NREL Transforming ENERGY

Project ID# ELT202

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

Andrew Meintz

National Renewable Energy Lab (Lead Lab)

Matt Lave – Sandia National Laboratories

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June 3, 2020

DOE Vehicle Technologies Program
2020 Annual Merit Review and Peer Evaluation Meeting

Overview

Timeline

- Project start date: October 2018
- Project end date: September 2021
- Percent complete: 50%

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

Barriers Addressed

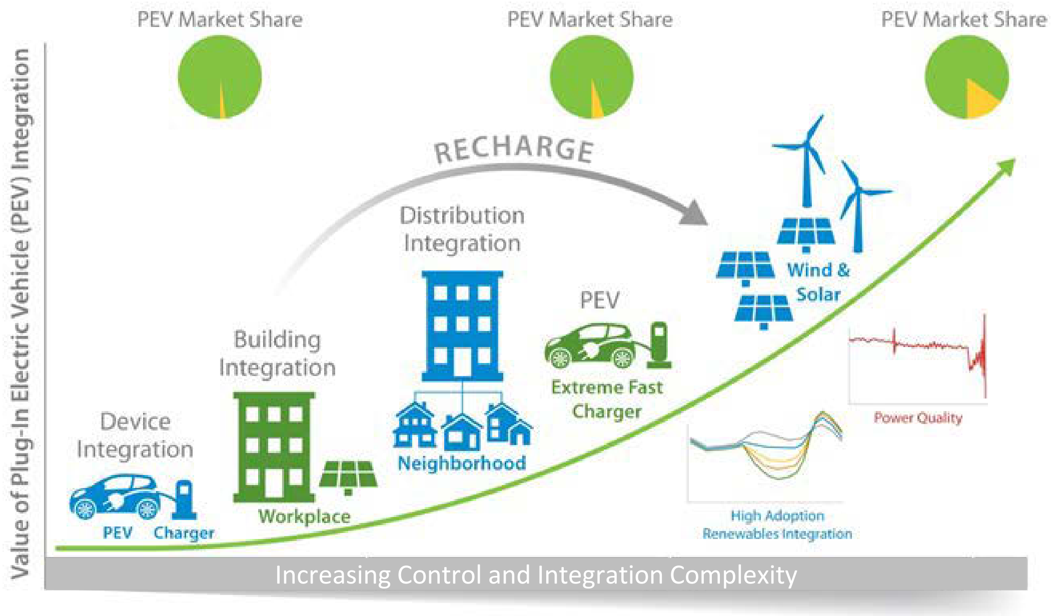
- Identification of when and how electric vehicles at Scale will impact the grid.
- Determination of how electric vehicle load can 'move' throughout the grid under various control and infrastructure scenarios.
- A need to develop and enable reduced costs for electric charging infrastructure.

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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SNL Team:

Matt Lave
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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

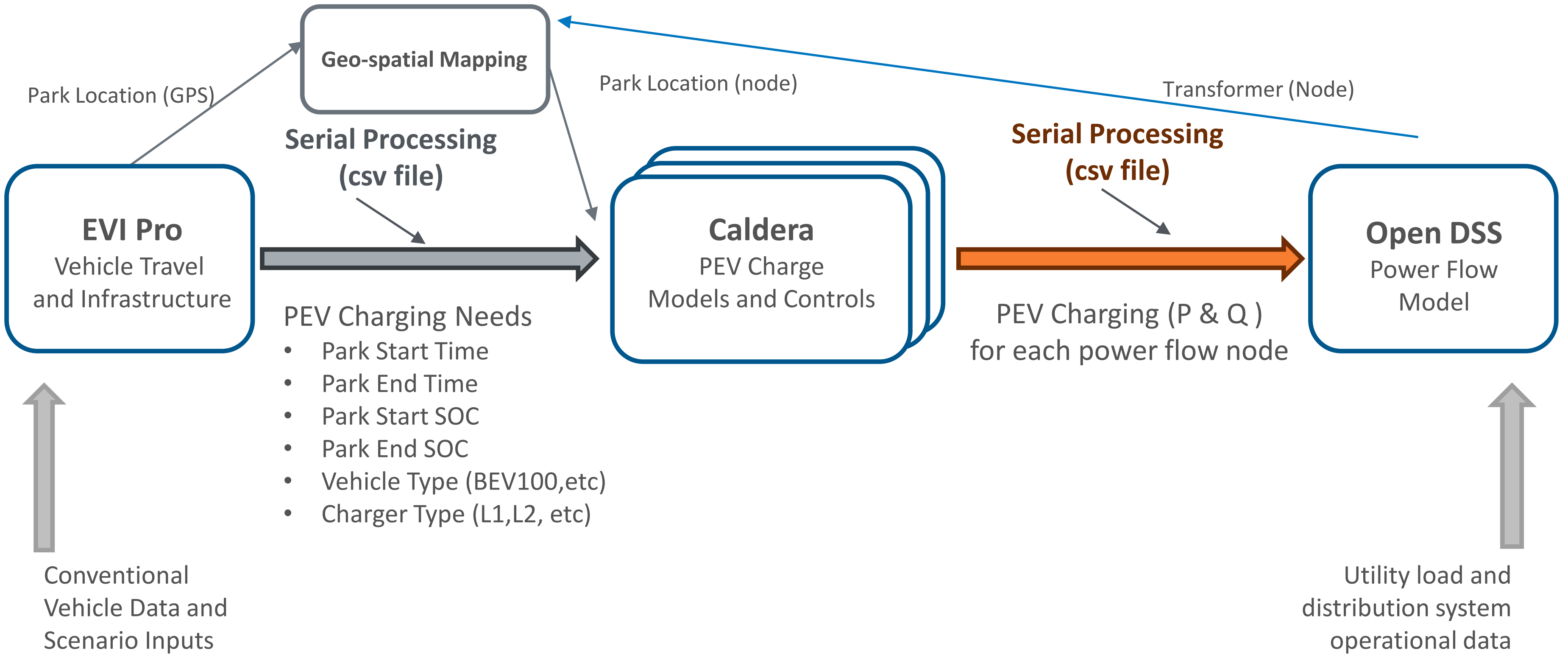
Milestone Name/Description	Task	Deadline	Milestone Type
Identify regions and establish utility partners for distribution system and PEVs at scale impact analysis.	1.1	12/31/2018	Quarterly Progress
Develop PEV charging load dataset for at least one of the two regions	2.1	3/31/2019	Quarterly Progress
OpenDSS-based 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	6/30/2020	Quarterly Progress
Quantify implementation costs of multiple smart charge management approaches	6.2.3	9/29/2020	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	9/29/2020	Go/No-Go Milestone
Transmission-level analysis showing EV charger impact to net load profiles and resulting modifications	6.2.2	12/31/2020	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	3/31/2021	Quarterly Progress
Incorporate building control and load prediction tools into commercial product	9.3.2	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

<u>Year 2 Milestones will show:</u>

1) Distribution impact analysis of uncontrolled charging
2) Development of smart control strategies in Caldera
3) Benefits of smart control strategies on distribution system upgrades and cost
4) Qualification of smart charge implementation strategies

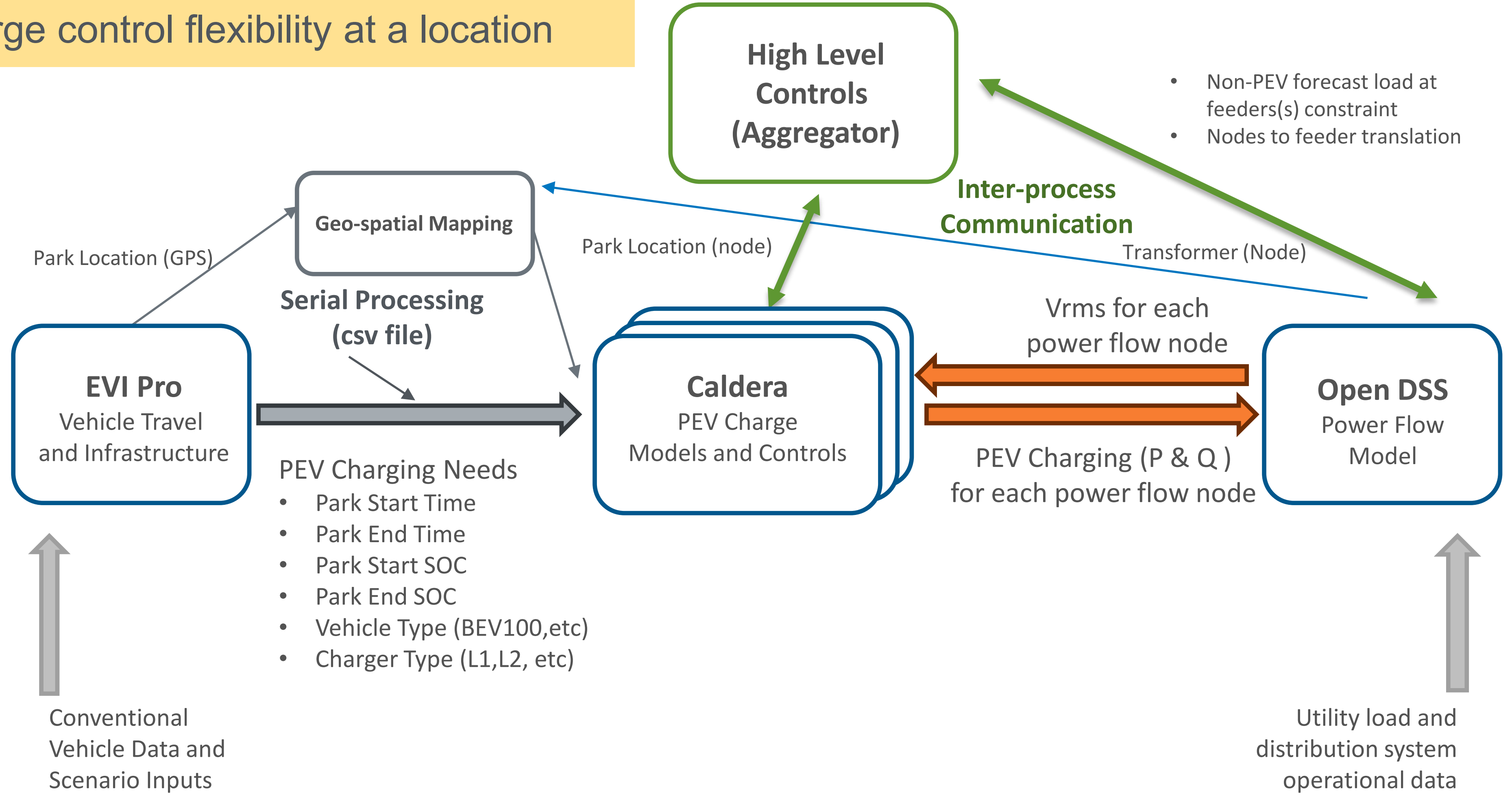
Approach: First, Understand PEVs at Scale with Unmanaged Charging

