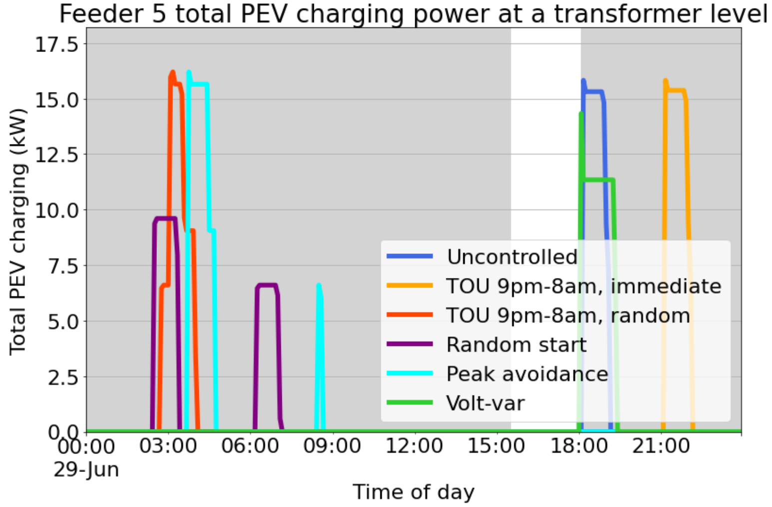
Minneapolis Feeder 5 : Service Transformer Analysis



