EV Smart Charge Management and High Power Fast Charging:

Integrating EVs with Buildings, Onsite Energy Resources, and the Grid

Tony Markel and Andrew Meintz
November 27, 2018

State Energy Advisory Board at NREL

EV Grid Integration @ NREL

- Facility Smart Charge Management: NREL employee workplace charging integration with building load for demand charge mitigation.
- DCFC Systems Integration: DC fast charging system integration with onsite storage, generation, L2 charging, and building load.
- Distribution System Vehicle-Grid Impacts: PHIL capability to emulate multiple nodes on a feeder at medium voltage to residential (L1/L2) and/or commercial (XFC) low voltage systems at up to 2 MW real load
- Wireless Charging and Transportation Systems: Energy use and design analysis for adding frequent intra-day charging to a shuttle services
- EVSE Cyber Security: Virtualized environment representing power and operational networks of a small distribution utility enables protect, detect, and isolate strategies for grid integrated infrastructure

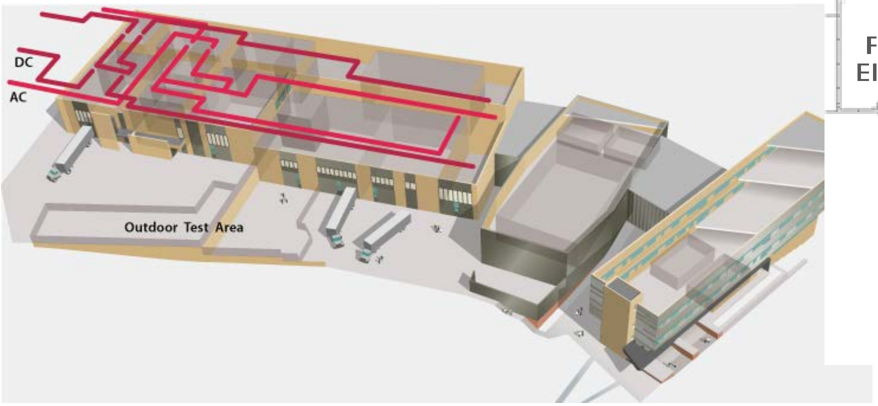
Energy Systems Integration Facility (ESIF)

- 182,500 sq. ft.
- 2x 1-MVA bi-directional grid simulator
- Low Voltage Distribution Bus
- Medium Voltage Outdoor Test Area
- Full Power Hardware in the Loop (PHIL) testing
- Petascale High Performance Computing (HPC)

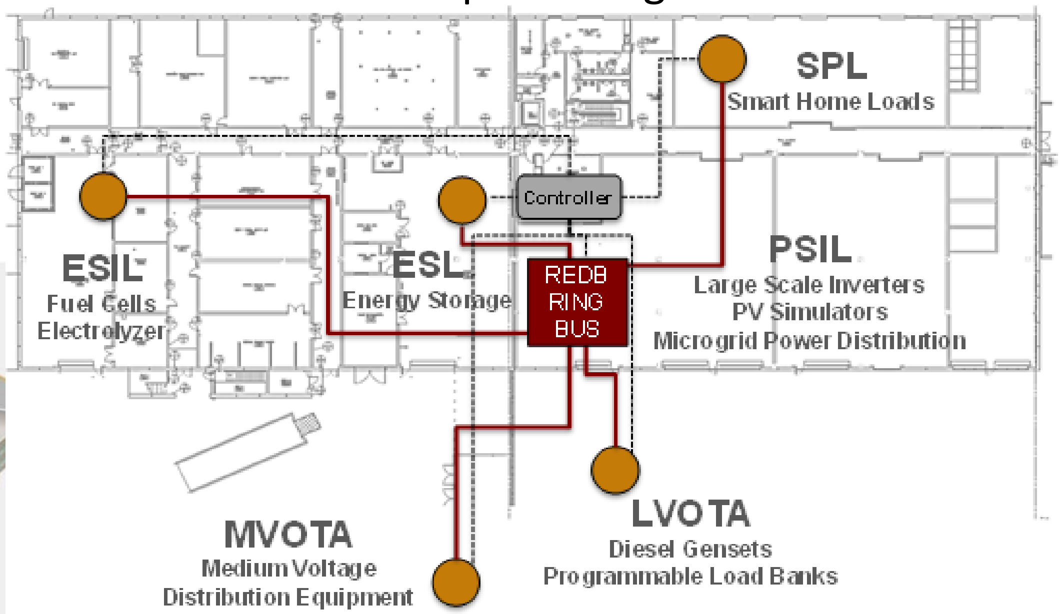
Research Electrical Distribution Bus (REDB)