– No charge control flexibility



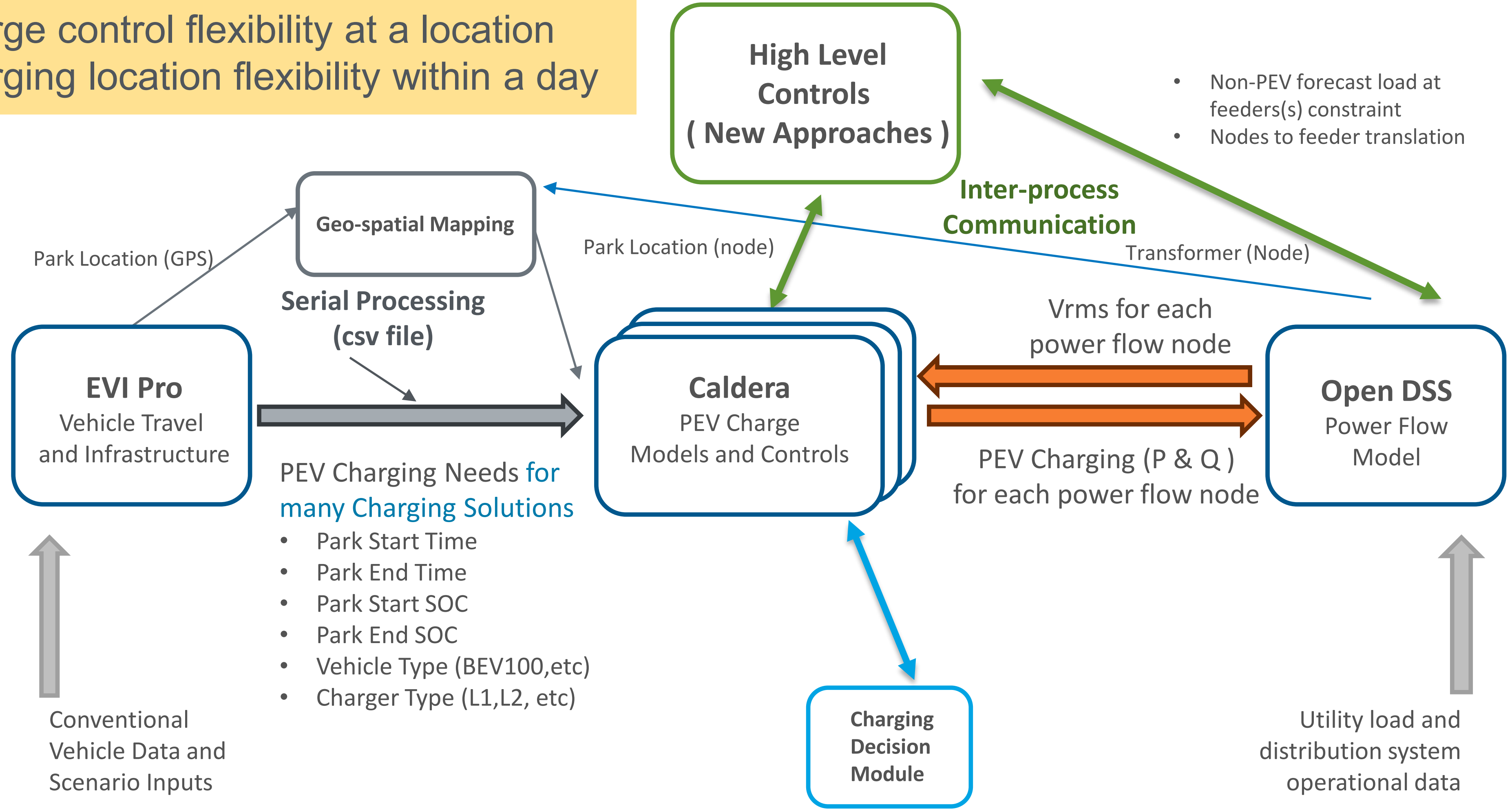
Approach: Next, Look at Managed Charging with Co-Simulation of PEV and Grid

– Charge control flexibility at a location



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

– Charge control flexibility at a location
– Charging location flexibility within a day



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 Advanced Charge Decision Model (Caldera)			■
9: Integration of Smart Charging with Building Loads	■	■	■
10: Integration of DER with Smart Extreme Fast Charging (XFC)			■

Technical Accomplishments and Progress:

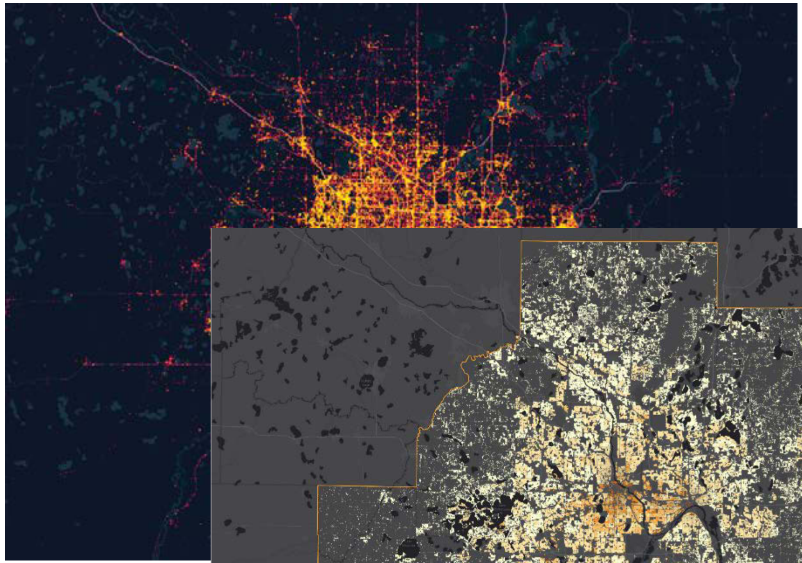
Task 1 - Scoping, Requirements, and Industry Engagement

- 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.

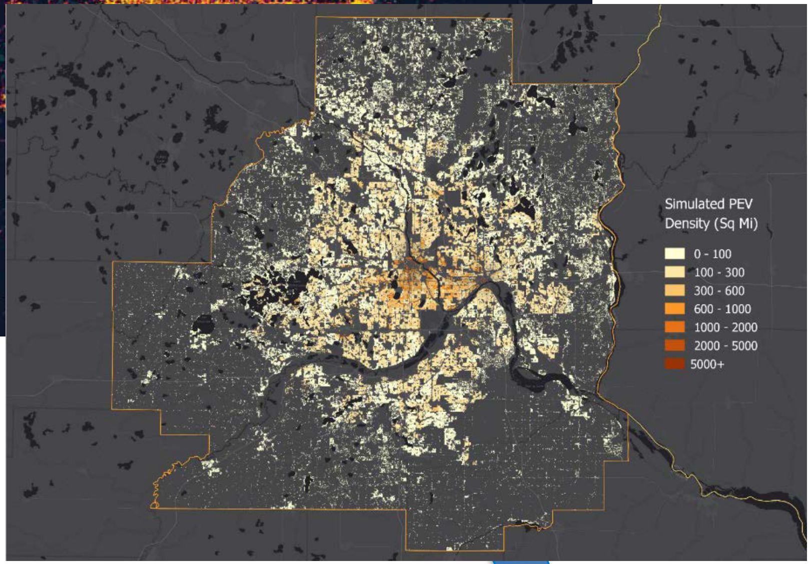
	Feeder	Description	# of customers on feeder	Peak Load [MW]
Minneapolis	1	Primarily residential and heavily loaded	2254	10.6
	2	Unbalanced, heavily residential and lightly loaded	283	1.4
	3	Long and evenly mixed customer types	1835	6.5
	4	Unbalanced and evenly mixed customer types	1558	5.9
	5	Heavily 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