Service Line loading



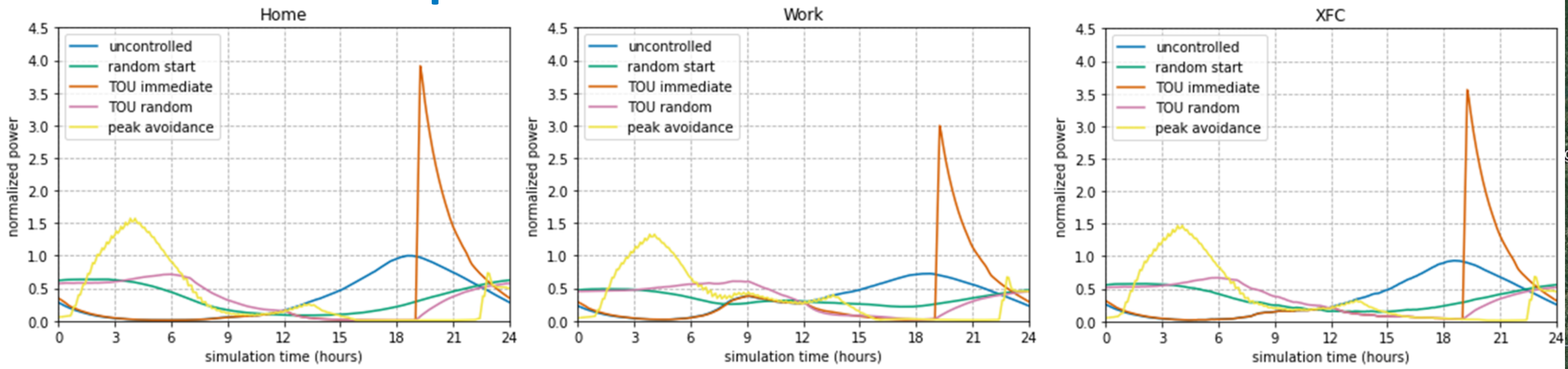
PEV charging power at the transformer

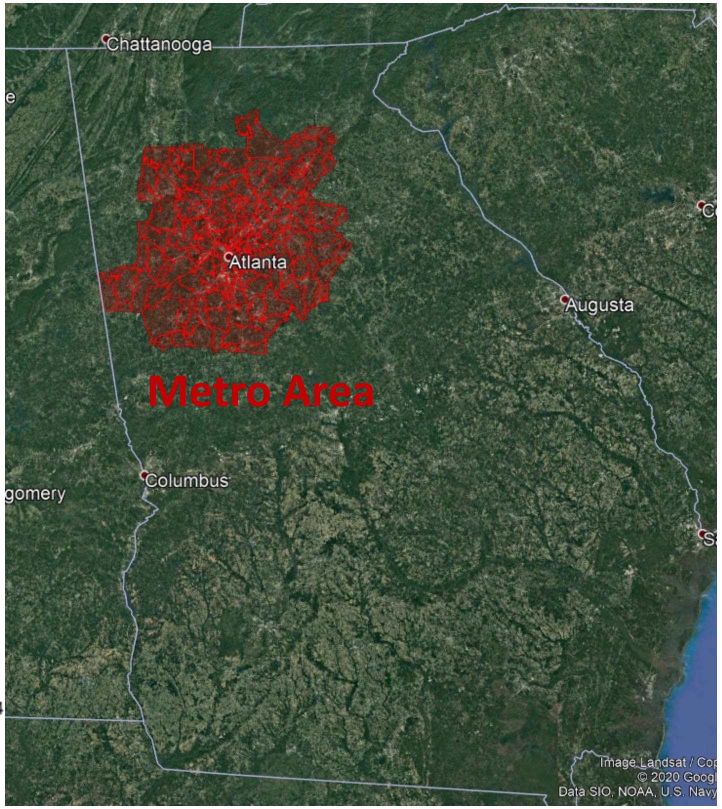


- 25 kVA residential transformer
- EV to customer ratio : 1

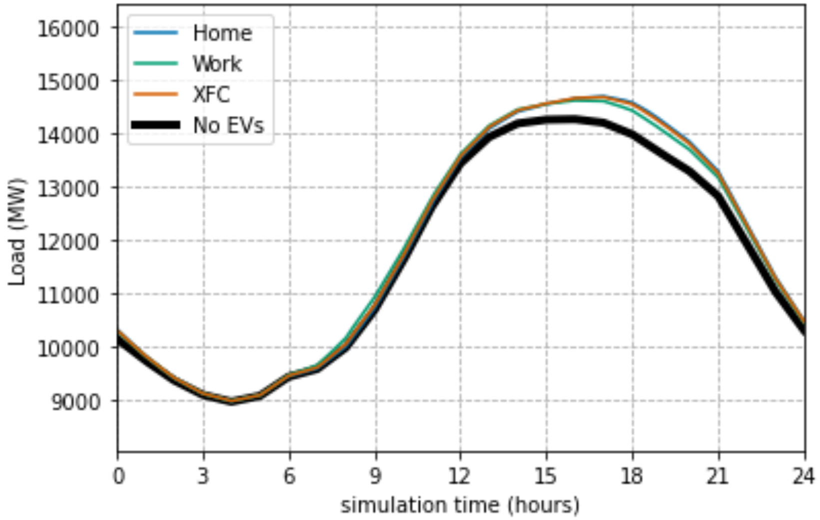
Metro Atlanta System Results

EV Consumption Normalized to Max in Home Scenario

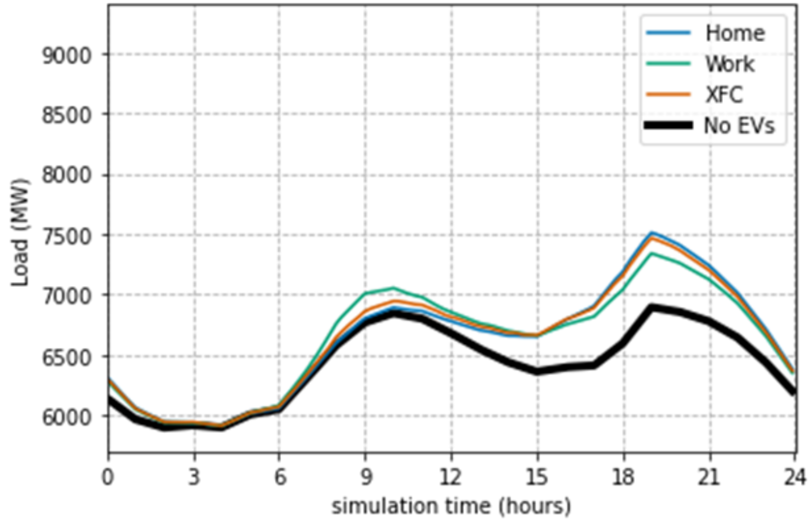




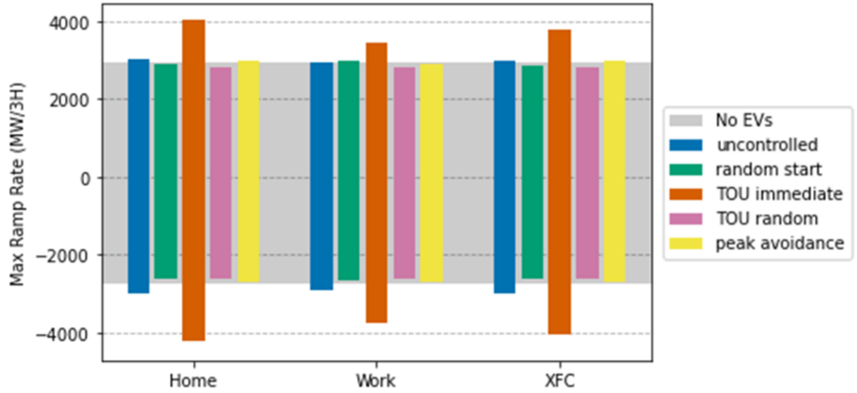
Peak Load + Uncontrolled EVs



Min. Load + Uncontrolled EVs



Ramp Rates



Grid Impact Analysis Summary

Secondary Analysis

- EV charging could potentially cause **higher voltage and line loading issues** in the **secondary** sides of the feeders **than the primary.**
- **Controlled EV charging strategies** such as TOU random, random start and peak avoidance help in spreading out the EV charging energy to different hours of the day, which could **prevent substantial number of lines and transformers from overloading.**