AC (600 V)
- 250 A
- 1600 A

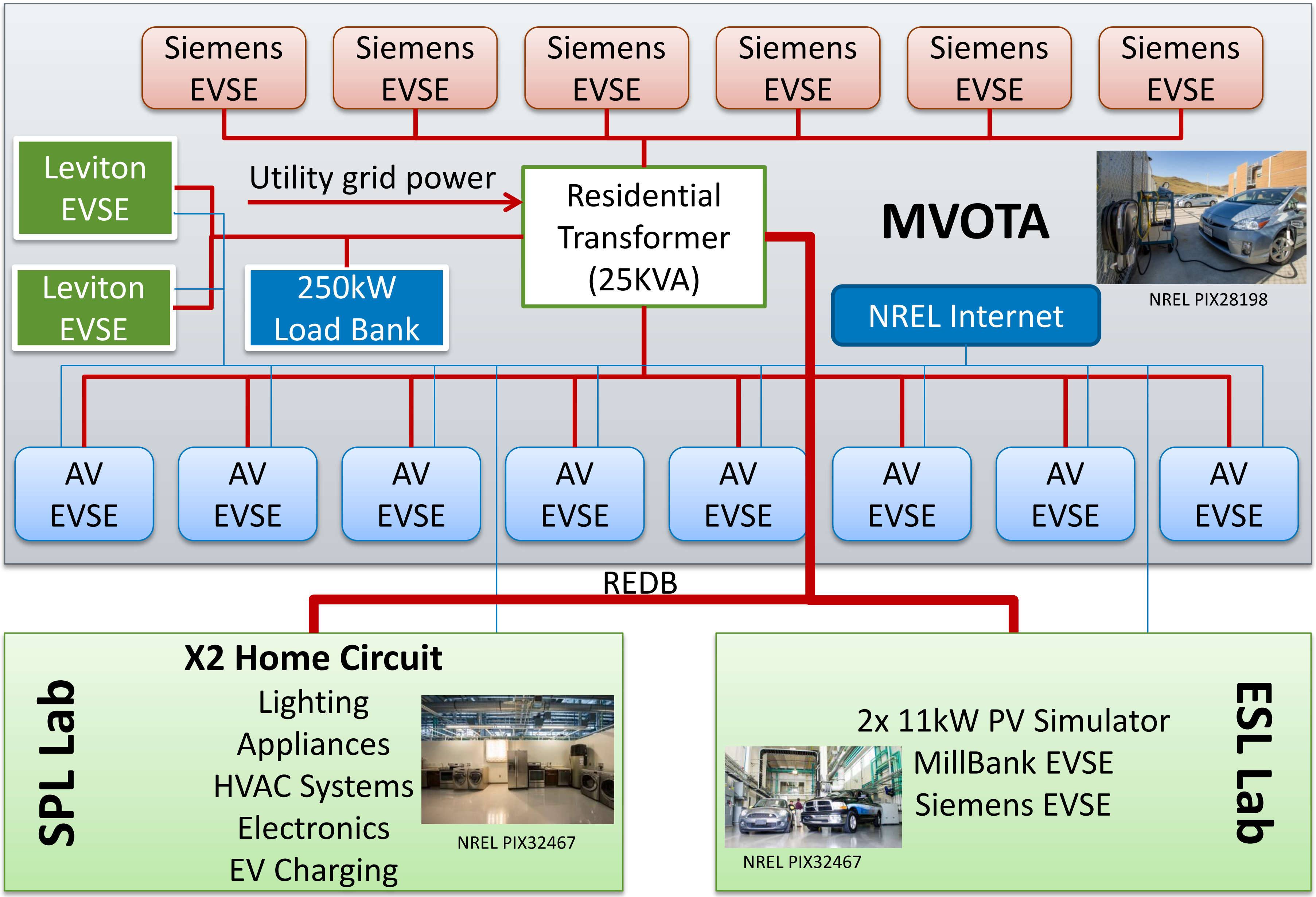
DC (±500 V)
- 250 A
- 1600 A



Example microgrid



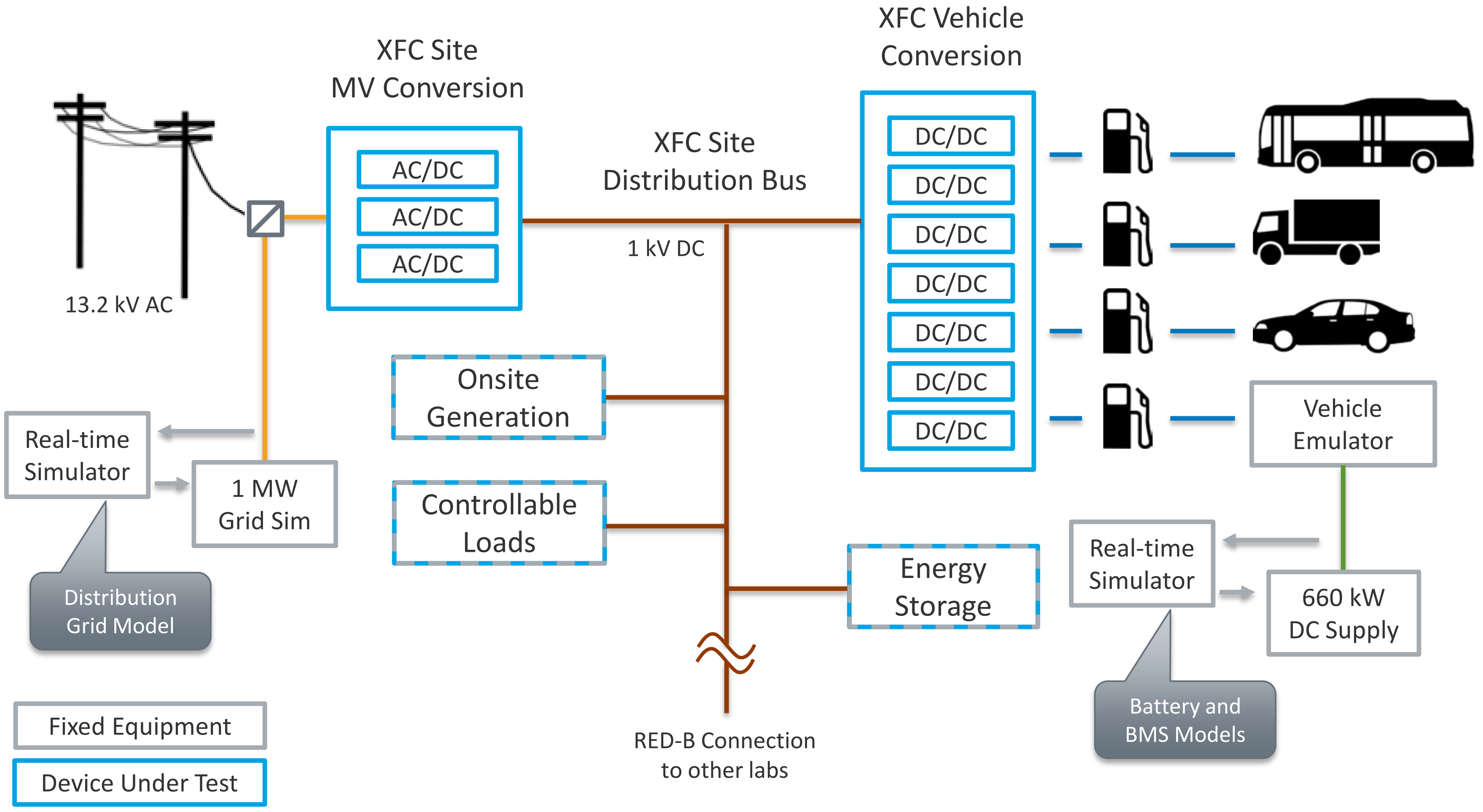
Experiments Evaluating High Penetration EV Integration in Residential Networks



MVOTA: Medium Voltage Outdoor Testing Area
SPL: Smart Power Laboratory
ESL: Energy Storage Laboratory
REDB: Research Electrical Distribution Bus

Communication line
Power line
REDB

Scenarios for High Voltage DC Distribution to XFC



PHIL enables evaluation of

- Grid **interface control** for reactive and real power
- Grid **system dynamics** with simulated feeders
- **Microgrid controller** interaction with multiple DER controllers
- **System conversion** and roundtrip **energy storage efficiency** under various operating conditions
- **Vehicle-to-vehicle** control **interactions** for site wide energy control

Key Messages

- Integrated EV infrastructure scenarios present challenges for both power and communications implementation
- Minimizing cost and complexity while enhancing functionality drives research agenda
- Future mobility systems rely on secure connectivity and coordination

EV Smart Charge Management

Integrating EVs with Buildings, Onsite Energy Resources, and the Grid

Challenges of Smart Charge Management in Workplaces

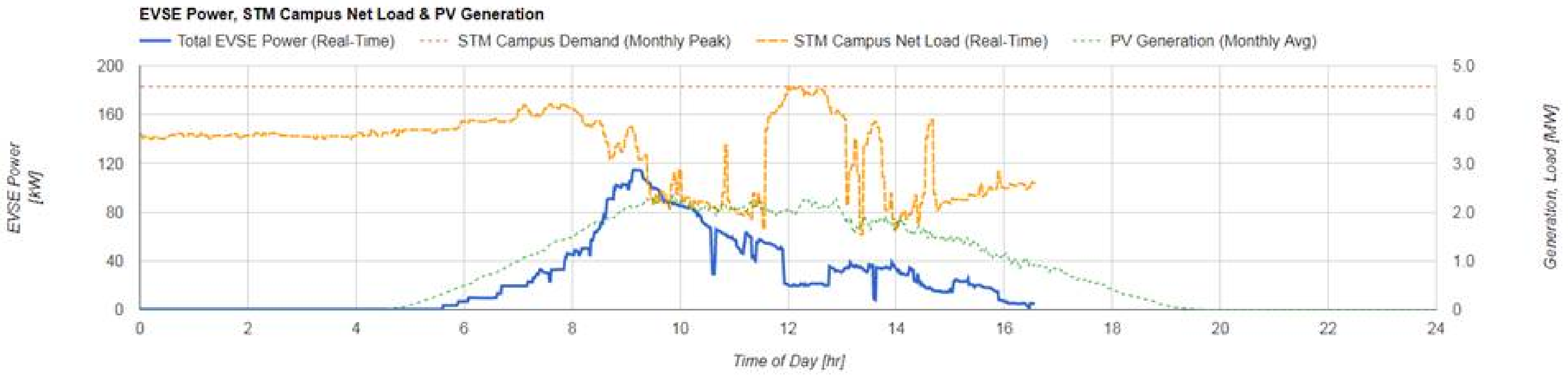
- Value of forecasting
  - Precise forecasts of loads and local generation combined with charge management offer electricity cost savings
- Better estimation of PEV users' energy requests and departure times
  - The information provided by users is not always reliable
  - Good estimation of user's energy request and departure time provides better performance of charge management


NREL PIX21661

Putting EV Smart Management to Work

NREL Parking Garage EVSE Status Display

6/19/2018, 4:43:34 PM



Monthly Peak	Campus Net Load	Total EVSE Power	Curtailed EVSE Load
4.576 [MW]	2.585 [MW]	0.063 [kW]	No load management

- The campus net load went from 1.6 MW to 4 MW in 6 minutes (fast moving storm)
- The curtailed EV load during the management is about 28 kW, which is about $470 based on NREL's demand charge rage ($16.79/kW).
- If same event happened during morning, more than 90kW could have been curtailed, saving >$1500.

Bi-directional Power Flow and Emergency Power Back-up

Integrating EVs with Buildings, Onsite Energy Resources, and the Grid

Bi-directional System Component Characterization

- Sharp Energy Storage System: 43 kWh, 30 kW IPC interface
- Via Motors Van - Coritech EVSE: 23 kWh, 14.4 kW V2G-V2H
- Nissan Leaf - Nichicon EV Power Station: 6 kW V2H
- Smith EV Truck - Coritech EVSE: 80 kWh, 60 kW
- Transpower School Bus - Milbank EVSE: 90 kWh, 22.6 kW
- Mini-E – Milbank EVSE: 30 kWh, 14.4 kW

- PV System (emulated: 22 kW and real: 18 kW)
- Residential and commercial loads (125 kW AC)
- 30 kW grid simulator and RTDS system

Nissan Leaf Nichicon V2H

Via Motors Van

Smith EV Truck

Sharp Stationary Storage

Export Power Using PEVs

- Via Motors Van with Coritech EVSE
  - 14.4-kW on-board bidirectional charger
  - Series hybrid PHEV with 23-kWh battery
  - V2H and V2G capable, SEP 2.0 grid link, Homeplug GREEN PHY
  - Single phase 120V/240V up to 60 A off-grid power generation

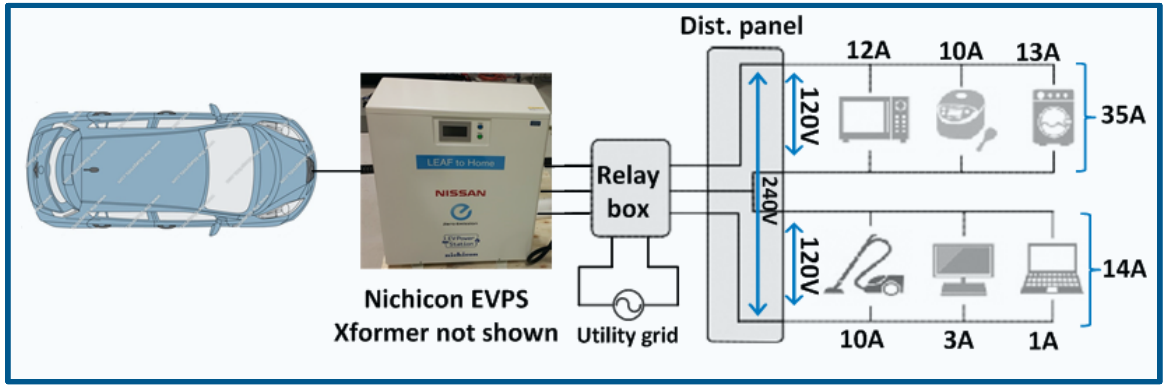
- Nichicon EV Power Station
  - 6-kW off-board charging capability
  - 120 V / 240 V, total 50 A@120 V V2H power capability
  - Runs with Chademo-compatible PEVs (Leaf, Mitsubishi i-MiEV)
  - Switching from grid-connected to grid-isolated operation

Research scope

- Analysis of powering real home loads with Nissan Leaf and Via Van w/o grid.
- Evaluating the emergency power capability of EV (Leaf) and PHEV (Via-Van).
- Integrating emulated/real solar PV systems with V2H to extend the emergency power duration.
- Investigating microgrid operation of vehicles to power several houses.