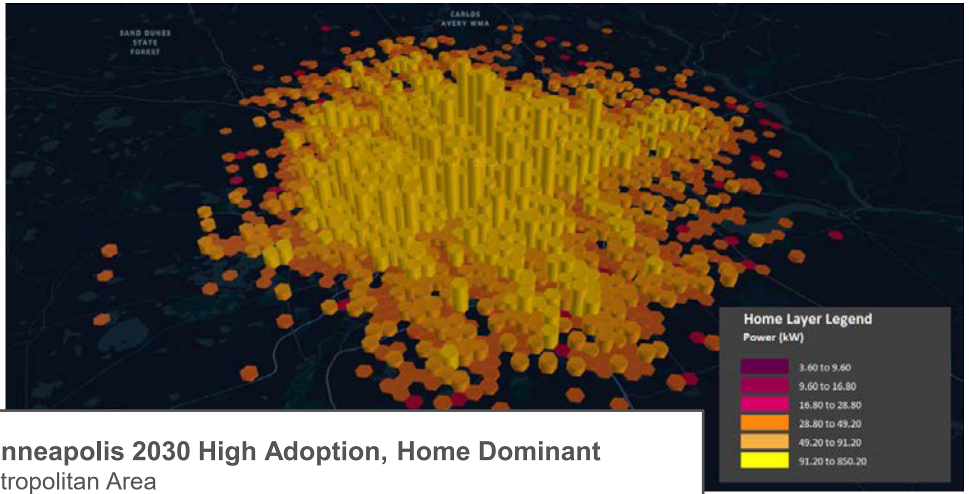


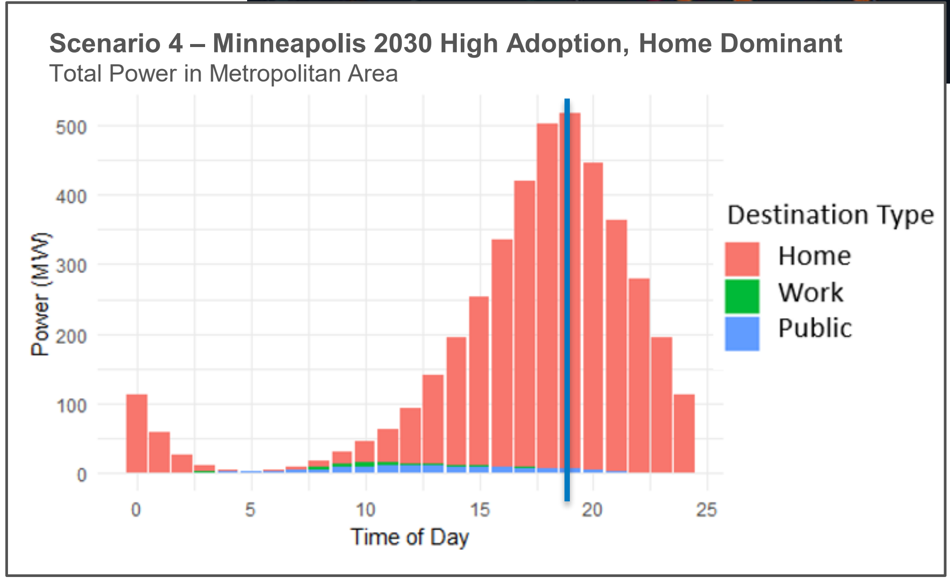
Travel Data



Land use and registration data

Spatial and temporal charging location is assigned from travel data



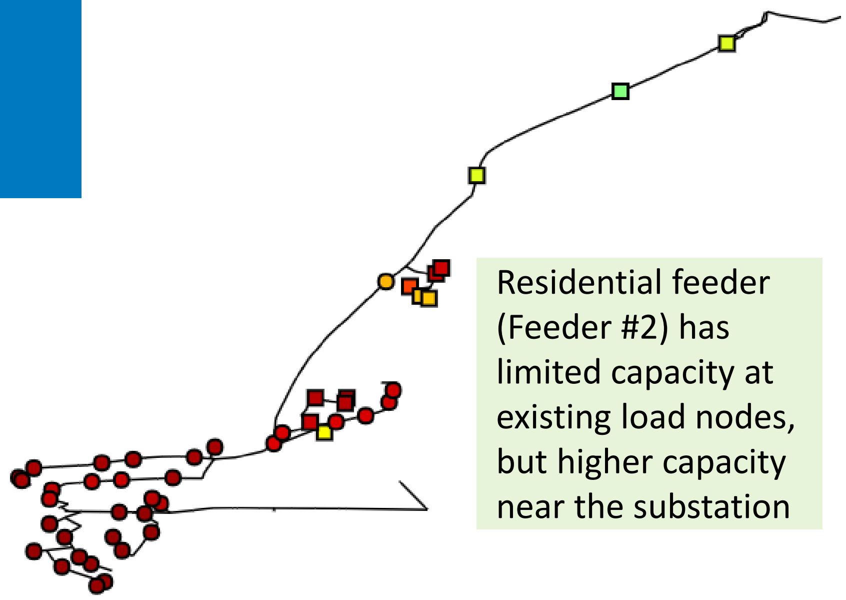


Technical Accomplishments and Progress:

Task 3 - PEV Charging and Distribution System Modeling

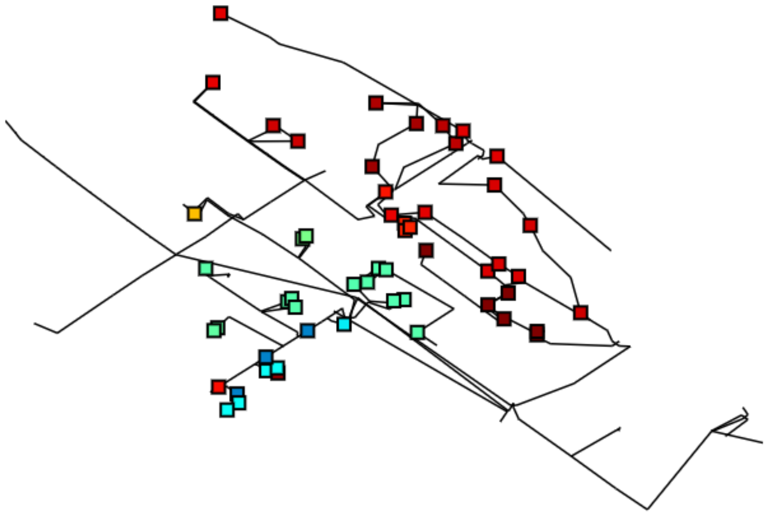
Minneapolis EV Hosting Capacity

- 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**

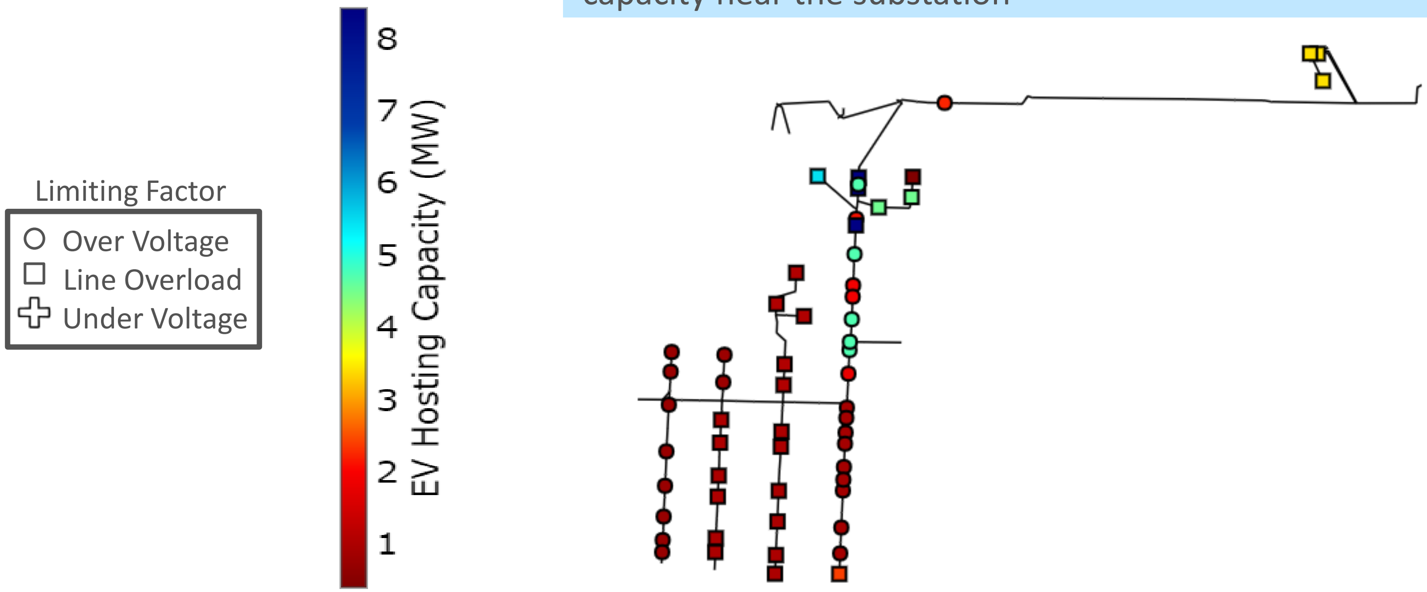


Residential feeder (Feeder #2) has limited capacity at existing load nodes, but higher capacity near the substation