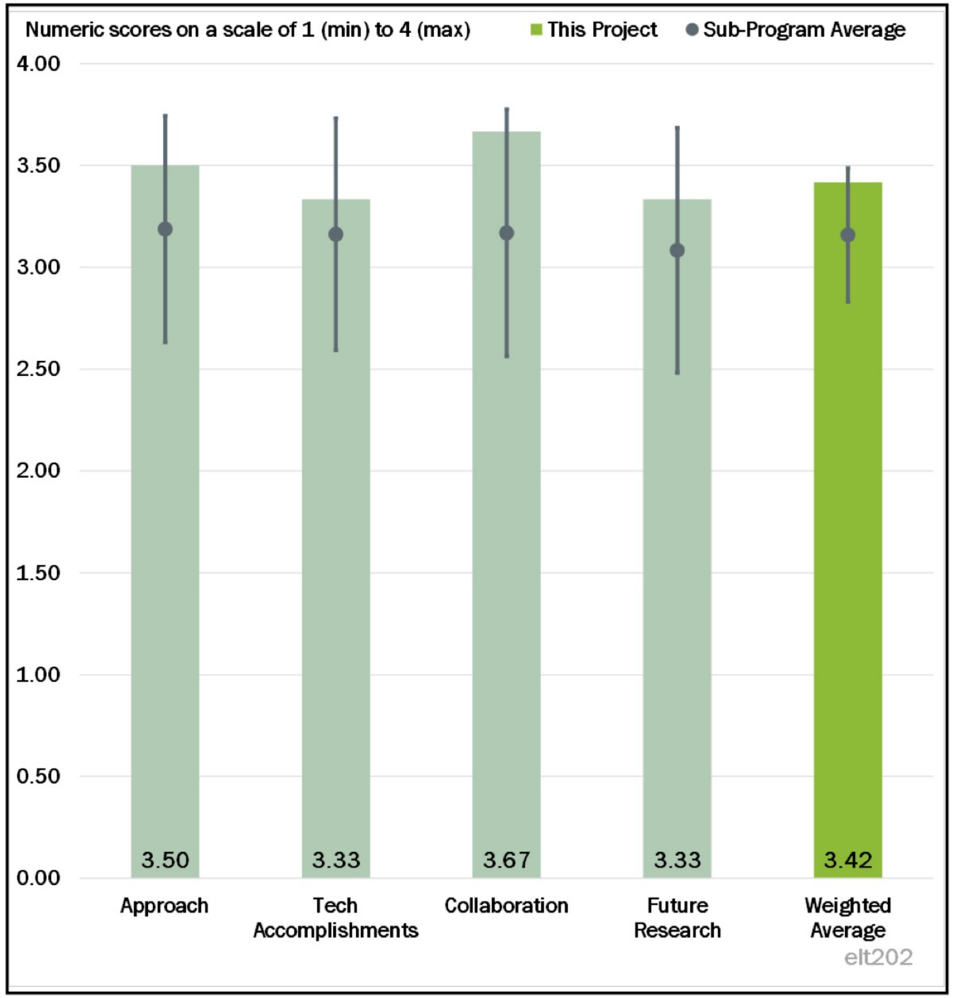
Bulk Analysis

- **Maximum impact** to bulk system load occurs from **uncontrolled EV charging**, as EV charging times are well-correlated with bulk load
- The **control strategies shift charging off-peak**, mostly to overnight periods
  - Some control strategies lead to an increase in maximum coincident EV charging
  - Alternative controls may be desired to utilize daytime PV generation
- **Only the time-of-use immediate** control strategy has a substantial **negative impact on ramp rates**
  - Ramp rates are modest compared to what is already seen on bulk systems due to PV

Reponses to Previous Year Reviewer's Comments

Three main concerns raised at the last AMR:

- *…the detailed results of task 5 "refine smart charge control strategies" have not been well explained.*
  - Response: The scope of smart charge control strategies was outlined in the beginning of year 2, accounting for a wide range of grid services, while the development work related to Task 5 occurred this past year (TOU, Random, Volt/VAR, Volt/Watt, etc.).
- *The grid impact analysis for two different cities is carried out by two different teams… In this AMR presentation, this advantage has not been observed yet.*
  - Response: Each of the two grid teams performs analysis on the primary voltage system for feeders in their respective cities in order to compare how EV charging impacts may differ across the country. Additionally, NREL has performed analysis on the secondary systems for all feeders in Minneapolis, while Sandia is investigating the impacts to the bulk electric supply in Atlanta.
- *This has established the basis for smart charging and is adding distributed energy resources (DER) functions that will complete the system by adding solar and stationary storage along with DER functions for grid stability.*
  - Response: The majority of smart charge controls developed for this project were developed and implemented through Caldera. However, the BTM/DER control and Volt/Watt control are being developed to operate on a HELICS co-simulation environment that includes DER such as solar PV and controllable energy storage.