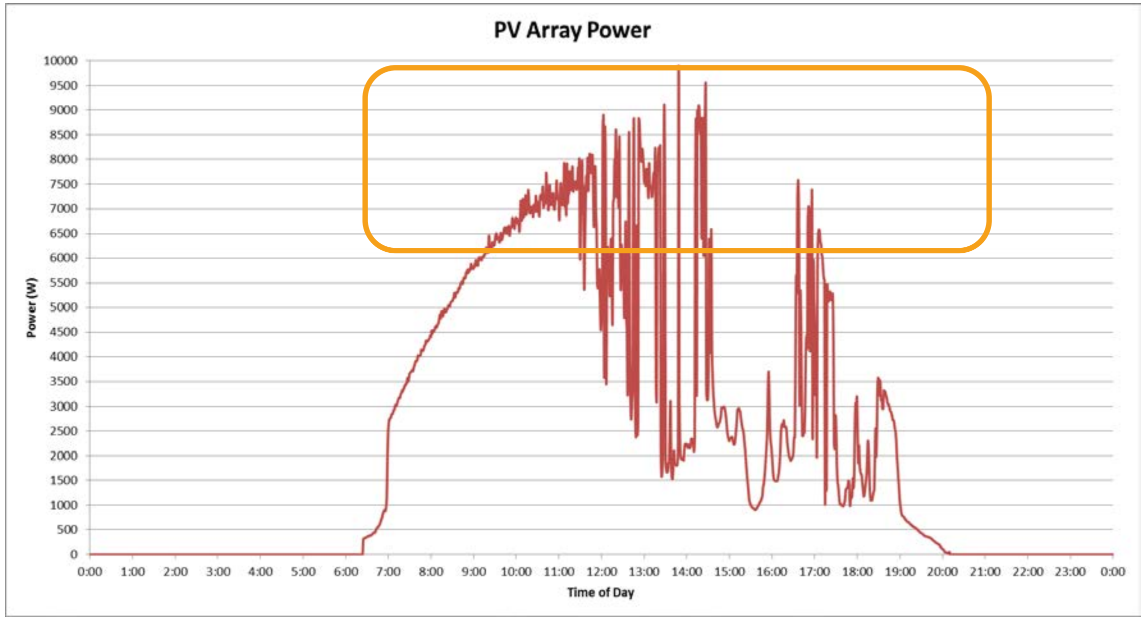
Via export power port

Source NREL, Mithat Kisacikoglu



Leaf-Nichicon power export

Emergency Power Backup



	HVAC	Water Heater	Dryer	Stove	Refrigerator	Washer	Dishwasher	Lights	Television
On Time (Min)	56.6	37.17	65.52	1.12	122.12	45.50	55.50	24.35	20.58
Energy (Wh)	1136.91	3519.60	3014.62	23.16	254.10	204.54	675.98	213.61	37.24
Avg. Power (W)	1205.20	5681.87	2760.78	1244.40	124.85	269.72	730.79	526.36	108.56
Peak Power (W)	4849.15	5776.56	6156.19	1293.11	351.61	1244.24	1033.68	550.13	112.16

PV Generation

Home Loads

Nissan Leaf

EVPS AC/DC

Relay Box

Grid

Truck Electrification Testing at ESIF

Exploring Grid Value Proposition with EV School Bus

Utility Truck Offering Ability to Power Local Transformers

Smart Charge Management (RECHARGE)

Integrating EVs with Buildings, Onsite Energy Resources, and the Grid

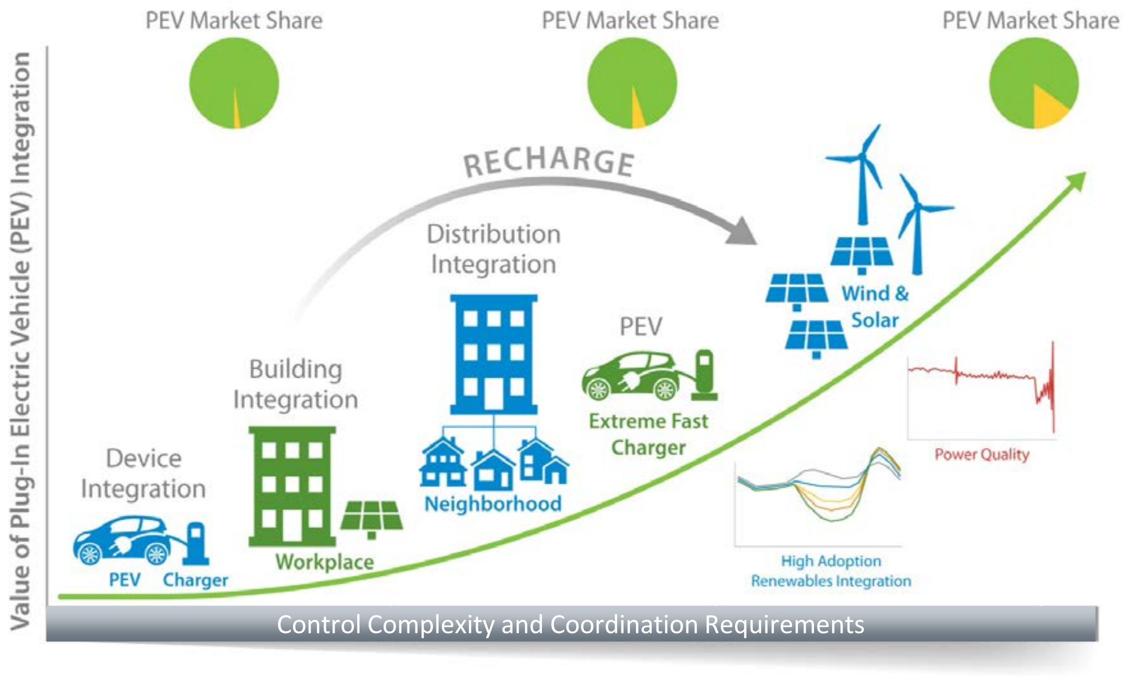
Smart PEV Charging for a Reliable and Resilient Grid (RECHARGE)

RECHARGE will consider the **impact to the grid of PEV charging at scale** under a variety of future scenarios, including

- adoption of different vehicle types,
- proliferation of extreme fast charging (xFC),
- expanded adoption of distributed energy resources (DER) throughout the system,
- and multiple smart charge management approaches

This project will address the following questions for smart charging of PEVs at Scale:

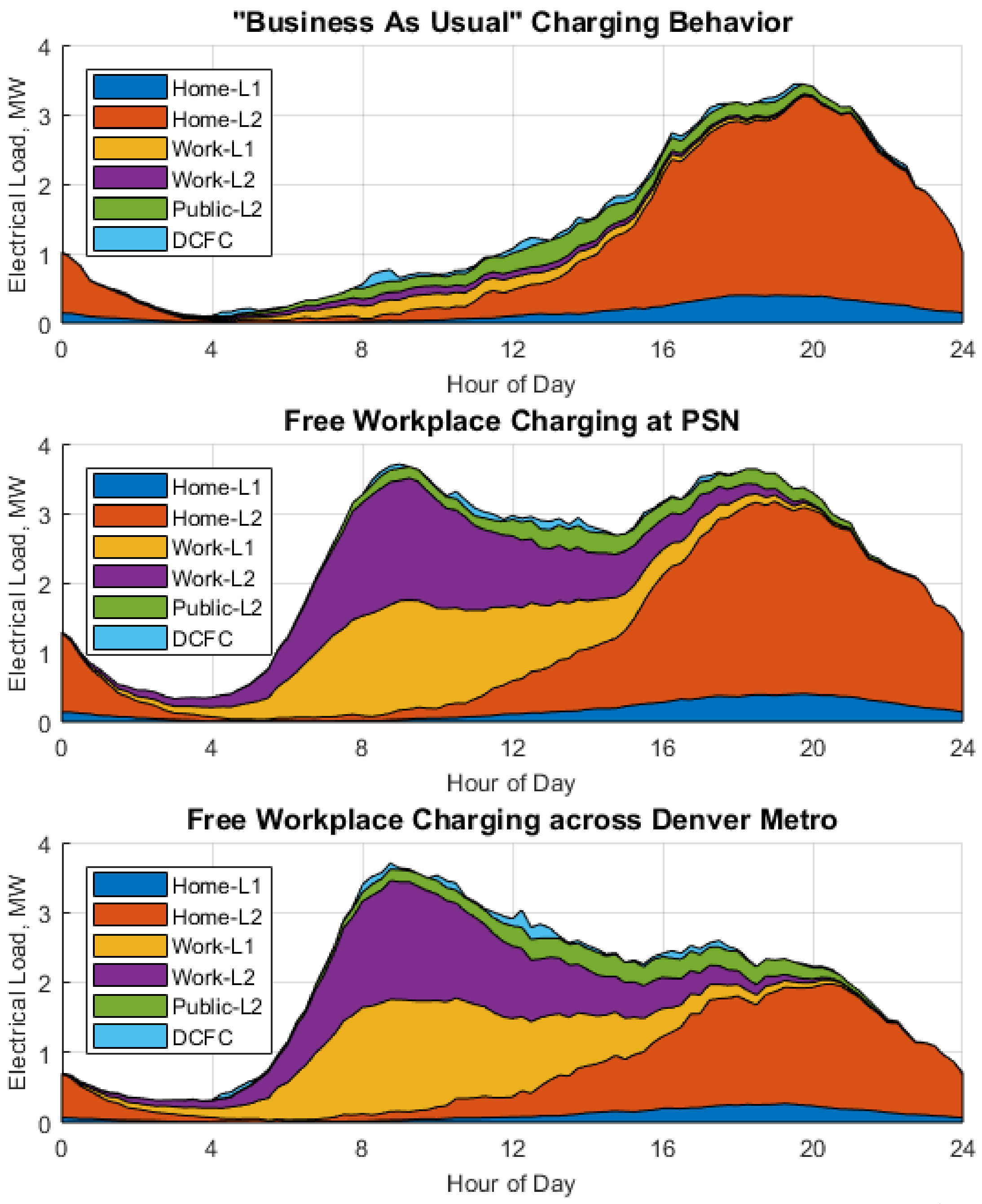
1. How would grid planning and operation need to change to minimize the impacts of **uncontrolled charging** at scale and at what cost?
2. Which control strategies for smart charging provide the most value in **avoiding grid adaptation** for PEVs?
3. What are the **critical strategies and technologies** required to enable high-value smart charging control?