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



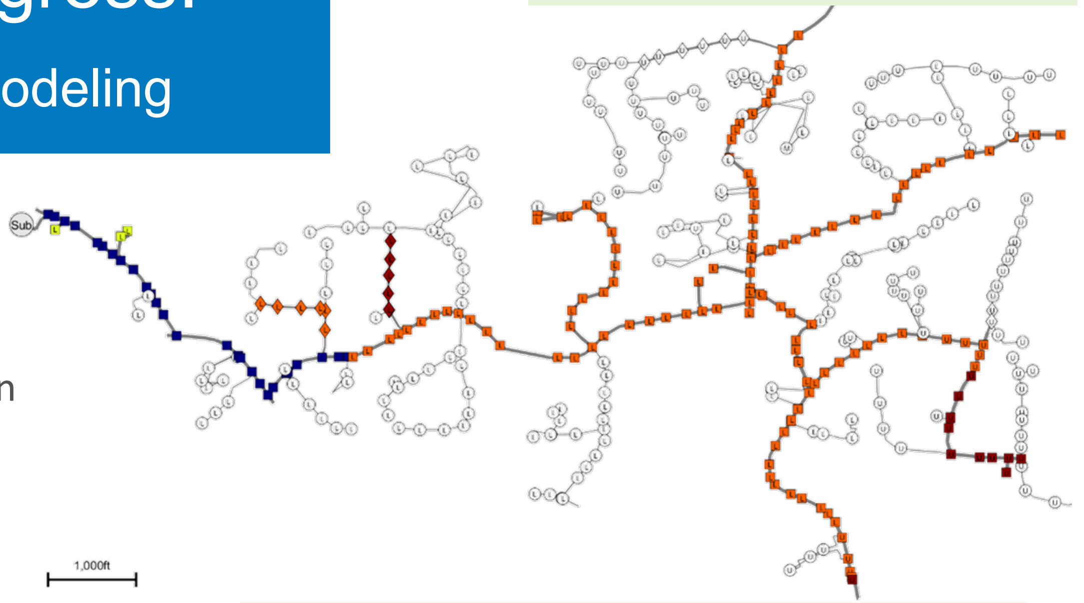
Technical Accomplishments and Progress:

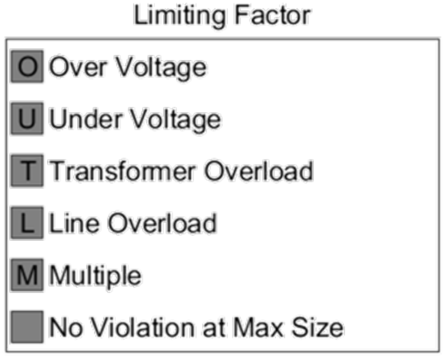
Task 3 - PEV Charging and Distribution System Modeling

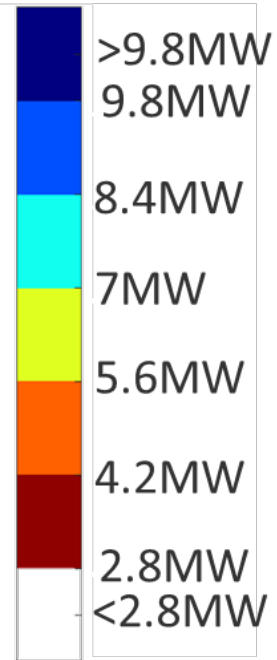
Atlanta EV Hosting Capacity

- 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**

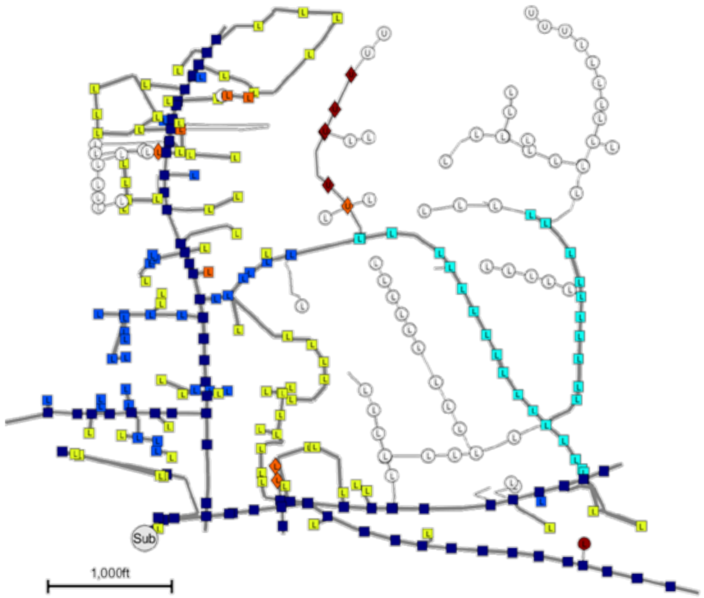
Residential feeder has capacity along main "backbone"



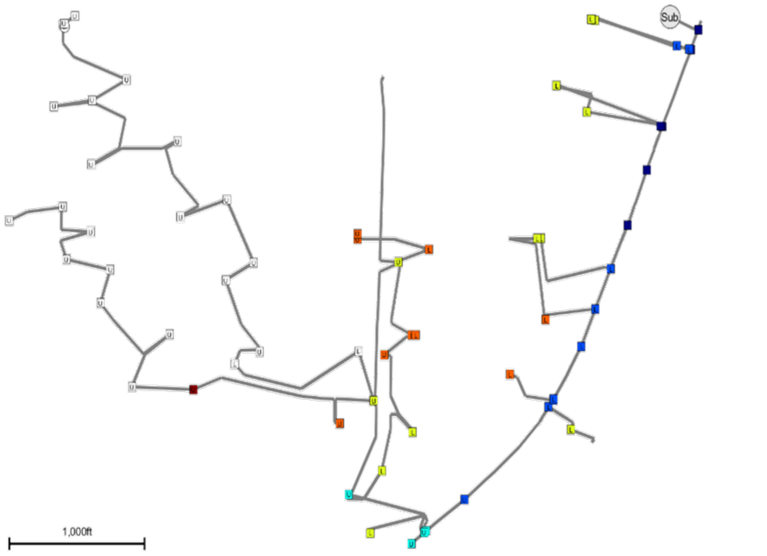




Commercial feeder has significant capacity at nearly all nodes



Industrial feeder capacity starts high but rapidly decreases away from substation



Technical Accomplishments and Progress:

Task 4 - Quantify the Impact of Uncontrolled Charging

Minneapolis

Impact of Residential EV charging

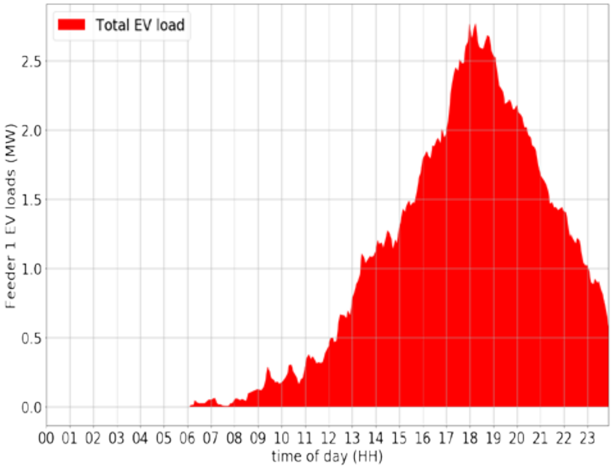
EV Load [MW]

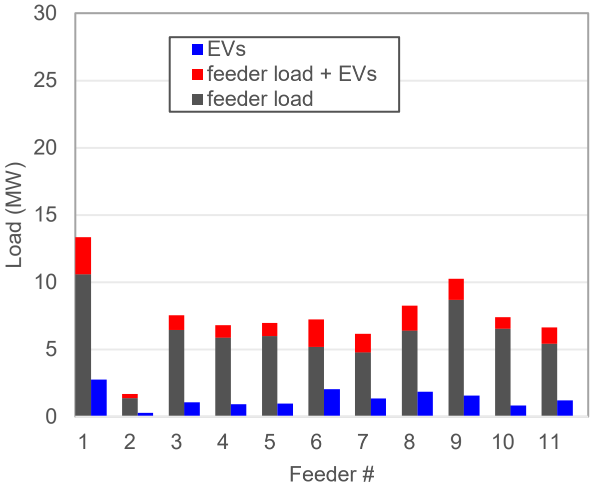
Total Load at Peak [MW]

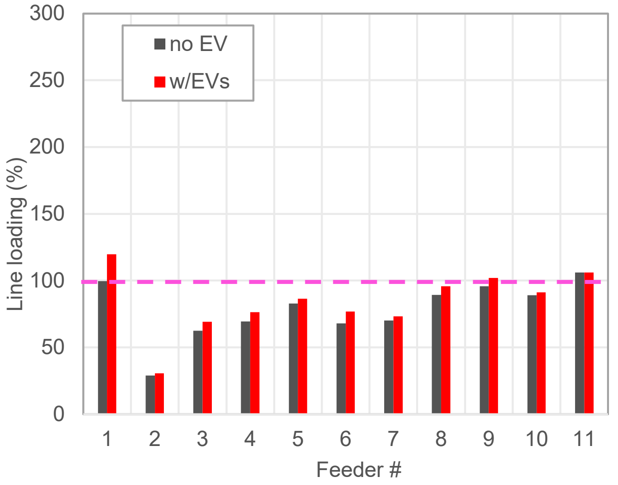
Line Loading at Peak [%]

"Reasonable":
2030 High, Home-Dominant

Under "reasonable" EV charging, EV impacts are modest due to medium EV adoption (**20-85% of personal vehicles are EVs**)* and weakly correlated charge start times. Some of the feeders in older parts of the metro exceed or are close to exceeding the thermal limits in this scenario. These feeders represent about 3.1% of EV load in Minneapolis for this scenario.