Collaboration and Coordination with Other Institutions

- **NREL:** Leading the project and developing PEV load profiles, as well as MN OpenDSS models
- **INL:** Co-funded sub to the project, responsible for developing aggregator model
- **SNL:** Co-funded sub to the project, responsible for developing Atlanta OpenDSS model
- **Xcel Energy:** Providing data from Minneapolis distribution grid to assess loads and hosting capacity
- **Southern Company:** Providing data from Atlanta distribution grid to assess loads and hosting capacity
- **INRIX:** Subcontractor providing Minneapolis and Atlanta travel/vehicle data to assess PEV spatial and temporal charging loads
- **EDF Renewables:** Subcontractor for smart charging system supporting integration with building loads.

The team also coordinates with the Automotive and Utility partners through the USDRIVE Grid Interaction Tech Team

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

Remaining Challenges and Barriers

- Develop DER integration with smart charge control strategies with DER integration operated through HELICS.
- Demonstrate the **value of smart charge control strategies** including on feeders which do not currently have a line overload or under voltage violation.
  - Inclusion of smart charge strategies to support secondary systems and/or bulk electric supply
  - Distribution services have traditionally not been monetized.
  - Control implementation during extreme weather events

Proposed Future Research

- Remainder of FY21:
  - External control development (BTM/DER, Volt/Watt)
  - Resiliency analysis of controls during extreme weather
  - Publication development

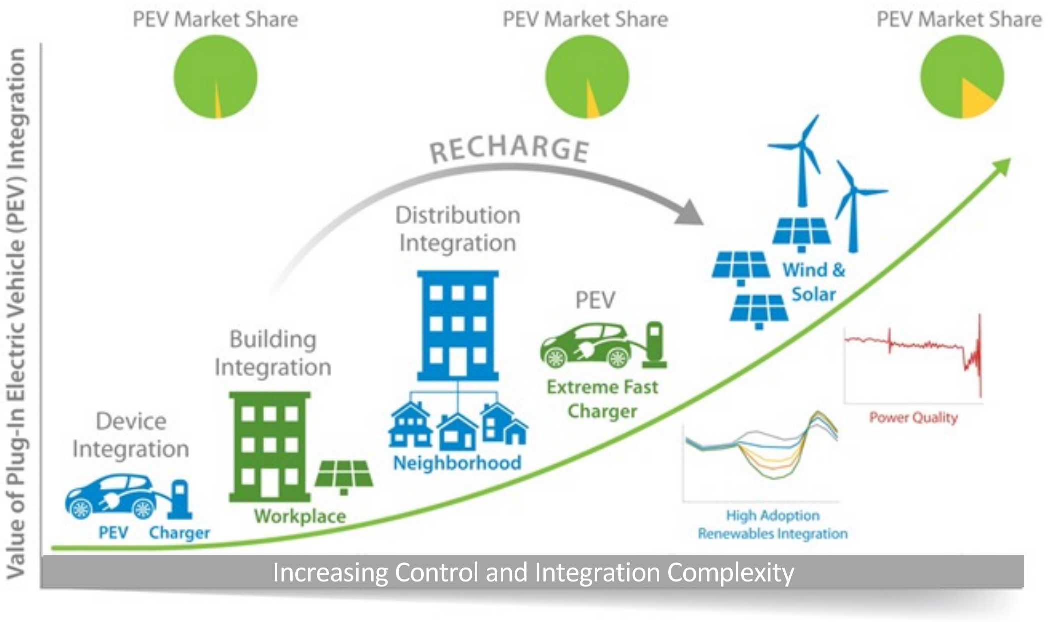
Milestone Name/Description	Task	Deadline	Milestone Type
Demonstration of the value of smart charging integration with other DER (PV, storage) to minimize cost and grid impacts	10.3.1 10.3.2	6/30/2021	Quarterly Progress
Resiliency analysis of smart charging control and value during extreme events which stress the grid	7.3.1	9/29/2021	Quarterly Progress
Develop joint journal publication(s) on smart charge strategies impact to the distribution system in Minneapolis and Atlanta.	10.3.1 10.3.2	12/31/2021	Annual Milestone

Any proposed future work is subject to change based on funding levels

Summary

This project will:

- Determine how **PEV charging at scale** in <u>two cities</u> could be managed to avoid potential negative grid impacts
- Allow for **critical strategies and technologies** to be developed for ‘non-wire’ solutions to PEV adoption.
- **Provide solutions to increase the value for PEV owners, building managers,** charge network operators, grid services aggregators, **and utilities**.



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Manoj Kumar
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SNL Team:

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Birk Jones
William Vining
Summer Ferreira

Thank You !
The RECHARGE Team

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Transforming ENERGY

Technical Back-Up Slides

Technical Back-up Slides:

Task 2 - Develop PEV Charging Requirements

- The following four PEV adoption scenarios (light blue column) were developed in RECHARGE for study of Atlanta and Minneapolis.
- RECHARGE in selecting the total fleet composition based on the following projections:
  - US Energy Information Administration's Annual Energy Outlook
  - NREL's Automotive Deployment Options Projection Tool (ADOPT)
  - ORNL's Market Acceptance of Advanced Automotive Technologies (MA3T)
  - Electric Power Research Institute (EPRI) Study[1]