Peña Station NEXT

Preliminary EV Load Scenarios

- Building occupancy data used as proxy for vehicle population (weekday)
- NREL's EVI-Pro and Columbus travel pattern data used to create typical EV energy demands by infrastructure type
- All scenarios assume:
  - **50% of LDVs as EVs** (about 10k EVs on campus throughout typical weekday)
  - **PSN residents** utilize PSN residential EVSE (but not PSN workplace/public EVSE)
  - **PSN commuters** utilize PSN workplace/public EVSE (but not PSN residential EVSE)
- EV loads will be integrated into UrbanOpt building loads to investigate impact on PSN microgrid



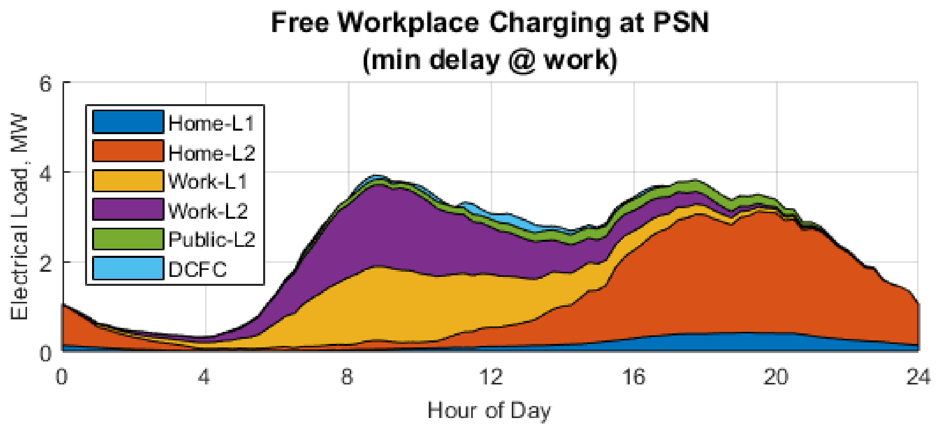
Exploring Flexibility

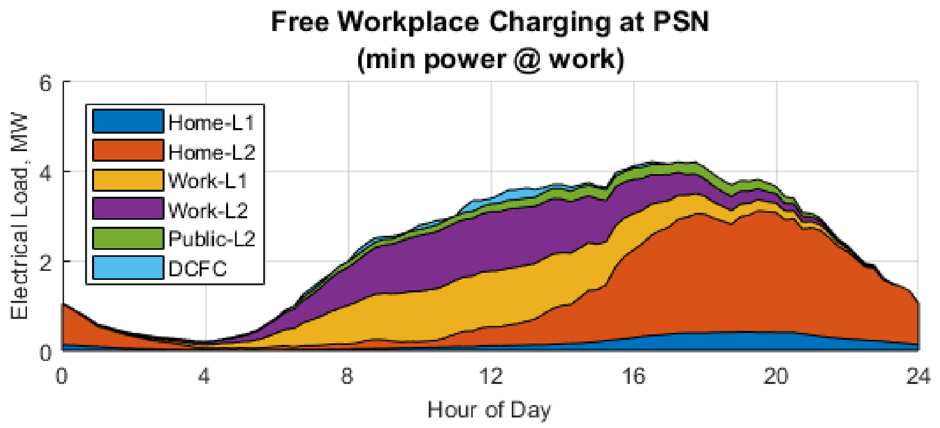
For next iteration… take “Free Workplace Charging at PSN” from previous slide and explore load flexibility of workplace charging.

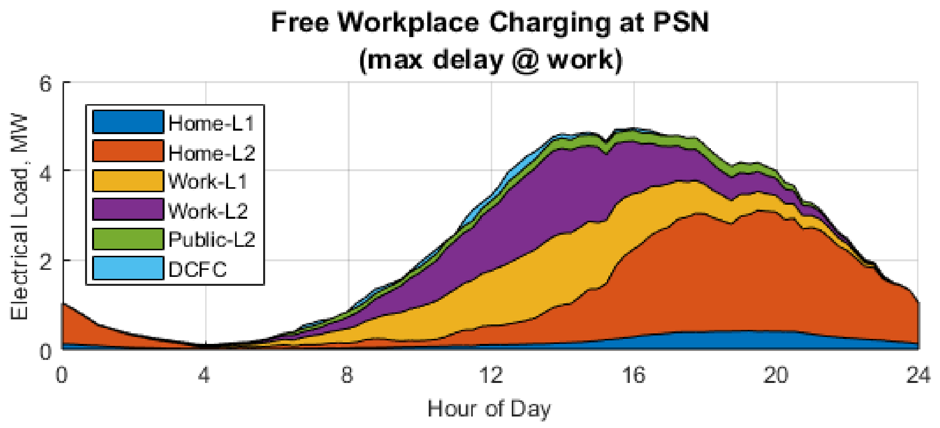
Three simulations:

1. Min delay – EVs begin charging immediately upon arriving at work
2. Min power – EVs are charged at minimum rate over park event
3. Max delay – EVs are plugged in immediately but do not begin charging until necessary

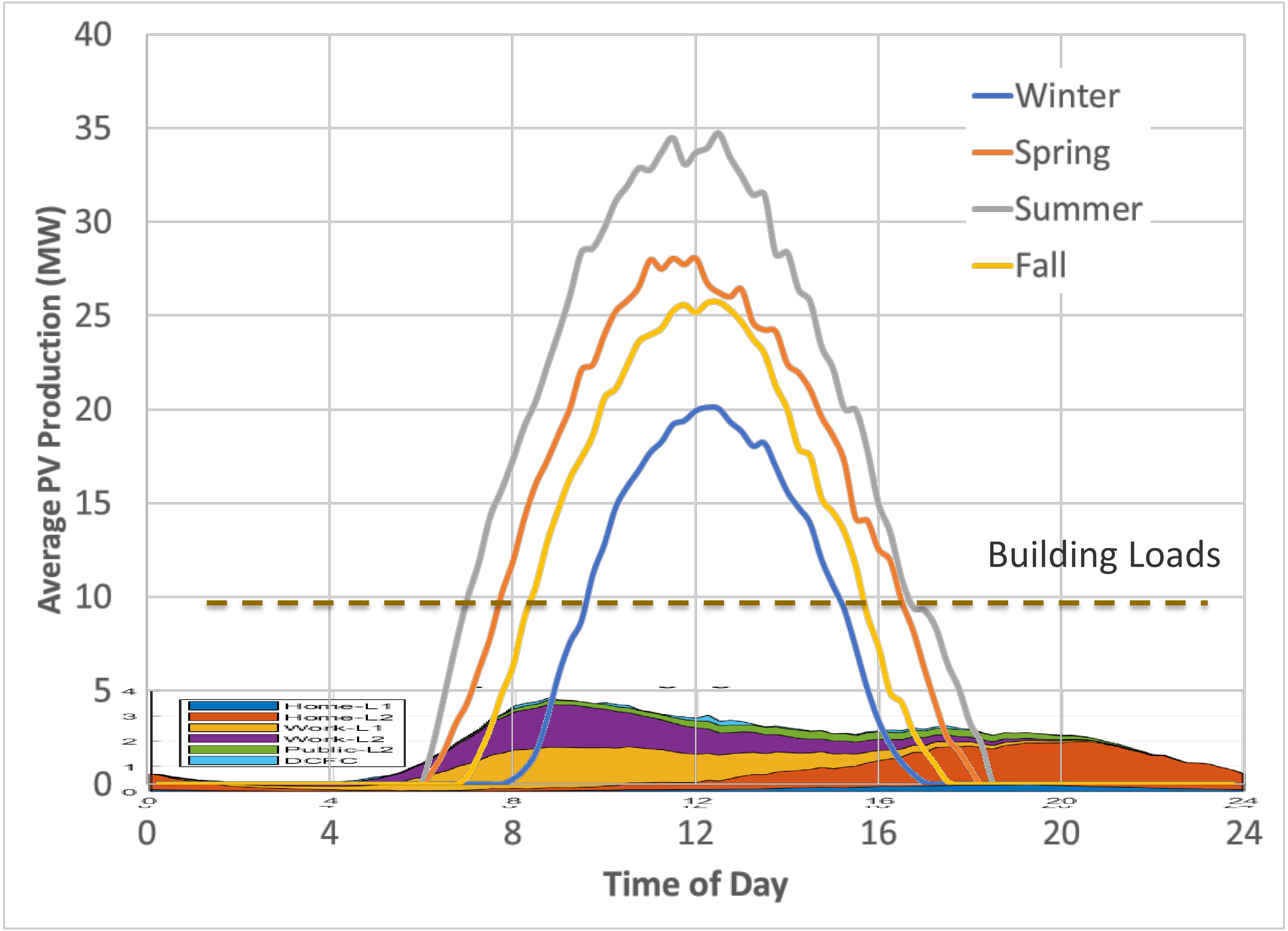
All simulations contain the same energy content per charging session, but explore flexibility within window of charging opportunity (only enabled at workplaces).







