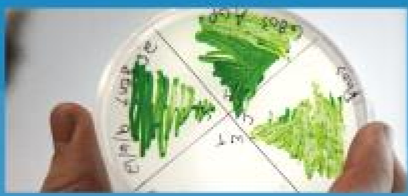




Integrating PEVs with Renewables and the Grid

Andrew Meintz

Tony Markel, Myungsoo Jun, Jiucai Zhang

2016 IEEE Transportation Electrification Conference and Expo

Dearborn, Michigan

June 29, 2016

NREL/PR-5400-66638

Vehicle Testing and Integration Facility (VTIF)

VTIF provides interior and exterior areas for systems EVGI communications and power exchange

18 kW solar PEV parking lot with 50 kW fast charger

NREL parking garage with 36 EVSEs that charge research and visiting vehicles

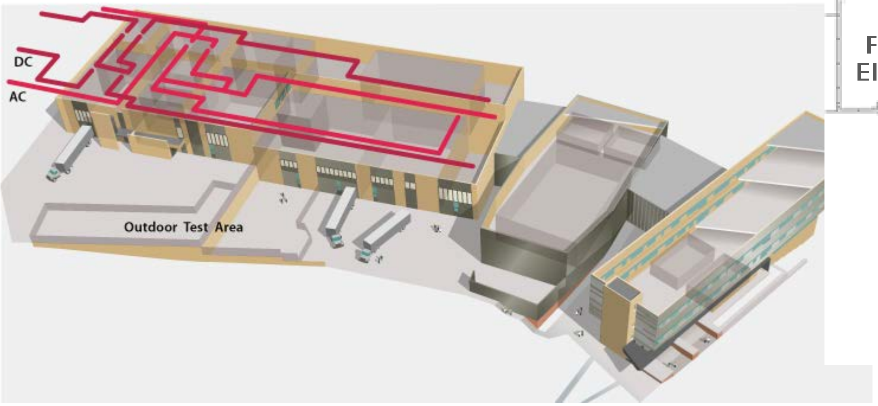
Energy Systems Integration Facility (ESIF)

- 182,500 sq. ft.
- 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)

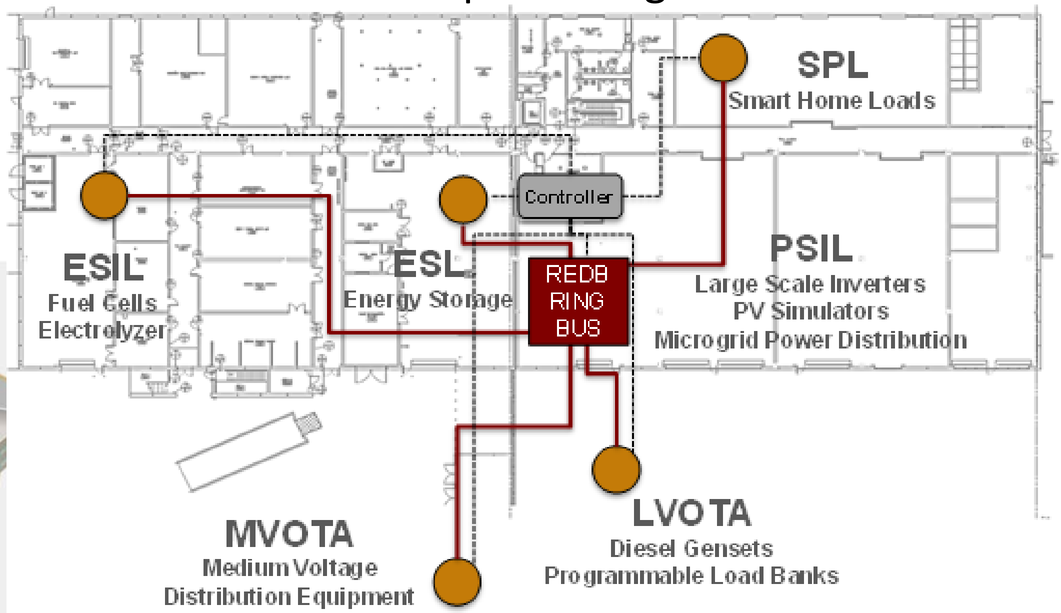
Research Electrical Distribution Bus (REDB)