Org/Model	EIA AEO 2019	EPRI	ADOPT	MA3T	EPRI	ADOPT	RECHARGE	
Scenario	ref	med	low tech	base	high	high tech	med	high
2025								
PEV Fleet Share	3.00%	2.60%	2.40%	1.00%	4.80%	2.70%	2.6%	4.8%
BEV/PEV ratio	72%	61%	51%	60%	60%	52%	72%	72%
BEV200+/PEV ratio	59%	NA	37%	NA	NA	34%	59%	59%
Sedan PEV share	83%	NA	51%	83%	NA	49%	67%	67%
2030								
PEV Fleet Size	5.10%	5.40%	4.10%	2.90%	13.20%	5.30%	5.4%	13.2%
BEV/PEV ratio	75%	65%	49%	69%	65%	49%	75%	75%
BEV200+/PEV ratio	63%	NA	34%	NA	NA	45%	63%	63%
Sedan PEV share	82%	NA	41%	75%	NA	38%	58%	58%

[1] Electric Power Research Institute, "Plug-in Electric Vehicle Market Projections: Scenarios and Impacts," EPRI Report #3002011613, https://www.epri.com/#/pages/product/3002011613/, 2017

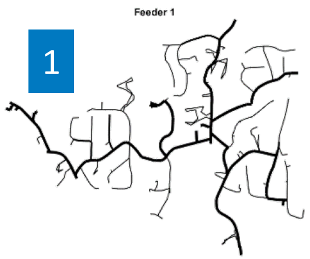
Technical Back-up Slides:

Task 2 - Develop PEV Charging Requirements

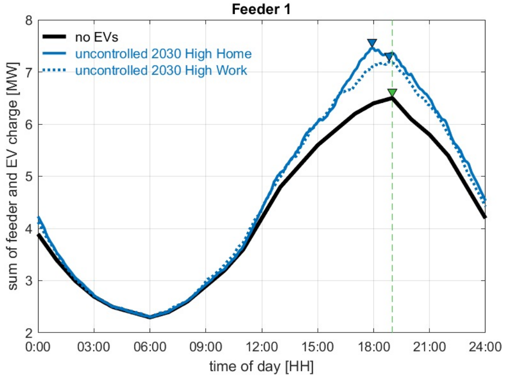
- The fleet wide parameters from these studies (BEV/PEV ratio, BEV200+/PEV ratio, to assign Sedan PEV share) were then used to assign to vehicle models that were defined to match the expected vehicle types fleet for 2025 to 2030

Car Type	Model Name	Fleet Share	Fleet Share	EV Range (miles)	Driving Efficiency (Wh/mile)	Usable Battery Capacity (kWh)	Rated Battery Capacity (kWh)	Fast Charging Power (kW)	AC Charging Power (kW)
		2025	2030						
Sports Car	XFC250_300kW	1%	1%	250	350	87.5	92.1	300	11.5
XFC 200 – Truck (Gen 1)	XFC200_150kW	25%	31%	200	475	95	100	150	9.6
XFC 275 – Car (Gen 1)	XFC275_150kW	9%	9%	275	300	82.5	86.8	150	9.6
BEV 250 – Car	BEV250_75kW	24%	22%	250	300	75	78.9	75	6.6
BEV 150 – Car	BEV150_50kW	13%	12%	150	300	45	47.4	50	6.6
PHEV 50 – Truck	PHEV50_SUV	8%	11%	50	475	23.75	25	None	9.6
PHEV 50 – Car	PHEV50	13%	9%	50	310	15.5	19.4	None	3.3
PHEV 20 – Car	PHEV20	7%	5%	20	250	5	6.3	None	3.3

Atlanta Feeder 1 (Residential)