Aligning EV Load with PV Generation May Offer System Value



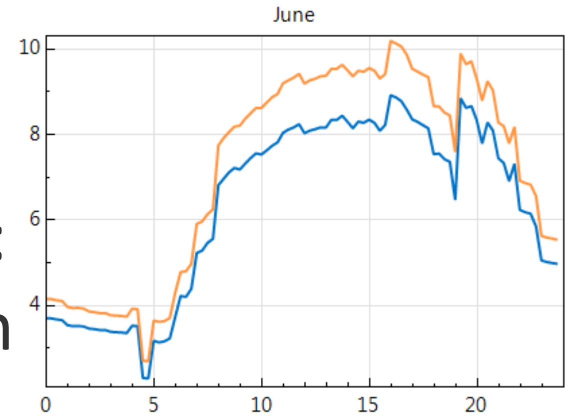
- Case 1: residen

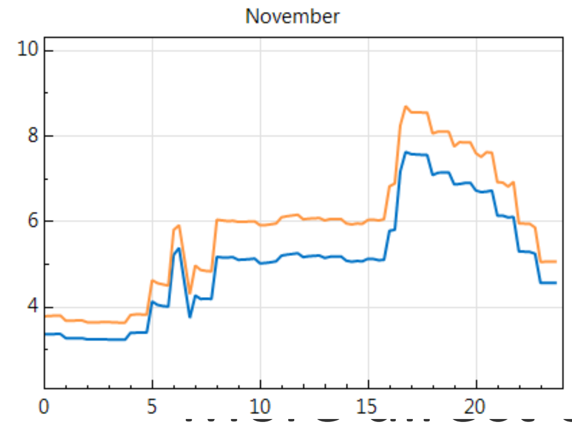
  – ge used

  gy

- PSN

  charging





- Case 3: Emphasize workplace everywhere
  – Less storage for evening demand

Summary Findings

- The introduction of electric vehicle loads to districts with high solar penetration levels can improve performance, 50% fleet electrification,
  - Reduced curtailment by 80%
  - Reduced local grid voltage violations by 65%
- Integration of grid, building, and vehicle modeling tools supported by high performance computing enabled robust design space exploration

Ultra-High Power Fast Charging or Extreme Fast Charging (XFC):

Integrating EVs with Buildings, Onsite Energy Resources, and the Grid

A Glimpse of the Future Station

Source: https://chargedevs.com/newswire/fastned-and-abb-unveils-new-generation-of-350-kw-charging-stations/

Source: Tritium

High Power Fast Charging Installations

Electrify America Chicopee MA
7 CCS ports, 1 CHAdeMO
Michael Scarpino, Volpe

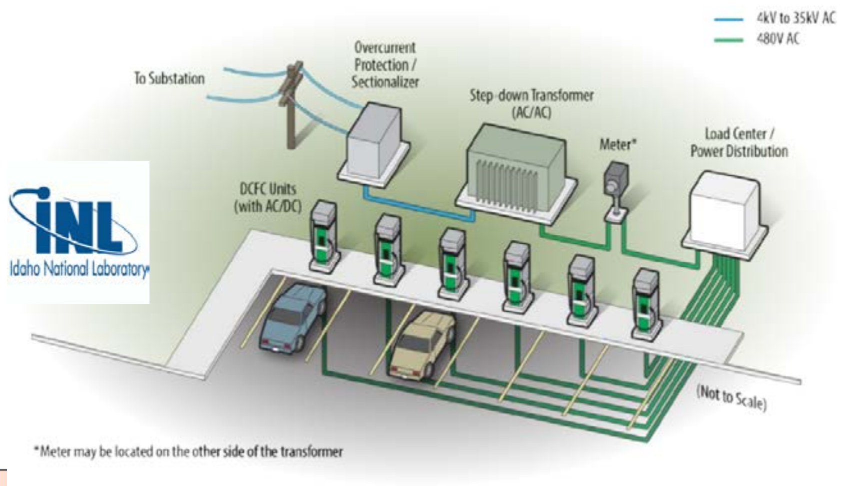
This photo was taken on July 18 at the Barrett Pavilion shopping center in Kennesaw, Georgia and uploaded to the popular EV charging infrastructure website PlugShare.com

Potential XFC Loads

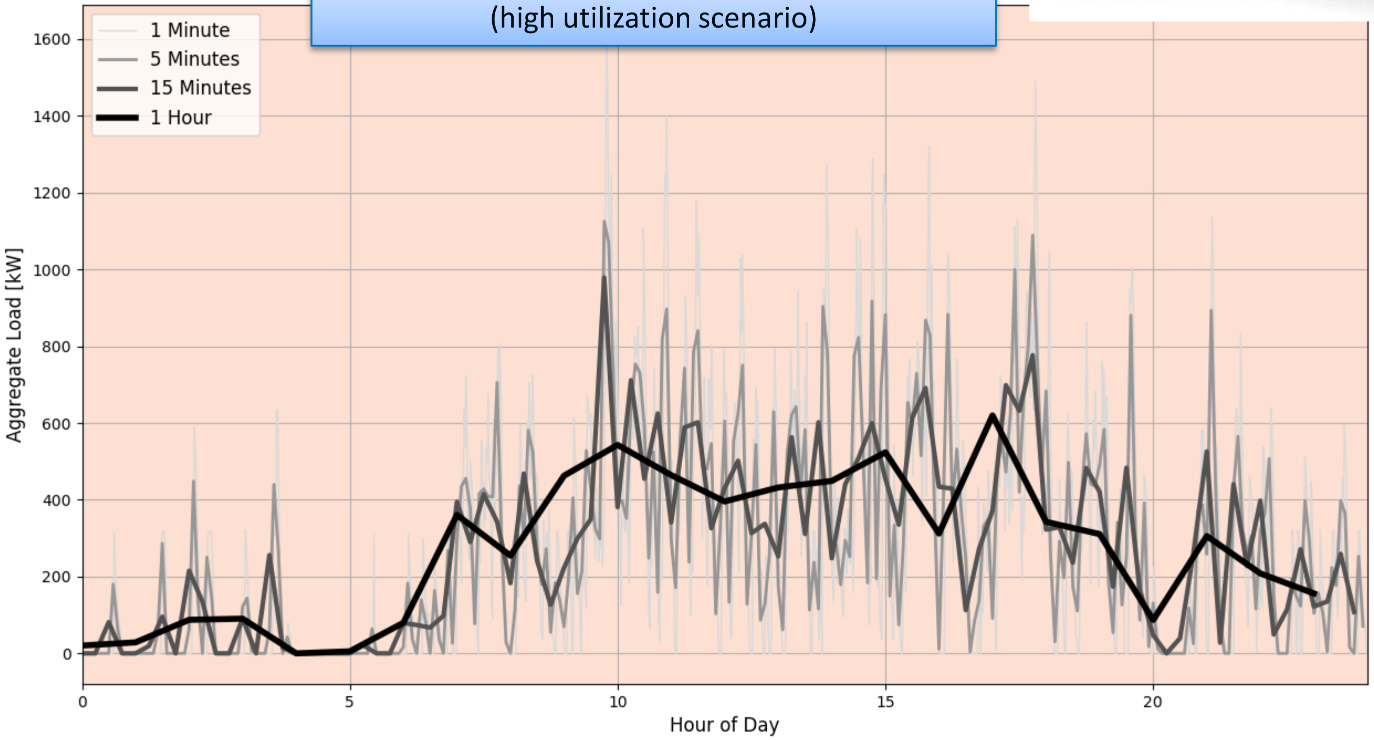
Lack of home charging availability for MUD residents and TNC drivers may drive needs for extreme fast charging

XFC station load has potential to be highly transient and large in magnitude
(below plot shows load aggregated at various time scales)

Hypothetical XFC station with 6-ports @ 350kW per
(source: Idaho National Laboratory)



Hypothetical XFC load from 6-ports @ 350kW per
(high utilization scenario)