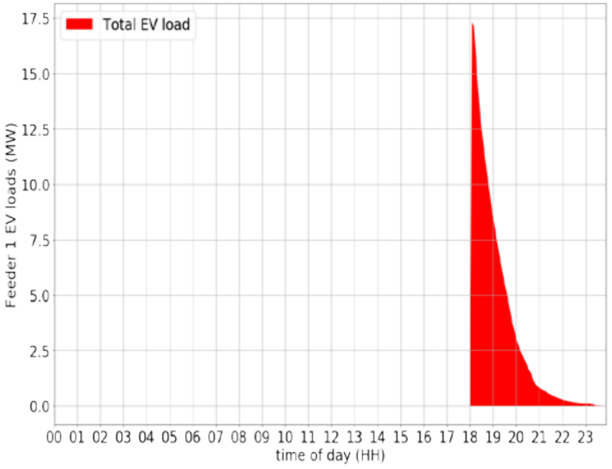


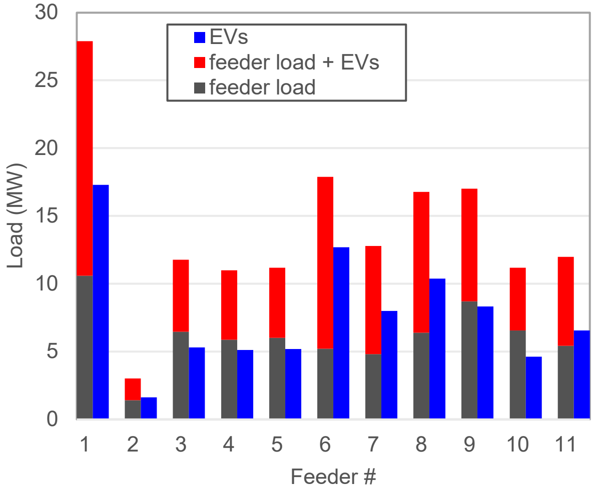


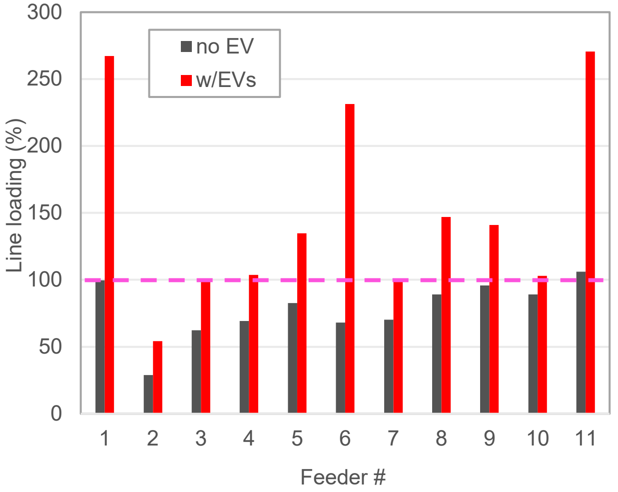


"Extreme": 1.8 EVs per Residential Customer; All EVs Begin Charging at 6PM

In the "extreme" case, **100% of personal vehicles are EVs**, and charge start times are perfectly correlated. This leads to line overloading and under voltage impacts on all feeders that have a lot of residential customers.







* Estimate is based on 1.8 EVs per residential customer on each feeder

Technical Accomplishments and Progress:

Task 4 - Quantify the Impact of Uncontrolled Charging

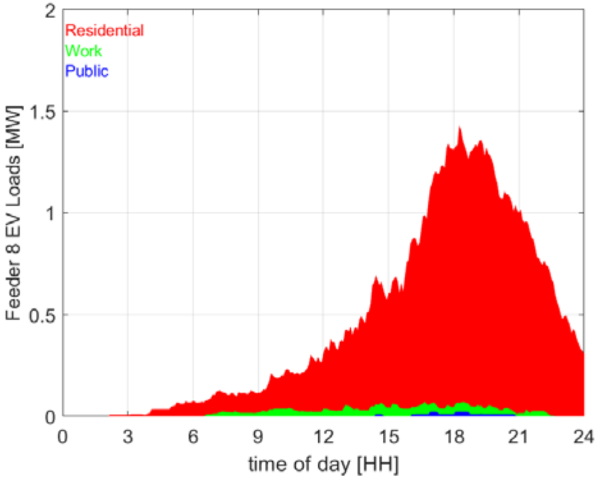
Atlanta

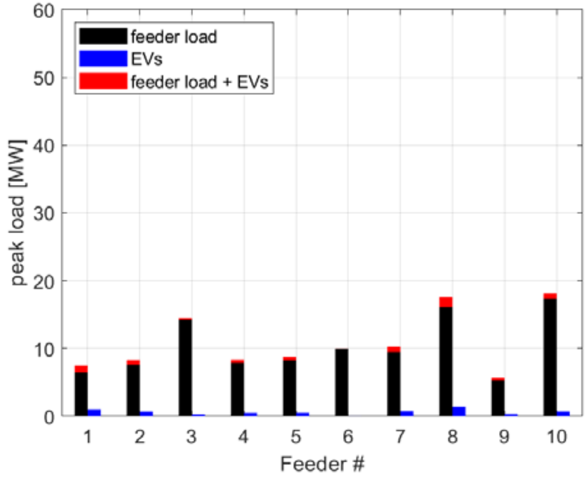
Impact of Residential EV charging

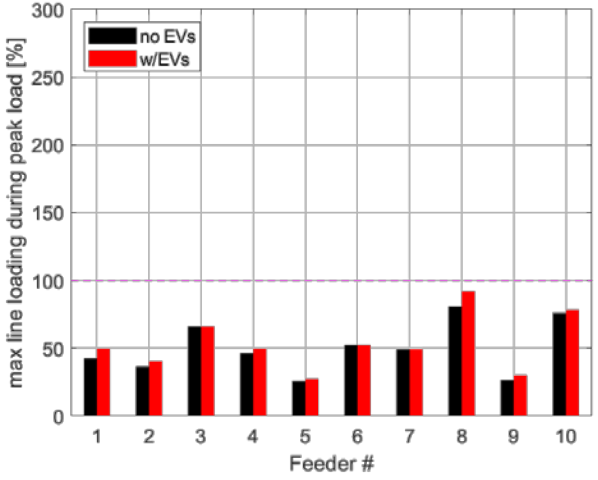
EV Load [MW]	Total Load at Peak [MW]	Line Loading at Peak [%]

“Reasonable”:
2030 High, Home-Dominant

Under “reasonable” EV charging, EV impacts are modest due to medium EV adoption (**5-60% of personal vehicles are EVs**)* and weakly correlated charge start times. These feeders represent about 1.9% of peak EV load in Atlanta for this scenario.