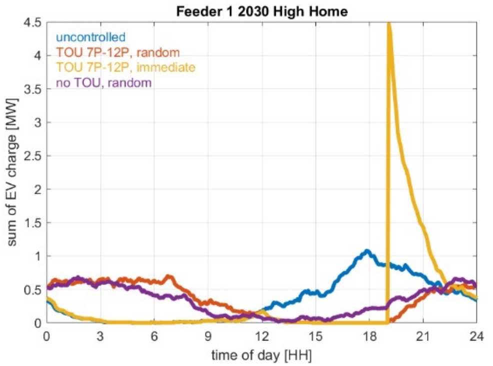


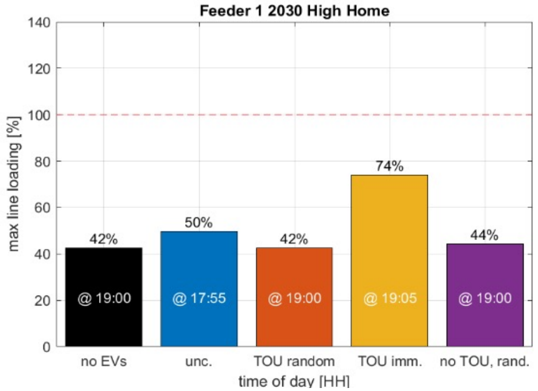
Feeder-Wide Analysis

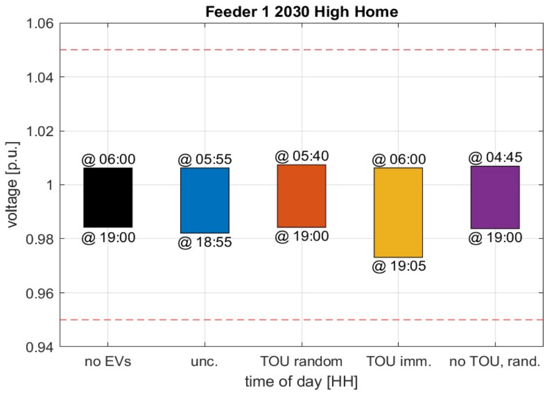


	2030 High Home					2030 High Work			
	No EVs	No Control	TOU Imm.	TOU Random	Random Start	No Control	TOU Imm.	TOU Random	Random Start
Feeder peak load (MW)	6.5	7.46	6.5	10.93	6.76	7.19	6.51	9.7	6.74
Minimum voltage (pu)	0.984	0.982	0.984	0.973	0.984	0.983	0.984	0.975	0.984
Maximum voltage (pu)	1.006	1.006	1.007	1.006	1.007	1.006	1.007	1.006	1.007
Max inc. in line loading (%)	0	7.1	0	31.6	1.7	3.9	0.1	22.5	1.6

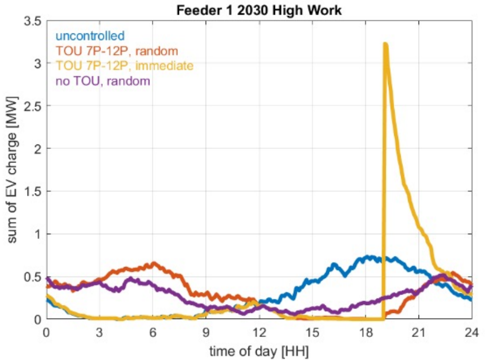
2030 High Home

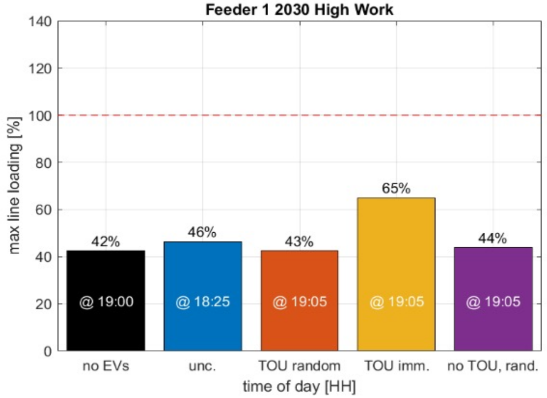


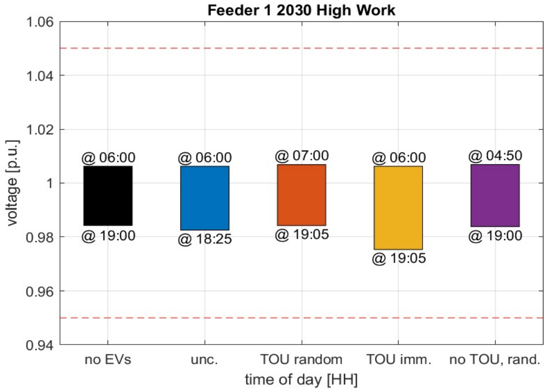




2030 High Work





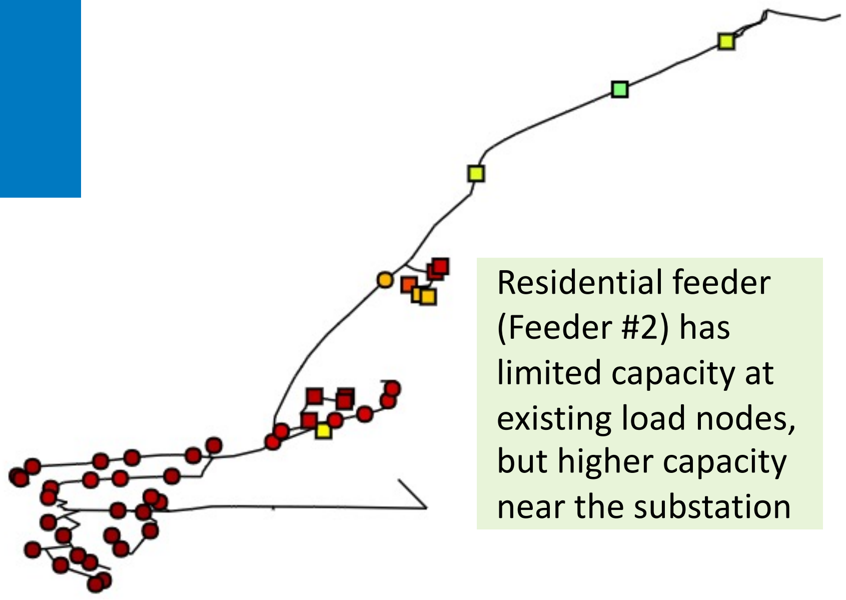


Technical Accomplishments and Progress:

Task 3 - PEV Charging and Distribution System Modeling

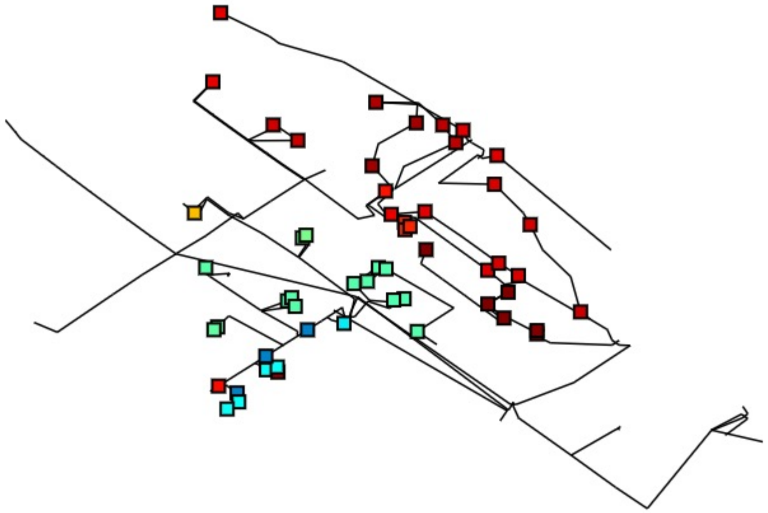
Minneapolis EV Hosting Capacity

- EV hosting capabilities vary by location on the feeder and on the feeder type
- **Line overloads are the most common limiting factor**, then under voltage
- Distance from substation is important: higher capacity closer to substation
- Feeders located in **older parts of the metro area tend to have lower hosting capacity** while newer feeders tend to have higher hosting capacities
- Some of the study feeders would likely host future public charging infrastructure and **all feeders have at least some locations capable of multiple 350 kW xFC**



Residential feeder (Feeder #2) has limited capacity at existing load nodes, but higher capacity near the substation

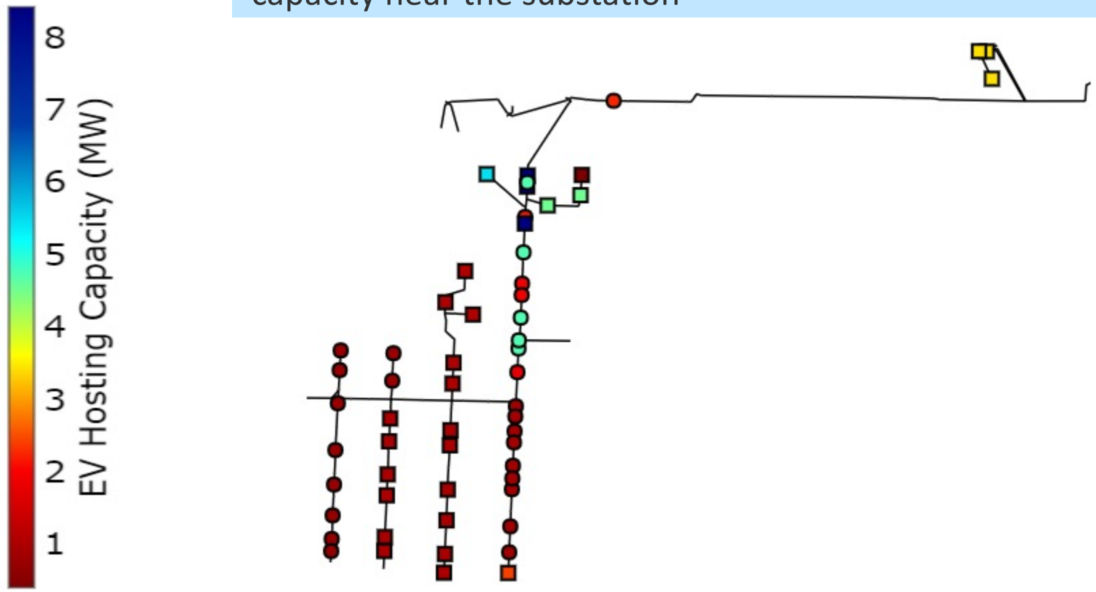
Industrial feeder (Feeder #5) can accommodate high EV loads in some sub-sections while the others have a limited hosting capacity