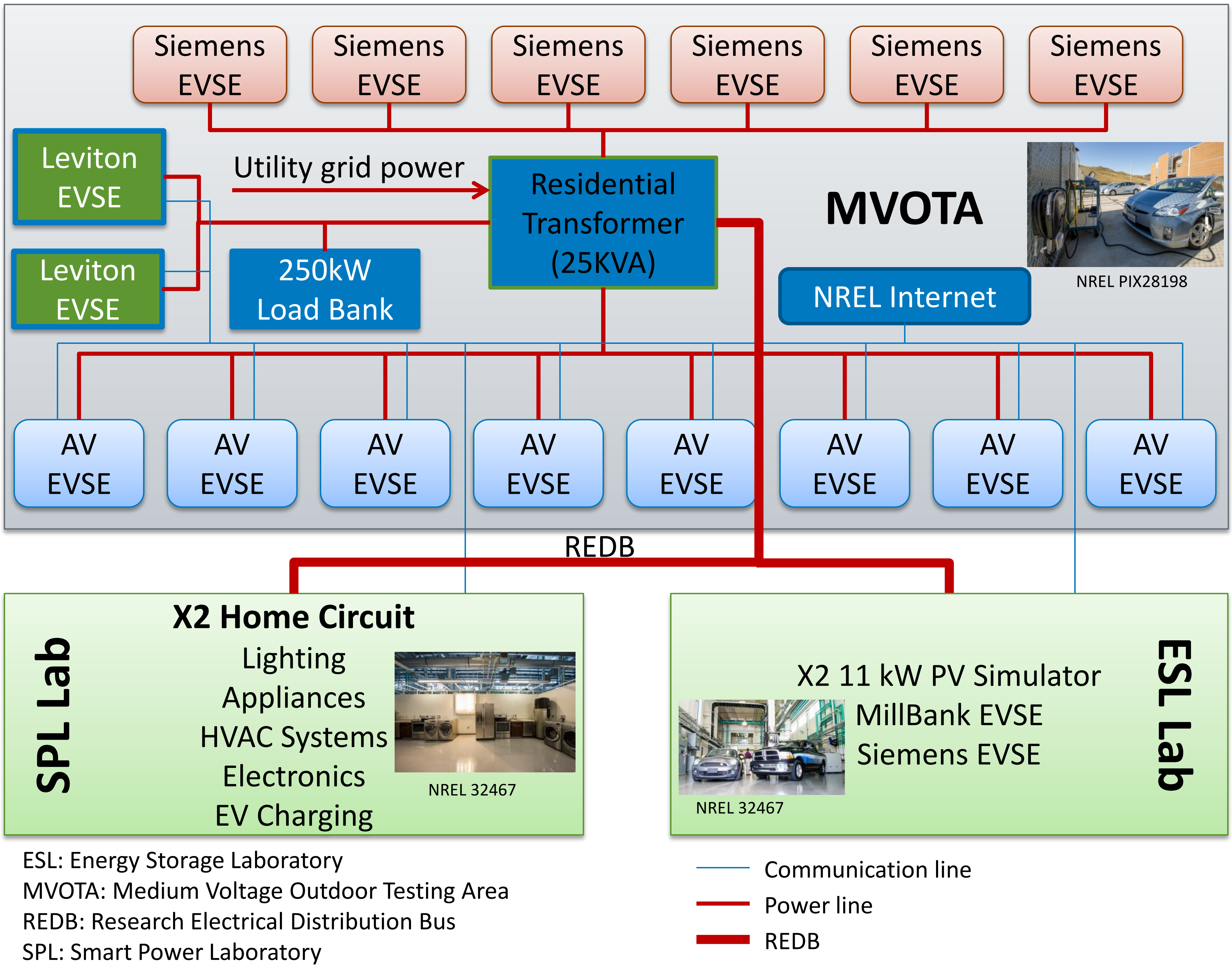
AC (600 V)
- 250 A
- 1600 A

DC (±500 V)
- 250 A
- 1600 A



Example microgrid




Siemens EVSE
Siemens EVSE
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Siemens EVSE
Siemens EVSE
Leviton EVSE
Leviton EVSE
Utility grid power
Residential Transformer (25KVA)
250kW Load Bank
MVOTA
NREL PIX28198
NREL Internet
AV EVSE
AV EVSE
AV EVSE
AV EVSE
AV EVSE
AV EVSE
AV EVSE
AV EVSE
REDB
SPL Lab
X2 Home Circuit
Lighting
Appliances
HVAC Systems
Electronics
EV Charging
NREL 32467
X2 11 kW PV Simulator
MillBank EVSE
Siemens EVSE
NREL 32467
ESL Lab
ESL: Energy Storage Laboratory
MVOTA: Medium Voltage Outdoor Testing Area
REDB: Research Electrical Distribution Bus
SPL: Smart Power Laboratory
Communication line
Power line
REDB