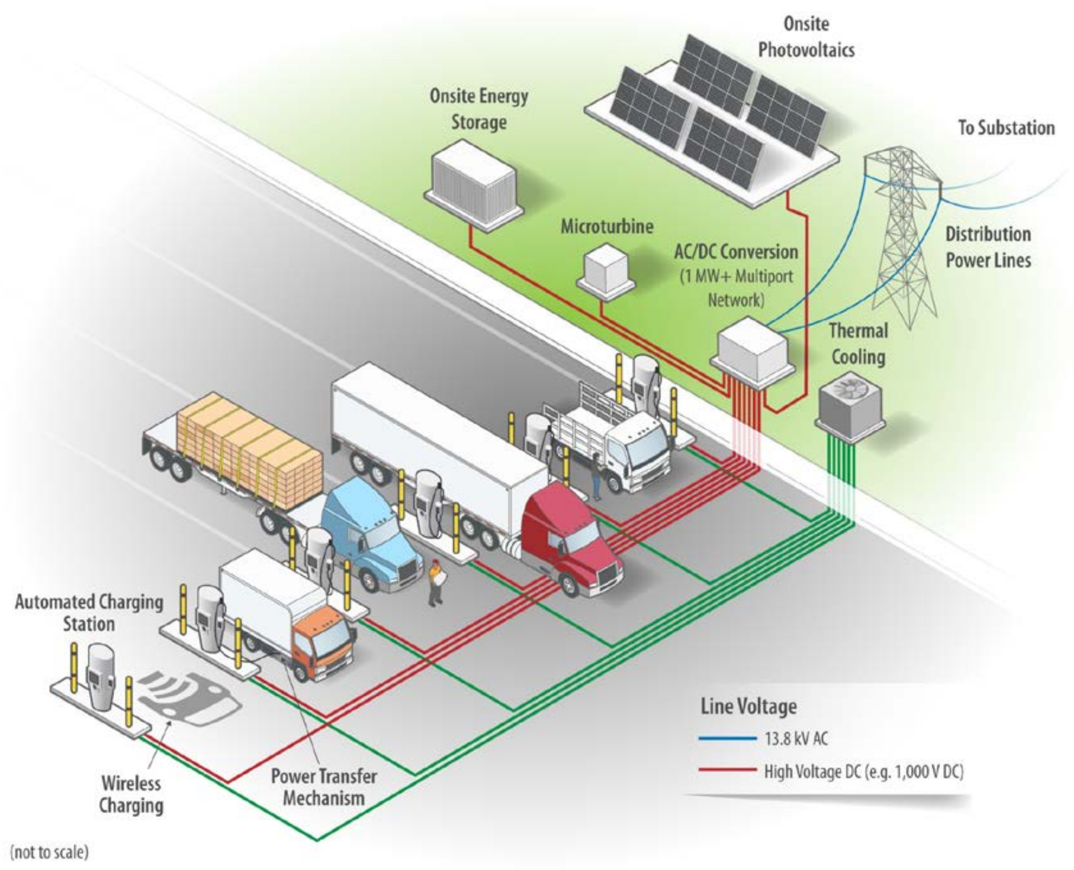


Multiport 1+ MW Charging System for MD and HD

Oak Ridge National Laboratory

Megawatt (MW)-scale charging systems that can quickly charge large capacity (~800 kWh) battery packs in less than ~30 minutes at an attractive charging cost ($/kWh). Many challenges must be met to realize such an integrated system, including

- Understanding and **optimizing power demand and management** requirements, configuring local infrastructure requirements,
- Developing **distribution voltage-level hardware** for the point of grid connection, designing grid interface converters,
- Understanding and overcoming **power electronics semiconductor** and architecture limitations,
- Developing safe and **robust hardware connections**
- Design model-based **real-time battery charge control** algorithms accounting for chemistry dynamics and thermal constraints while minimizing peak power
- Developing **robust thermal management systems**, and
- Assessing and developing **vehicle-side power** delivery architectures.

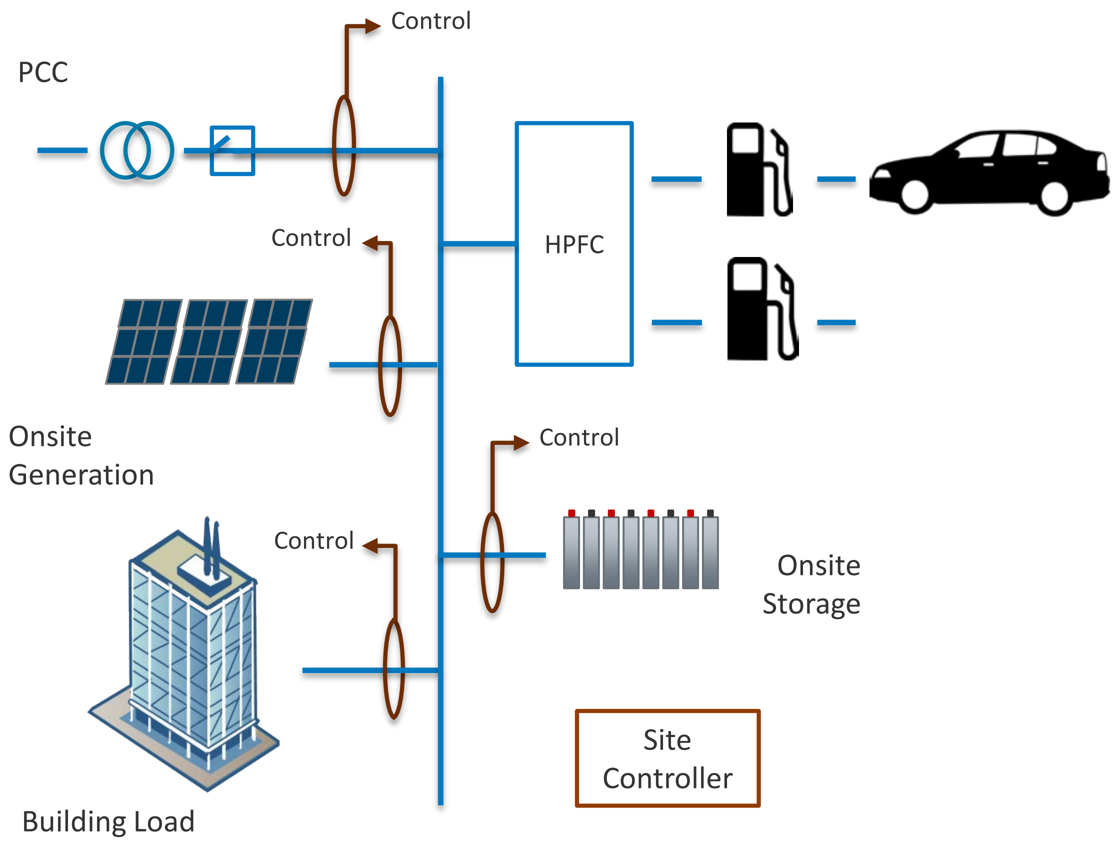


XFC Challenges and Gaps:
Buildings, Onsite Resources, and the Grid

What technology solutions will support integration of convenient XFC charging into the grid at a cost comparable to L1/L2 charging that is reliable and resilient?

- Site optimization of XFC with onsite
  - Distributed energy resources (DER) such as energy storage or photovoltaics (PV)
  - Commercial buildings, and/or other large flexible loads
- Resilient energy supply through onsite generation that utilizes alternative fuels with the potential to operate in a microgrid.
- XFC site control technologies for distribution system operation that mitigate capacity expansion, line upgrades, and voltage management

XFC Challenges and Gaps: Site Optimization and Resilience



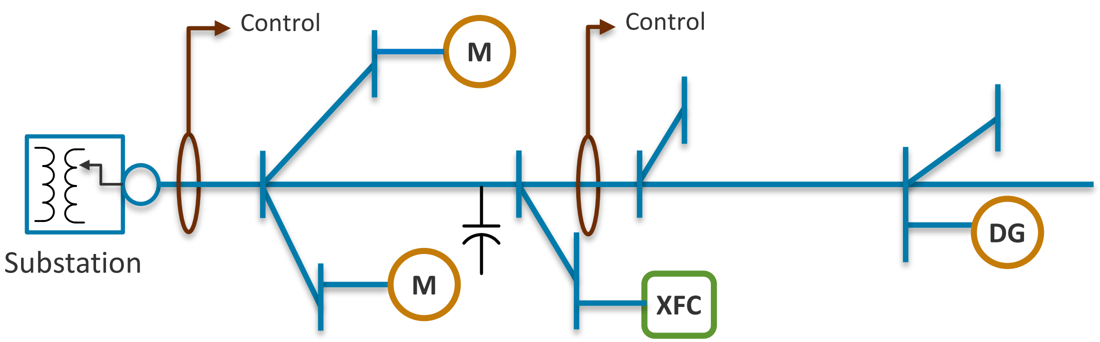
Load and generation estimation is required for optimal energy storage integration

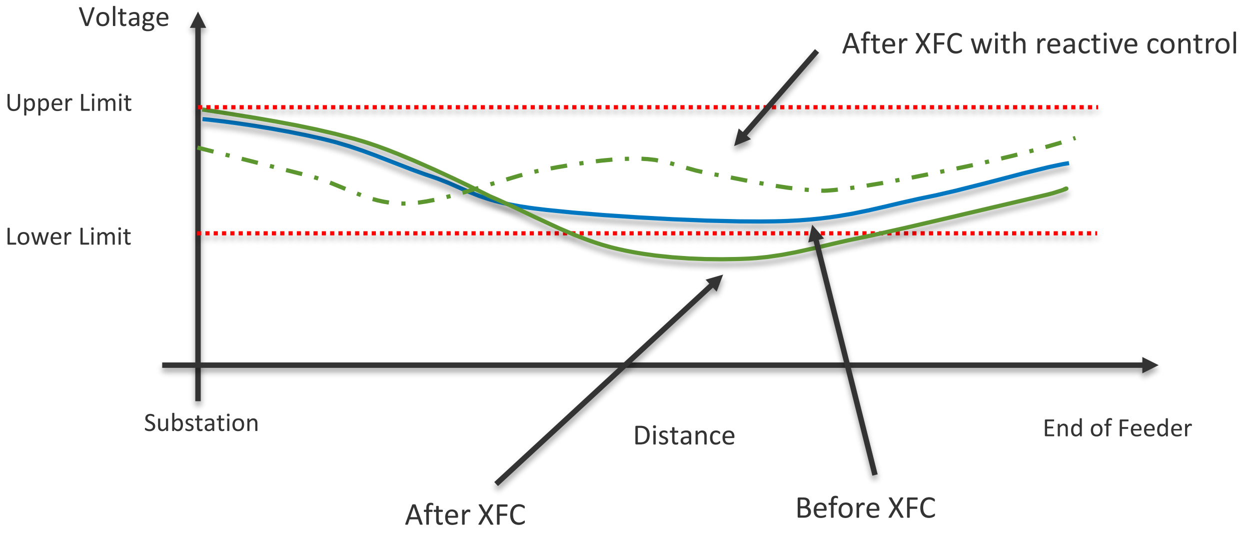
- **HPFC load** will vary depending on charging infrastructure and travel patterns
- Onsite **renewable generation** will be dependent on regional conditions
- **Building load** will be dependent on occupancy, building design, and is subject to seasonal weather variation