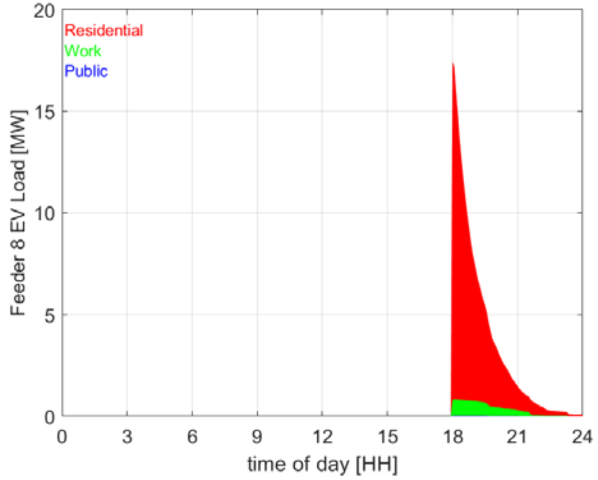


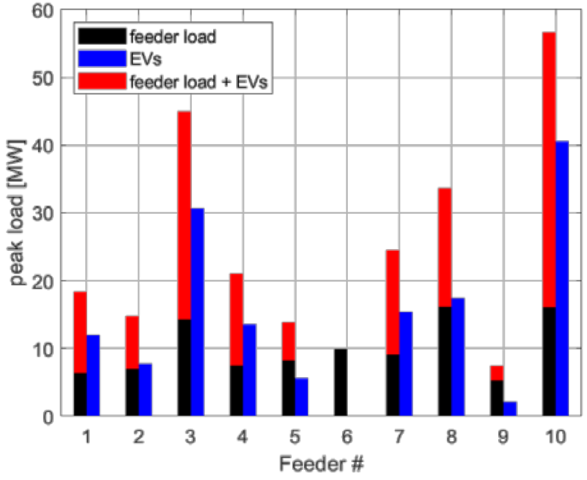


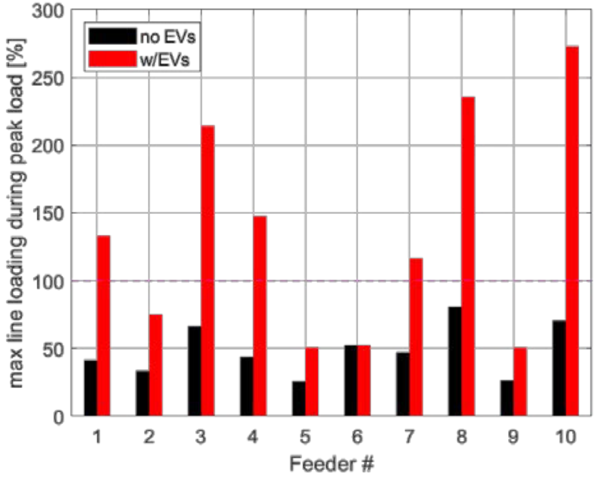


“Extreme”: 1.8 EVs per Residential Customer; All EVs Begin Charging at 6PM

In the “extreme” case, **100% of personal vehicles are EVs**, and charge start times are perfectly correlated. This leads to line overloading and under voltage impacts on all feeders that have a lot of residential customers.







* Estimate is based on 1.8 EVs per residential customer on each feeder

Technical Accomplishments and Progress:

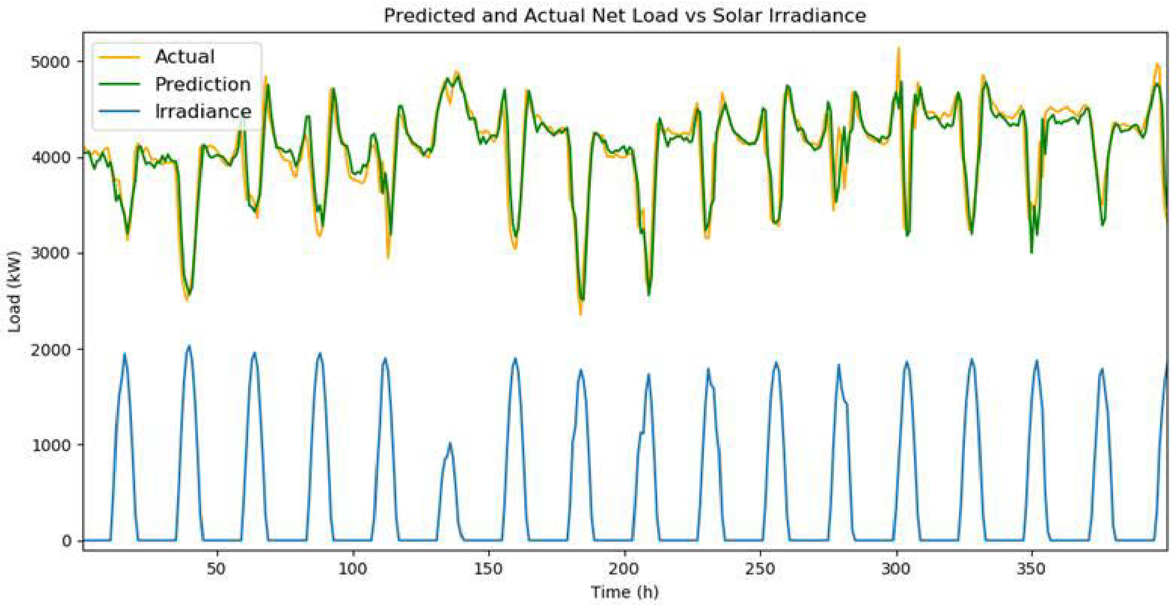
Task 5 - Refine Smart Charge Control Strategies (Caldera)

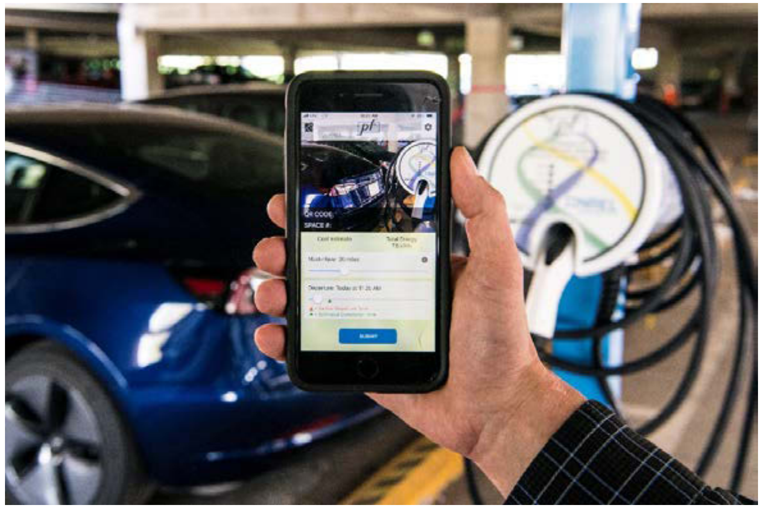
- Multiple control approaches of varying complexity will be studied in project.
- Caldera has been upgraded with a framework to easily implement new control approaches
- Several control strategies have already been added:
  - **Voltage support using autonomous droop-based control.**
  - **Shifting charge energy using centrally optimized control approach.**
  - Shifting charge energy using time of use rates.
  - Shifting charge energy using time of use rates **with randomized charge times**.
- Other control strategies may be added in future:
  - **Shift charge energy using aggregator assisted decentralized approach**
  - **Shift charge energy using fully distributed approach minimizing load variance across chargers**
  - **Centrally optimized voltage support**

Technical Accomplishments and Progress:

Task 9 - Integration of Smart Charging with Building Loads

- A new commercial smart charging EVSE system at the NREL garage is capable of supporting building integration activities through
  - **Aggregate and circuit-level control**
  - **Cost recovery mechanisms**
  - **User input data (departure, energy)**
- Charging data with up to a 3-year history has been joined with building load and weather forecasts allowing for **deep-learning models to support integration with building load and generation predictions**.

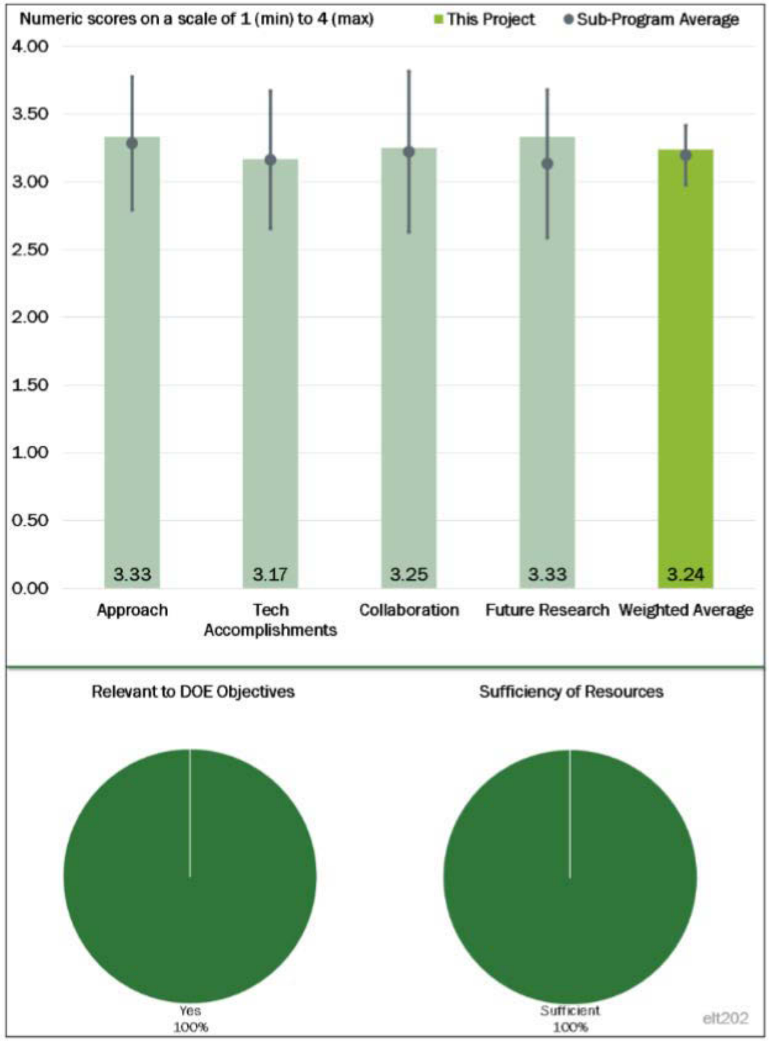




Reponses to Previous Year Reviewer's Comments

Three main concerns raised at the last AMR:

- *The reviewer wanted to see some discussion on how localized renewables would play a role in the data that are being gathered.*
  - <u>Response:</u> Investigation of local renewables integration with xFC charging and transmission-level implications, that will include utility-scale renewables is planned for year 3.
- *… Given that the research is taking place in Minneapolis and Atlanta, the reviewer asked what sort of extrapolation could be expected in a more rural setting*
  - <u>Response:</u> Extrapolation to a rural setting will be difficult given different travel and feeder characteristics. The team believes that a future study in a new region is a better approach.
- *… it is difficult to convince the reviewer that grid impact analysis for two different cities have to be done by two different teams… it should be more reasonable for one team to handle both...*
  - <u>Response:</u> The team meets on a bi-weekly basis to promote alignment across both transportation and grid analysis tasks. While the two-region, two-group approach presents challenges it also provides fresh perspectives. Additionally, one team will be focused on secondary aspects while the other is focusing on the bulk system.