Achieved

In Process

Electric Vehicle Grid Integration at NREL

Vehicles, Renewable Energy, and Buildings Working Together

Managed Charging

Evaluate functionality and value of load management to reduce charging costs and contribute to standards development

- GE Wattstation in NREL Parking Garage
- Grid2Home EVSE and Gateway with SEP2.0
- Leviton with Modbus
- AV EVSE via Wifi

Local Power Quality

Leverage charge system power electronics to monitor and enhance local power quality and grid stability in scenarios with high penetration of renewables

- Toyota collaboration leverages vehicles and ESIF
- Light- and heavy-duty wireless charging systems
- Bi-directional fast charge

Emergency Backup Power

Explore strategies for enabling the export of vehicle power to assist in grid outages and disaster-recovery efforts

- Via Motors van with export to loads
- Nissan Leaf with V2H unit for backup

Bi-Directional Power Flow

Develop and evaluate integrated V2G systems, which can reduce local peak-power demands and access grid service value potential

- Mini-E with Univ of Del and NRG
- PGE utility truck characterization in ESIF
- Smith EV truck from Ft. Carson microgrid project
- Via Motors van with grid SEP2.0

Life Impacts

Can functionality be added with little or no impact on battery and vehicle performance?

- Using BLAST-V for scenario assessment

Information Flow and Control

How is information shared and protected within the systems architecture?

- Developed data entry and campus connections

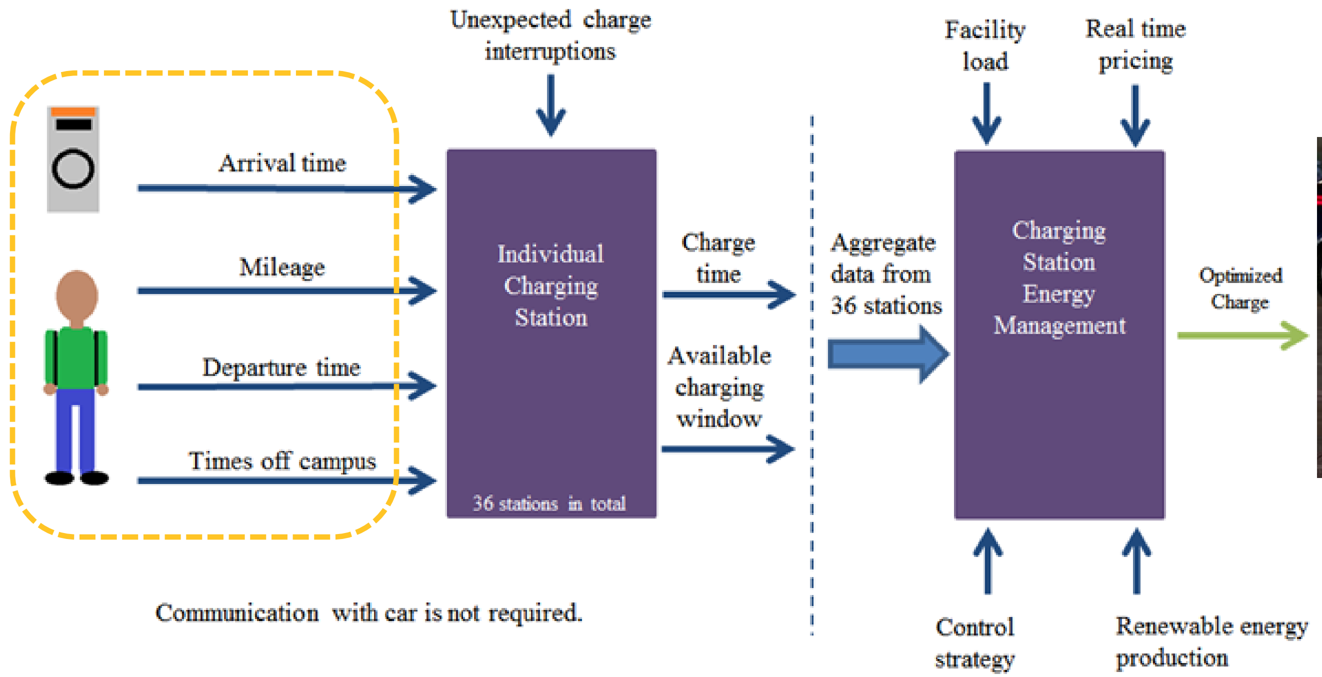
Holistic Markets and Opportunities

What role will vehicles play and what value can be created?