Control integration is required for energy system and microgrid management

- **Interoperability** of communication and control across multiple sectors
- Resolving **multi-objective optimization** across the building, transportation, and grid interface that is open yet cybersecure

XFC Challenges and Gaps: Distribution system operation





The **value of reactive and real power** control for the XFC site will need to be understood

- What will be the **impact on voltage regulation hardware** from XFC installation
- Value of system efficiency and avoidance of line upgrades with **reactive XFC support**
- Capacity deferral opportunities through real power control at XFC sites to **avoid concurrent peak load** on the feeder

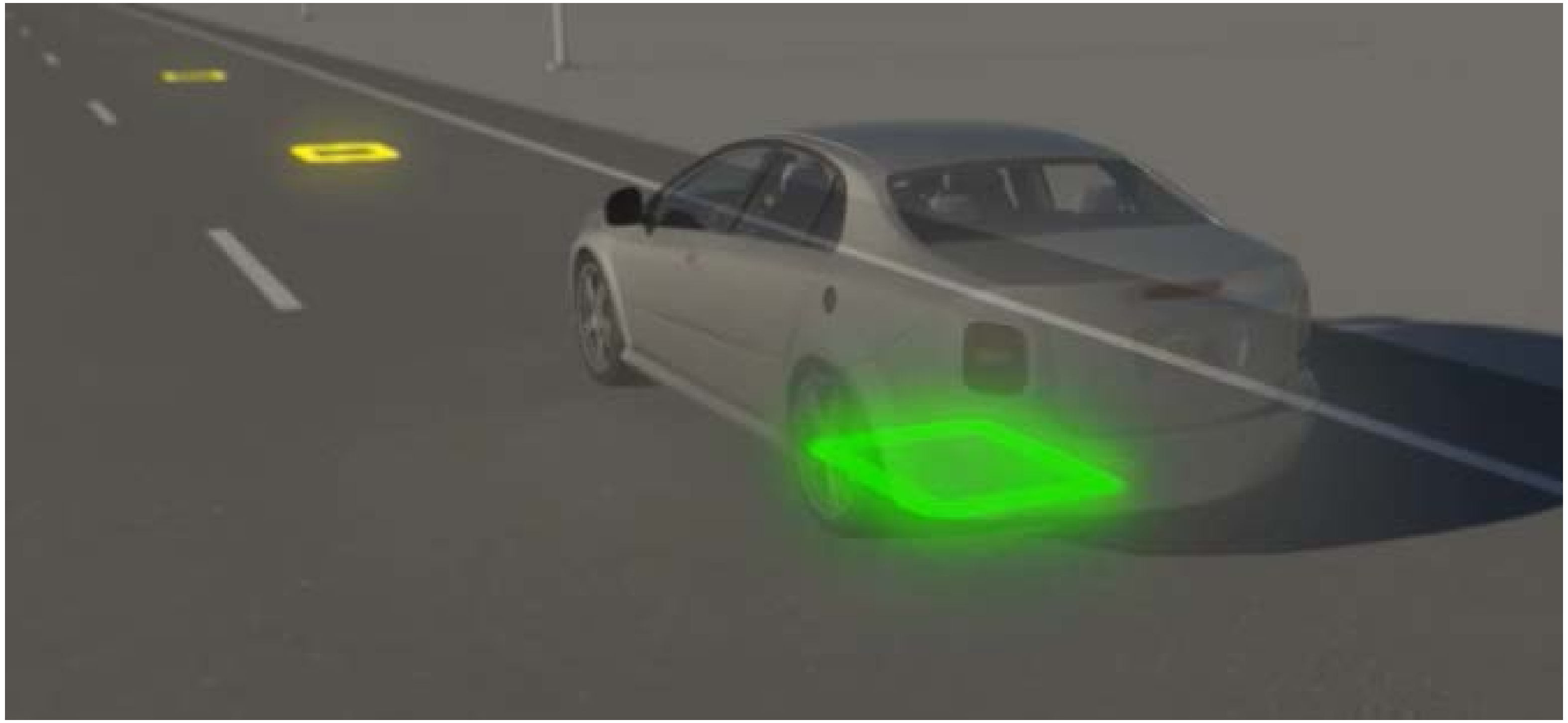
How does the addition of XFC affect stability of the distribution system control

- Impacts of load that is fast ramping, highly variable, and a constant power device
- Integration requirements for **onsite generation** to support microgrids and support system resiliency

Wireless Charging Scenarios

Integrating EVs with Buildings, Onsite Energy Resources, and the Grid

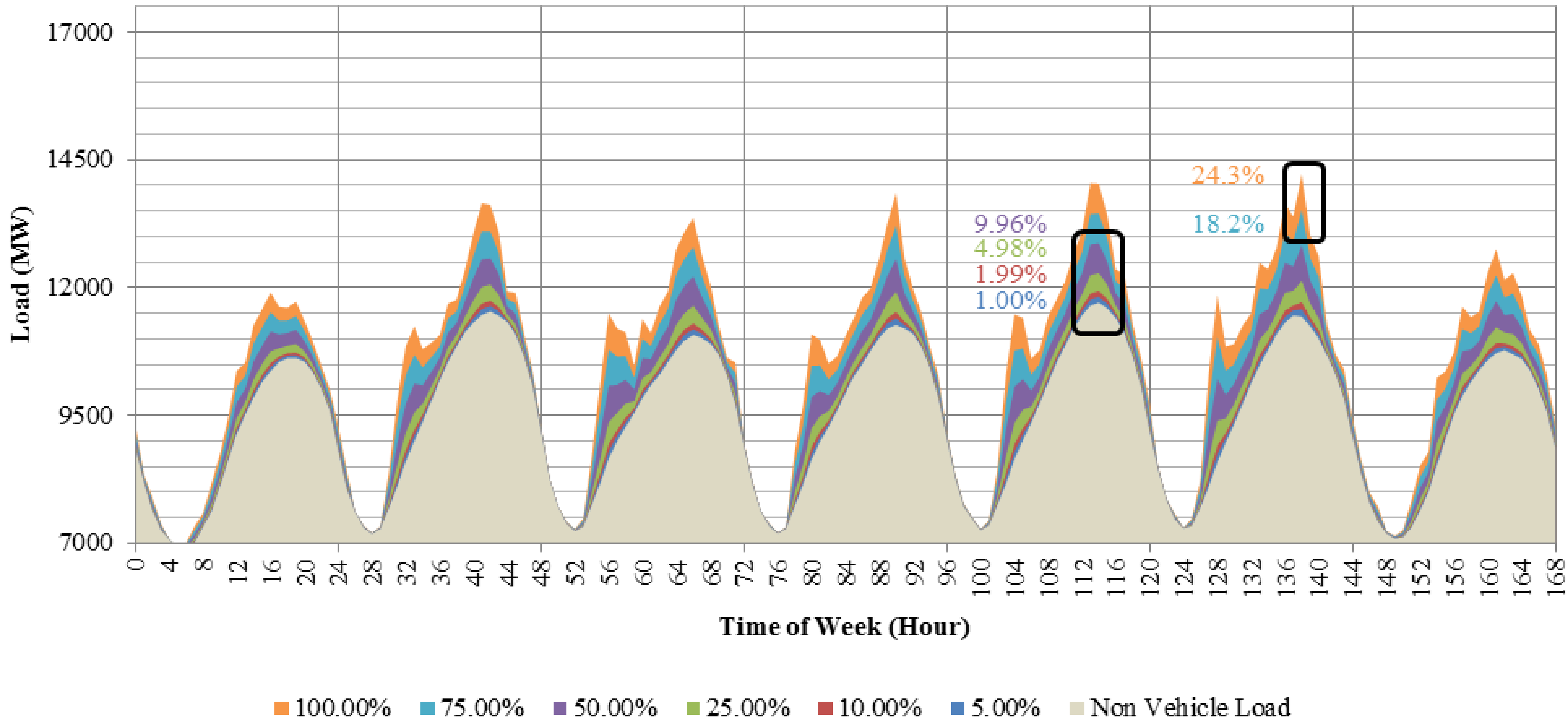
Electric Roadways



https://www.youtube.com/watch?v=gqfih5swB8Q

Search: nrel e-roadway animation

Addition of E-Roadway to Grid Loads (Spring)