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

- 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 for system-wide benefit
  - Distribution services have traditionally not been monetized.
- Develop Caldera API to enable smart charge control strategy development outside of Caldera.
- Inclusion of **XFC in distribution grid simulations** at locations that are reasonable both based on grid connections (i.e., area with high hosting capacity), but also based on development and travel in area.

Proposed Future Research

- Project, as a proposed and funded is a 3-year project.
- Remainder of FY20:
  - Identification of smart charging control strategies
  - Quantification of implementation costs
  - Distribution impact analysis for uncontrolled and controlled scenarios

Milestone Name/Description	Task	Deadline	Milestone Type
Distribution impact analysis including hosting capacity, distribution system upgrades, and costs performed for the smart control strategies identified	6.2.1	6/30/2020	Quarterly Progress
Quantify implementation costs of multiple smart charge management approaches	6.2.3	9/29/2020	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	9/29/2020	Go/No-Go Milestone

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

Proposed Future Research

- Remainder of FY21:
  - Transmission-level analysis
  - Integration of smart charging with extreme fast charging and distributed energy resources
  - Integration and development into final tools

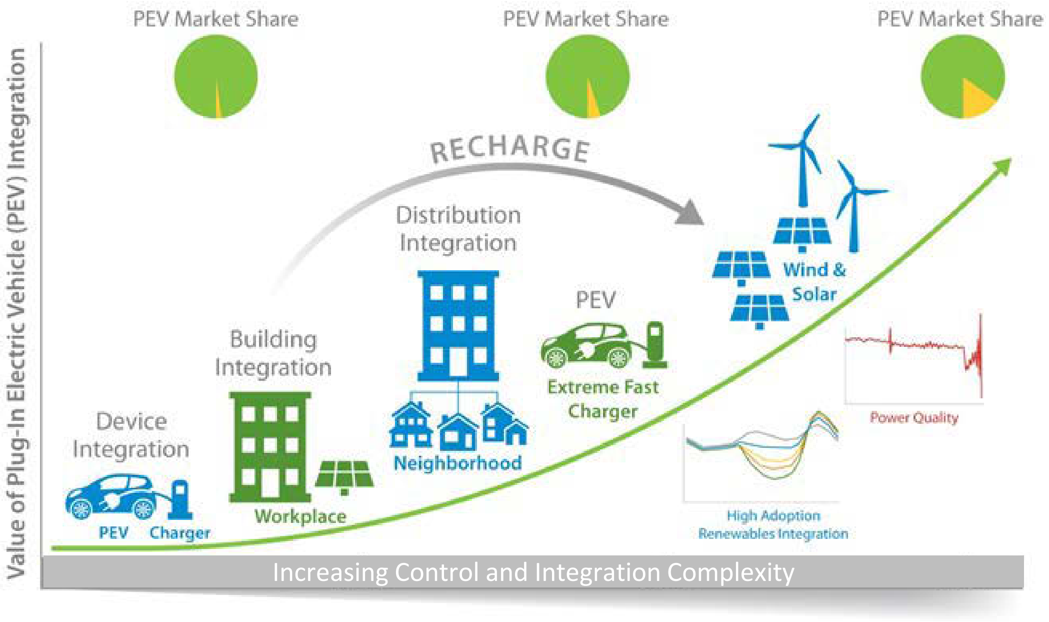
Milestone Name/Description	Task	Deadline	Milestone Type
Transmission-level analysis showing EV charger impact to net load profiles and resulting modifications	6.2.2	12/31/2020	Quarterly Progress
Demonstration of the value of smart charging integration with other DER (PV, storage) to minimize cost and grid impacts	10.3.1 10.3.2	3/31/2021	Quarterly Progress
Incorporate building control and load prediction tools into commercial product	9.3.2	6/30/2021	Quarterly Progress

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

Summary

This project will:

- Determine how **PEV charging at scale** in two cities 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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INL Team:

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Zonggen Yi
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SNL Team:

Matt Lave
Birk Jones
Summer Ferreira

Thank You !

The RECHARGE Team

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NREL
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

Technical Accomplishments and Progress:

Task 4 - Quantify the Impact of Uncontrolled Charging

Minneapolis

Impact of Residential EV charging

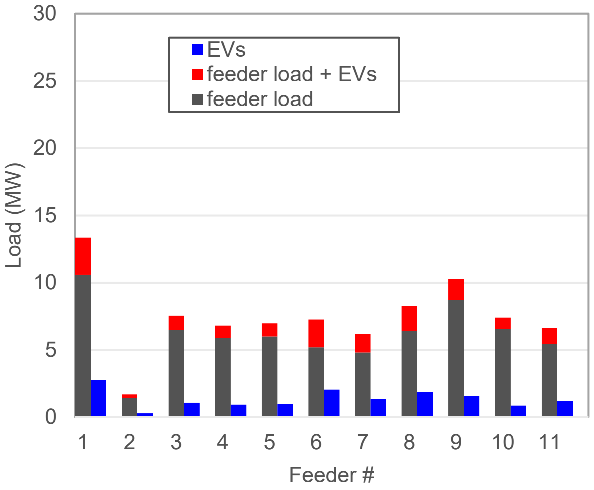
“Reasonable”:
2030 High, Home-Dominant

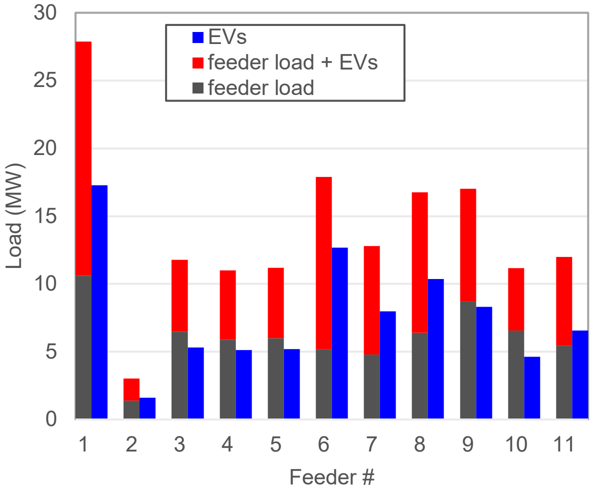
Under “reasonable” EV charging, EV impacts are modest due to medium EV adoption (**20-85% of personal vehicles are EVs**)* and weakly correlated charge start times. Some of the feeders in older parts of the metro exceed or are close to exceeding the thermal limits in this scenario. These feeders represent about 3.1% of EV load in Minneapolis for this scenario.

“Extreme”: 1.8 EVs per Residential Customer; All EVs Begin Charging at 6PM

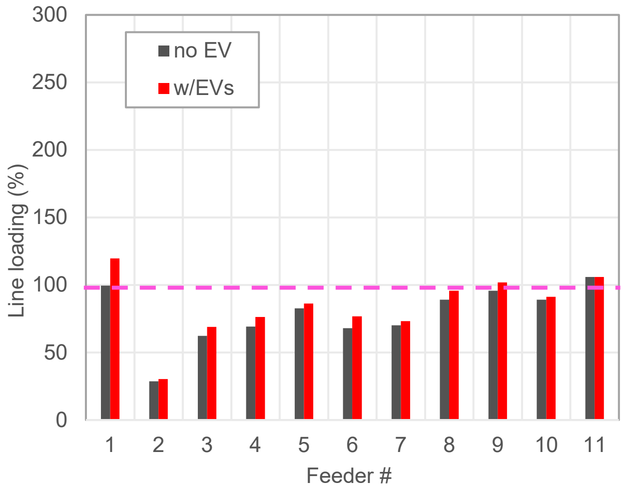
In the “extreme” case, **100% of personal vehicles are EVs**, and charge start times are perfectly correlated. This leads to line overloading and under voltage impacts on all feeders that have a lot of residential customers.