Commercial feeder (Feeder #8) has high hosting capacity near the substation

Limiting Factor

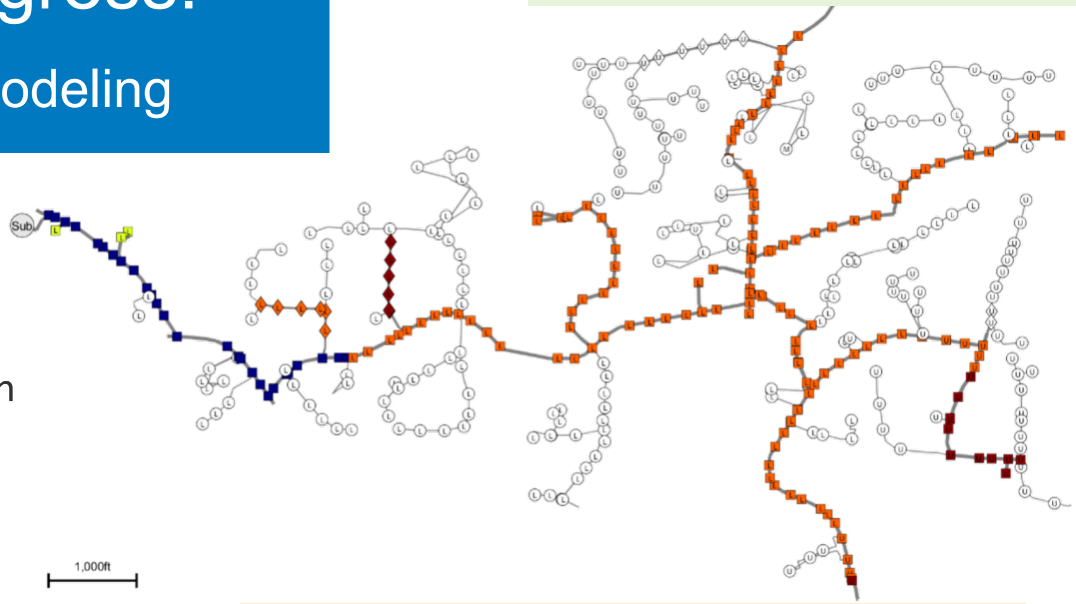
- O Over Voltage
- □ Line Overload
- ✚ Under Voltage



Technical Accomplishments and Progress:

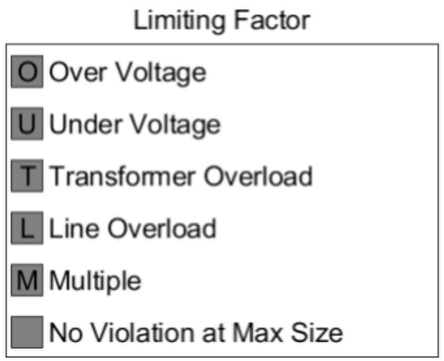
Task 3 - PEV Charging and Distribution System Modeling

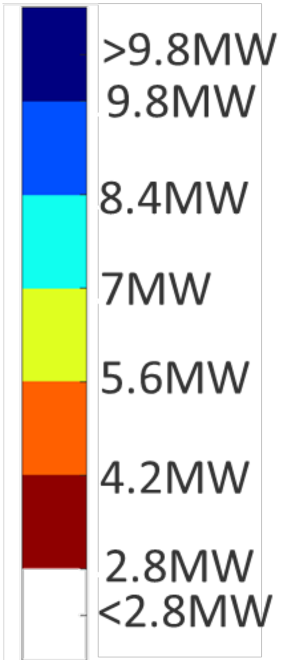
Residential feeder has capacity along main “backbone”



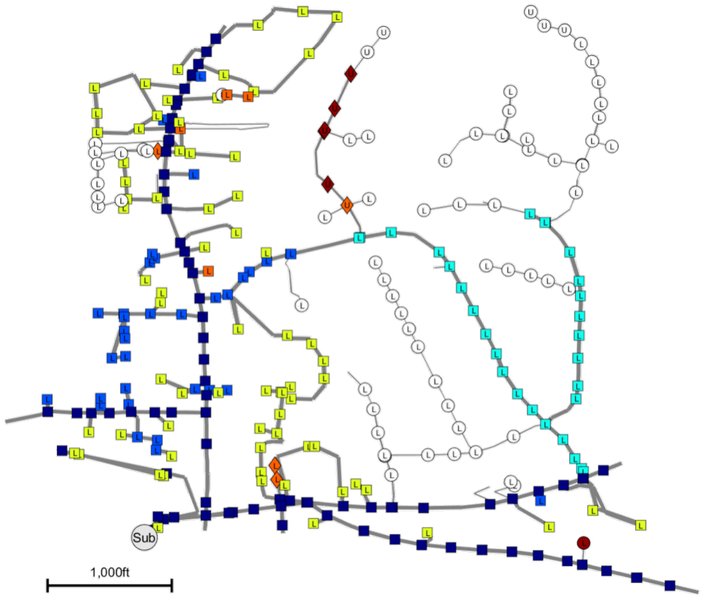
Atlanta EV Hosting Capacity

- EV hosting capabilities vary by location on the feeder
- **Line overloads are the most common limiting factor**, then under voltage
- Distance from substation is important: higher capacity closer to substation
- **Commercial feeders tend to have the most nodes with high capacity**
- Some of the study feeders would likely host future public charging infrastructure and **all feeders have at least some locations capable of multiple 350kW xFC**





Commercial feeder has significant capacity at nearly all nodes



Industrial feeder capacity starts high but rapidly decreases away from substation