Source: https://www.nrel.gov/docs/fy16osti/65449.pdf

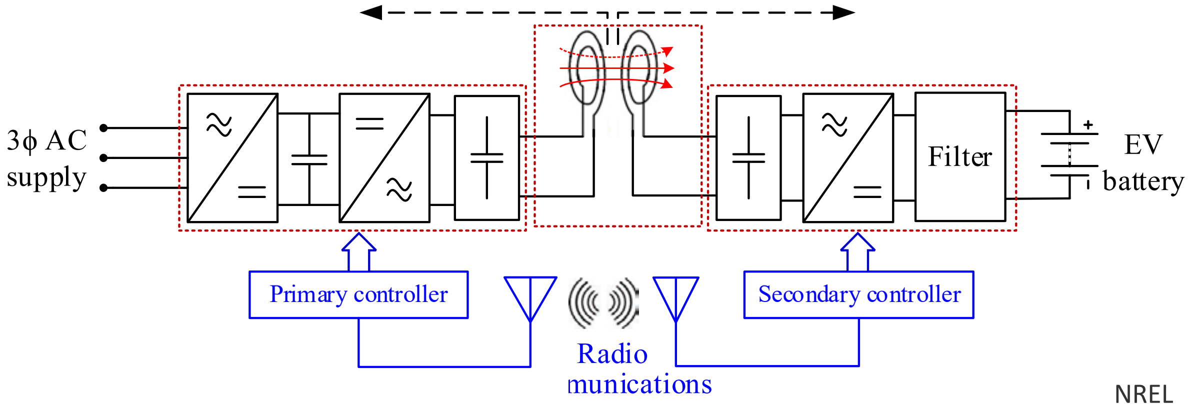
Description of MD WPT at NREL's Campus

✓ Wirelessly Charged NREL's Shuttle

- Full electric on-demand
- 16 passenger
- 62.1 kWh battery capacity
- 100 miles range
- 7600 curb weight, including VA
- 6.6 kW on-board charger

✓ Momentum Dynamics WPT system

- 36"x36" symmetrical square pads
- 25 kW maximum power transfer
- 20 (19-21) kHz nominal operating frequency



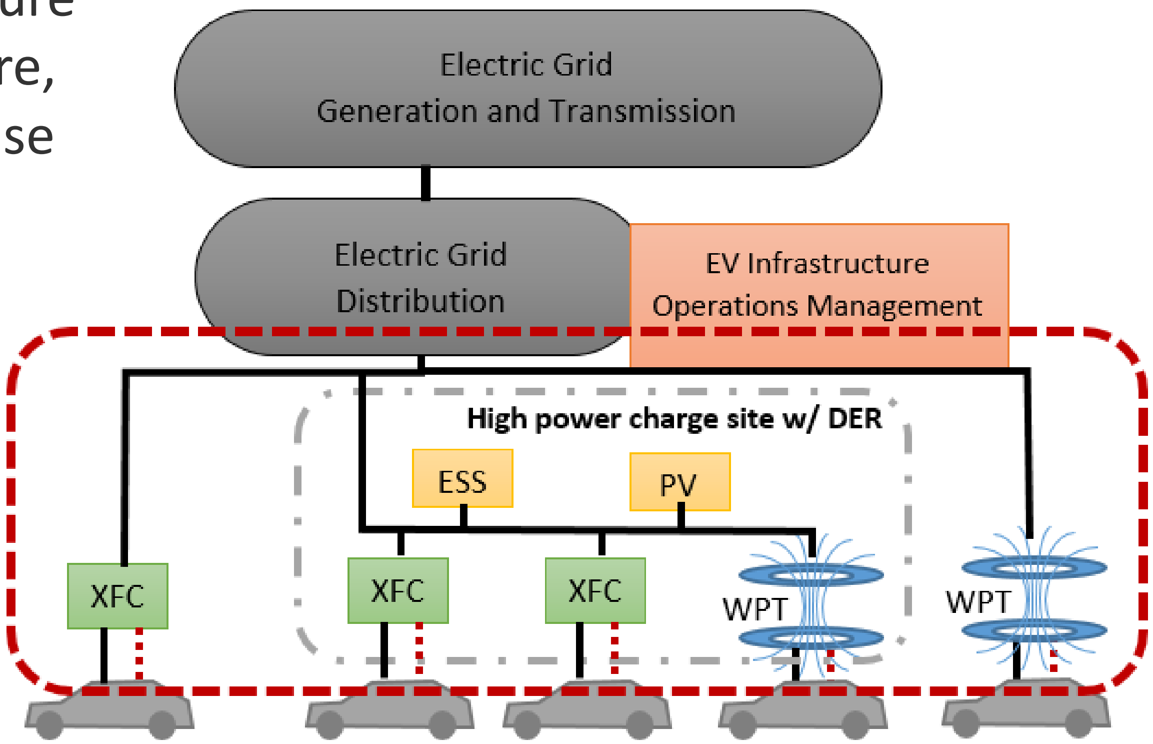
Expanding Infrastructure Analysis to Consider Security and Resilience

Integrating EVs with Buildings, Onsite Energy Resources, and the Grid

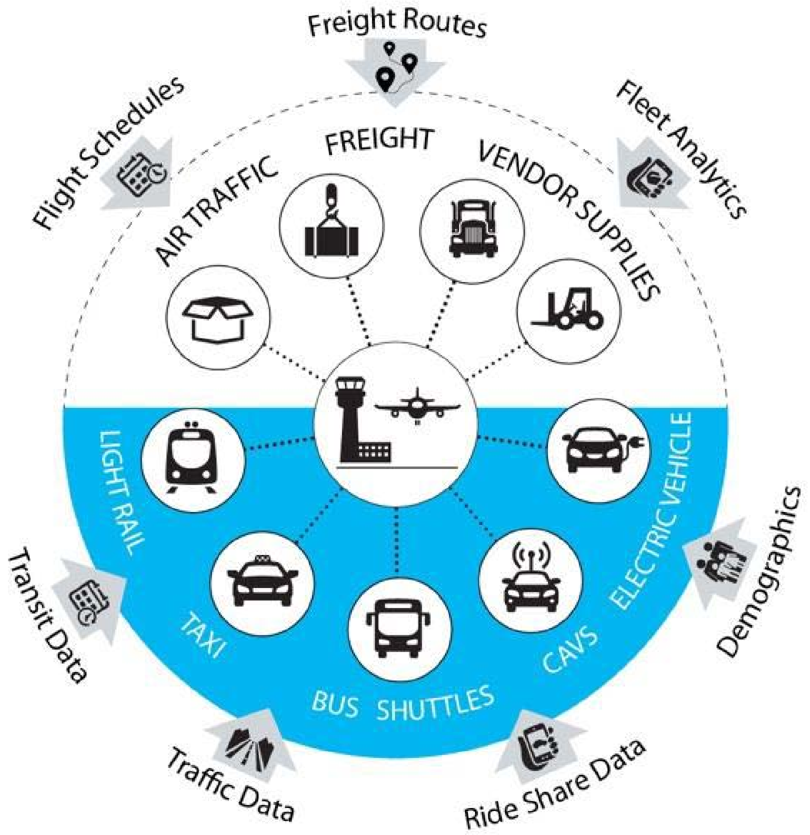
Consequence-Driven Cybersecurity for High-Power Charging Infrastructure

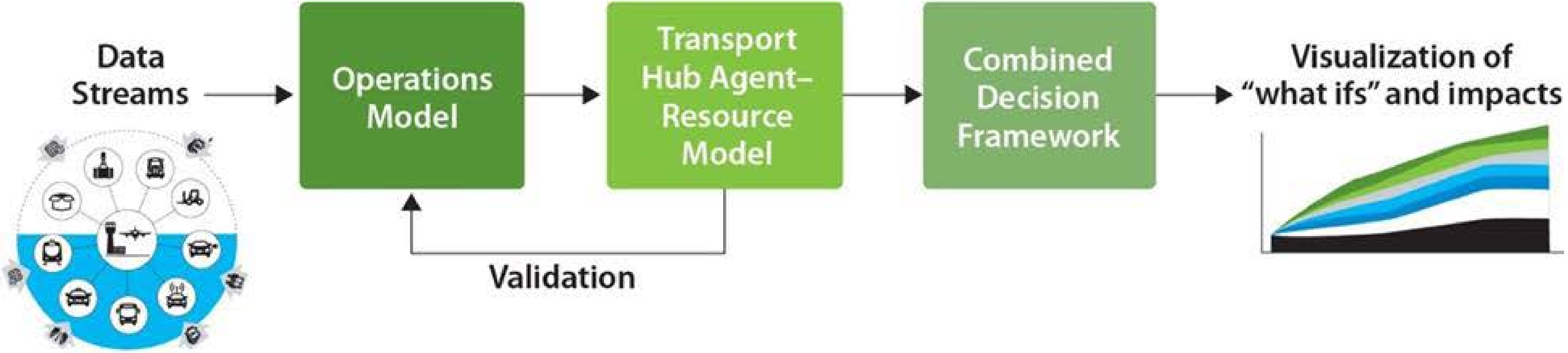
- Conduct a full threat assessment of XFC and high-power WPT (i.e., >200 kW) charging infrastructure ecosystems, utilizing PEV, charging infrastructure, and electric grid R&D and cybersecurity expertise at three national laboratories

- Lab Partners:
  - INL, NREL, ORNL
- Industry:
  - Electrify America, ABB, Tritium
- Outcomes:
  - Vulnerability testing methods and simulated environments to evaluate mitigation strategies



ATHENA: Modeling Transportation Hubs





www.nrel.gov

Thank You!

Tony Markel, Sr. Engineer

Tony.Markel@NREL.gov

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