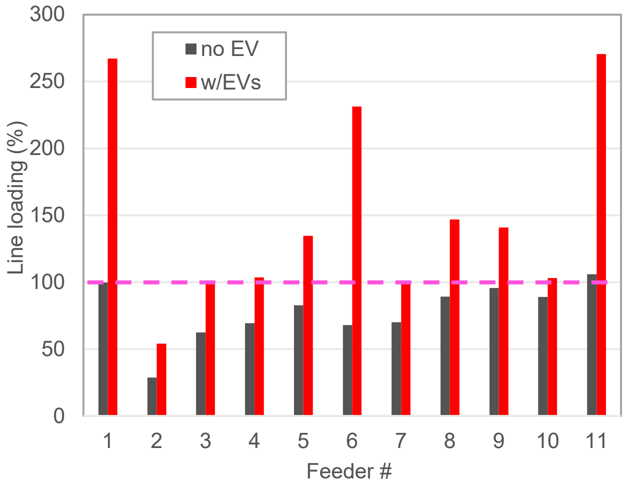
Total Load at Peak [MW]



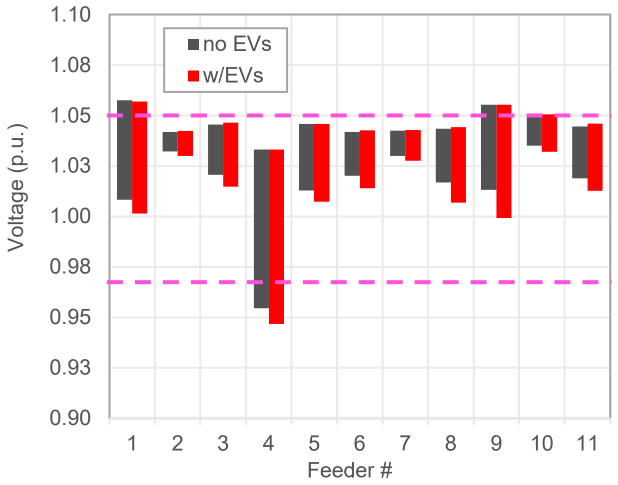


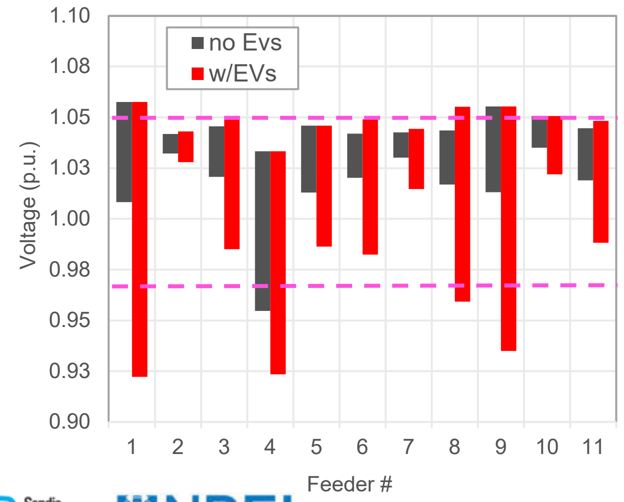
Line Loading at Peak [%]





Voltage Range at Peak [p.u.]





* Estimate is based on 1.8 EVs per residential customer on each feeder

Technical Back-up Slides:

Task 4 - Quantify the Impact of Uncontrolled Charging

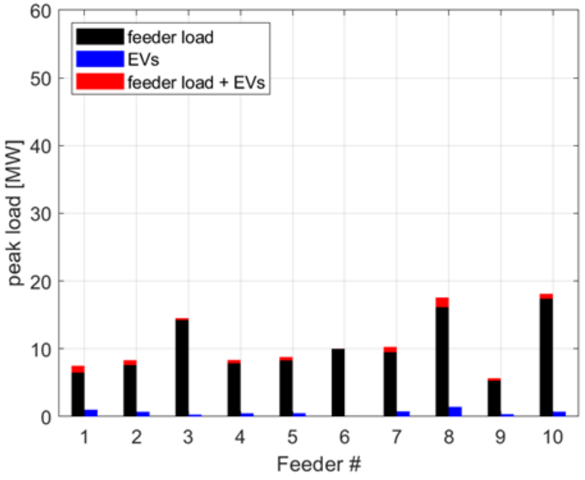
Atlanta

Impact of Residential EV charging

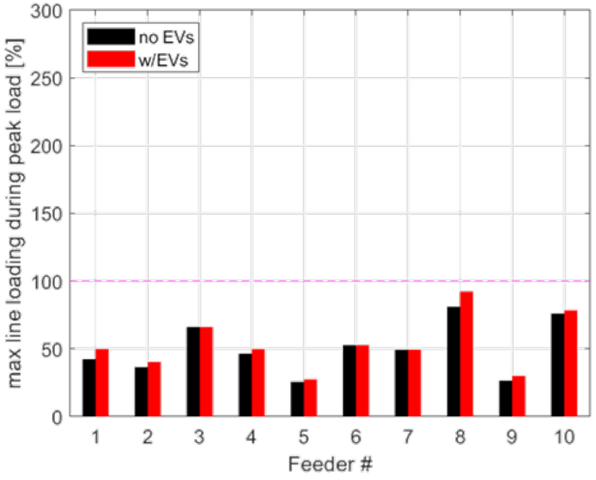
"Reasonable":
2030 High, Home-Dominant

Under "reasonable" EV charging, EV impacts are modest due to medium EV adoption (**5-60% of personal vehicles are EVs**)* and weakly correlated charge start times. These feeders represent about 1.9% of peak EV load in Atlanta for this scenario.

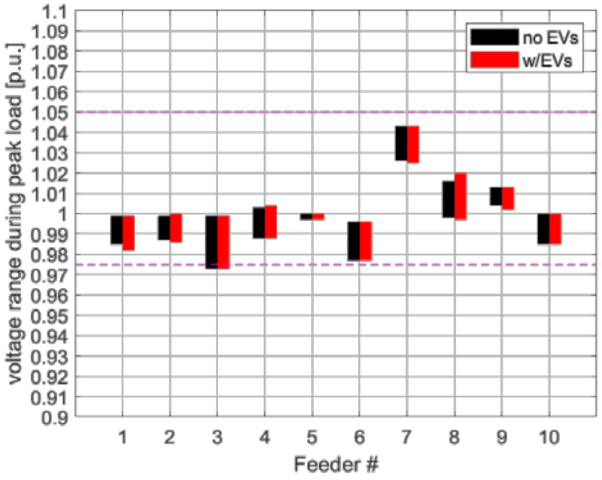
Total Load at Peak [MW]



Line Loading at Peak [%]

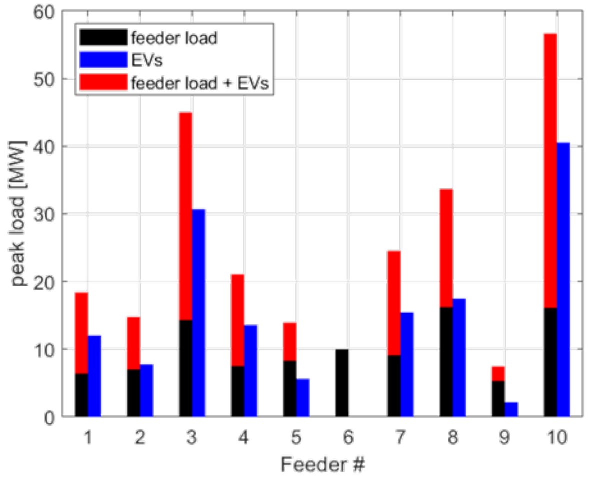


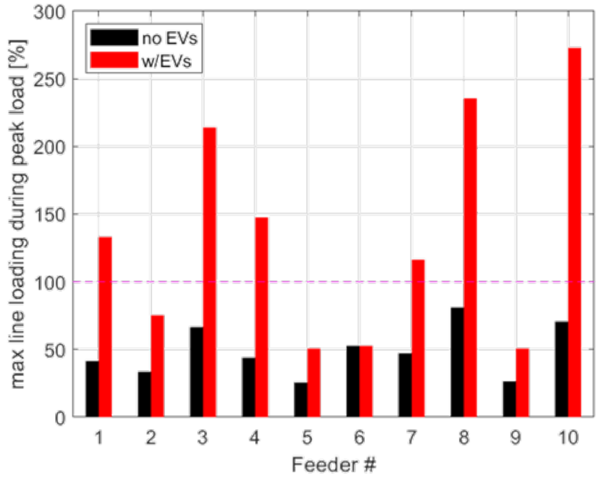
Voltage Range at Peak [p.u.]

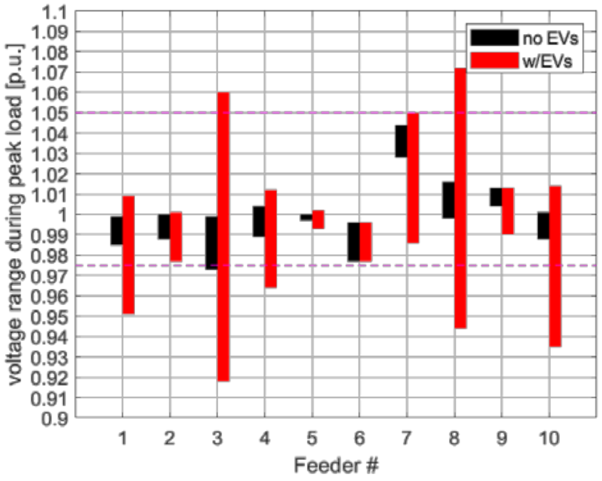


"Extreme": 1.8 EVs per Residential Customer; All EVs Begin Charging at 6PM

In the "extreme" case, **100% of personal vehicles are EVs**, and charge start times are perfectly correlated. This leads to line overloading and under voltage impacts on all feeders that have a lot of residential customers.







* Estimate is based on 1.8 EVs per residential customer on each feeder

Technical Back-up Slides:

Task 5 - Refine Smart Charge Control Strategies (Caldera)

Caldera Enables Co-Simulation of Charging Infrastructure and the Grid; while applying Smart Charging Control Strategies