- SEAC collaboration on market opportunities report

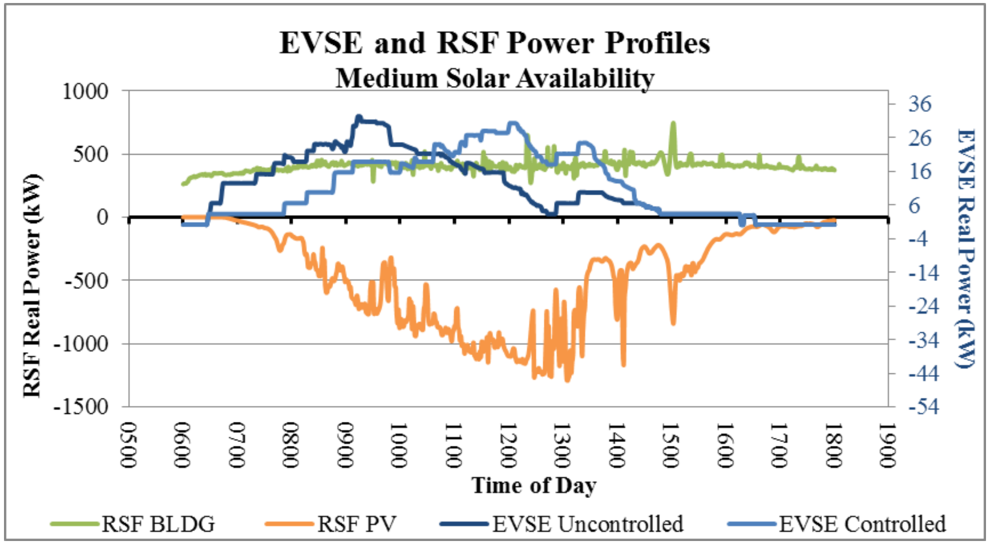
Managed Charging and Local Power Quality

PEV Charge Management with Renewable Sources



NREL PIX21661

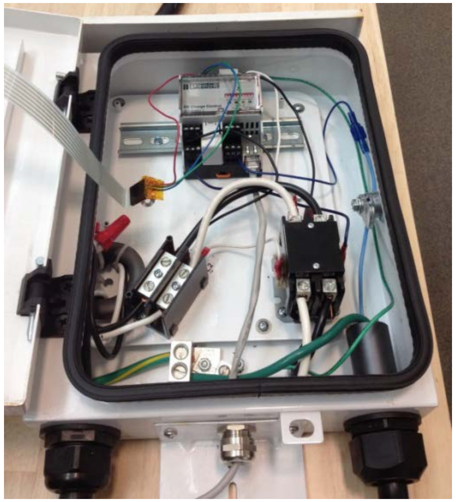
Provide simple interface with least information necessary to create managed individual and aggregate scenarios with status display



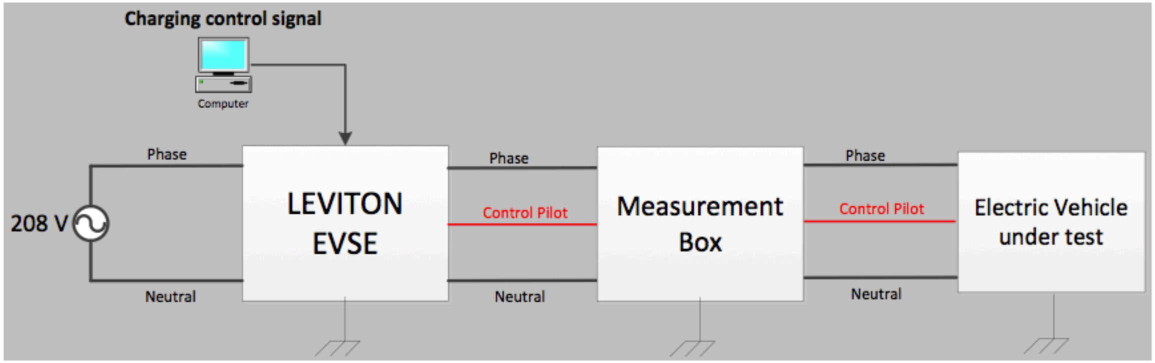
RSF = Research Support Facility

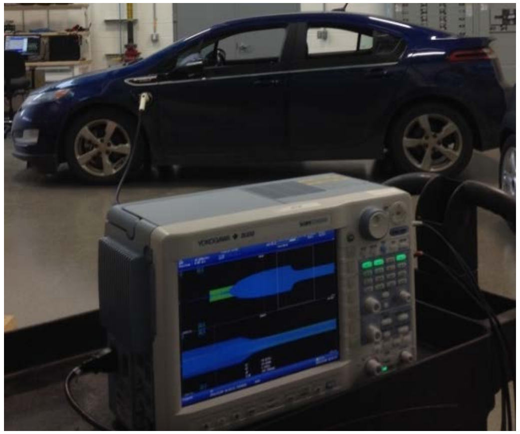
On-board Charging Characterization

- Unidirectional control of EVSEs over Modbus using market vehicles
- 5- to 10-A step-up/down tests to validate dynamic performance



Source NREL, Mithat Kisacikoglu





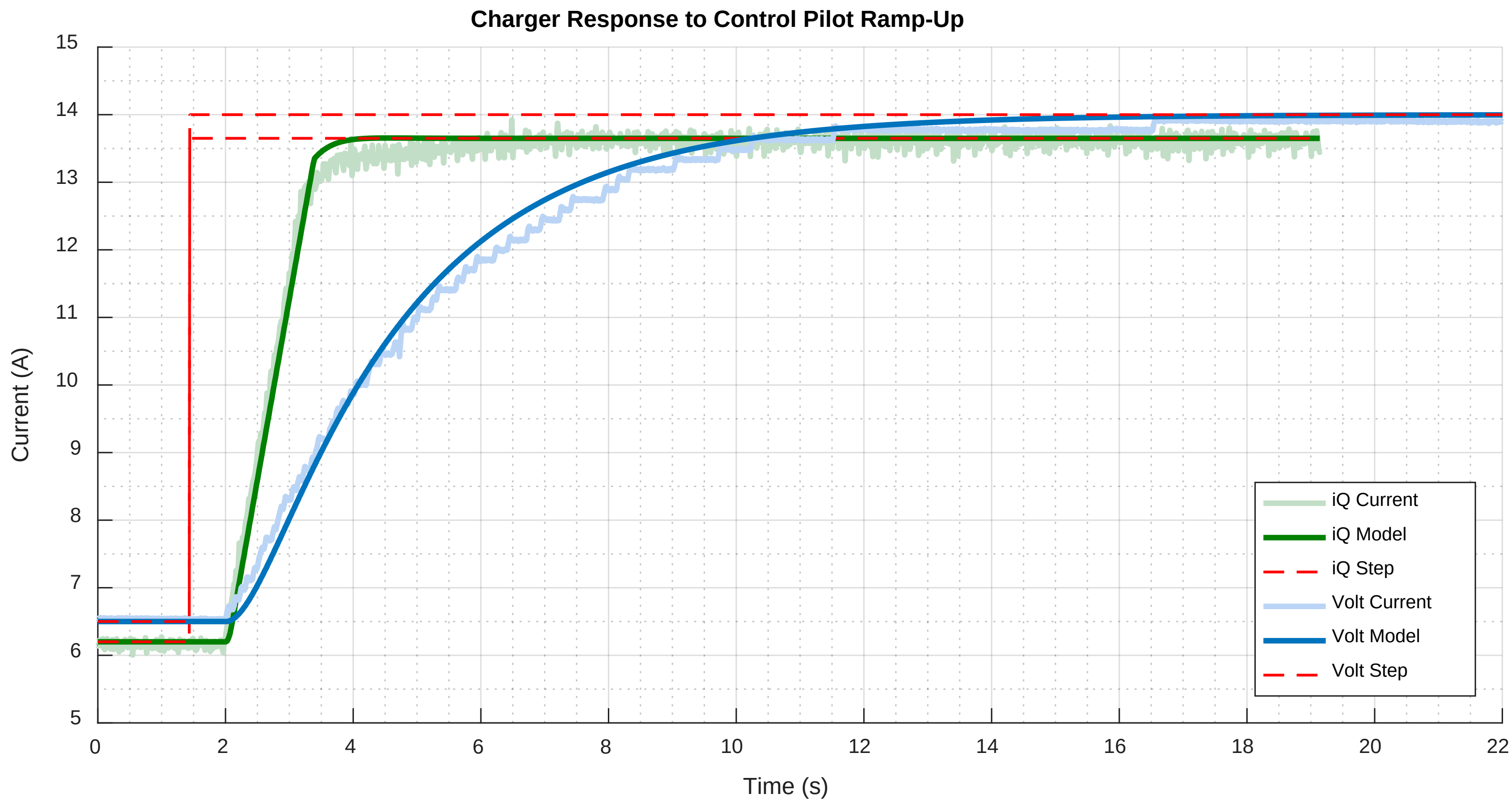
Source NREL, Mithat Kisacikoglu

NREL 29382

Source NREL, Mithat Kisacikoglu

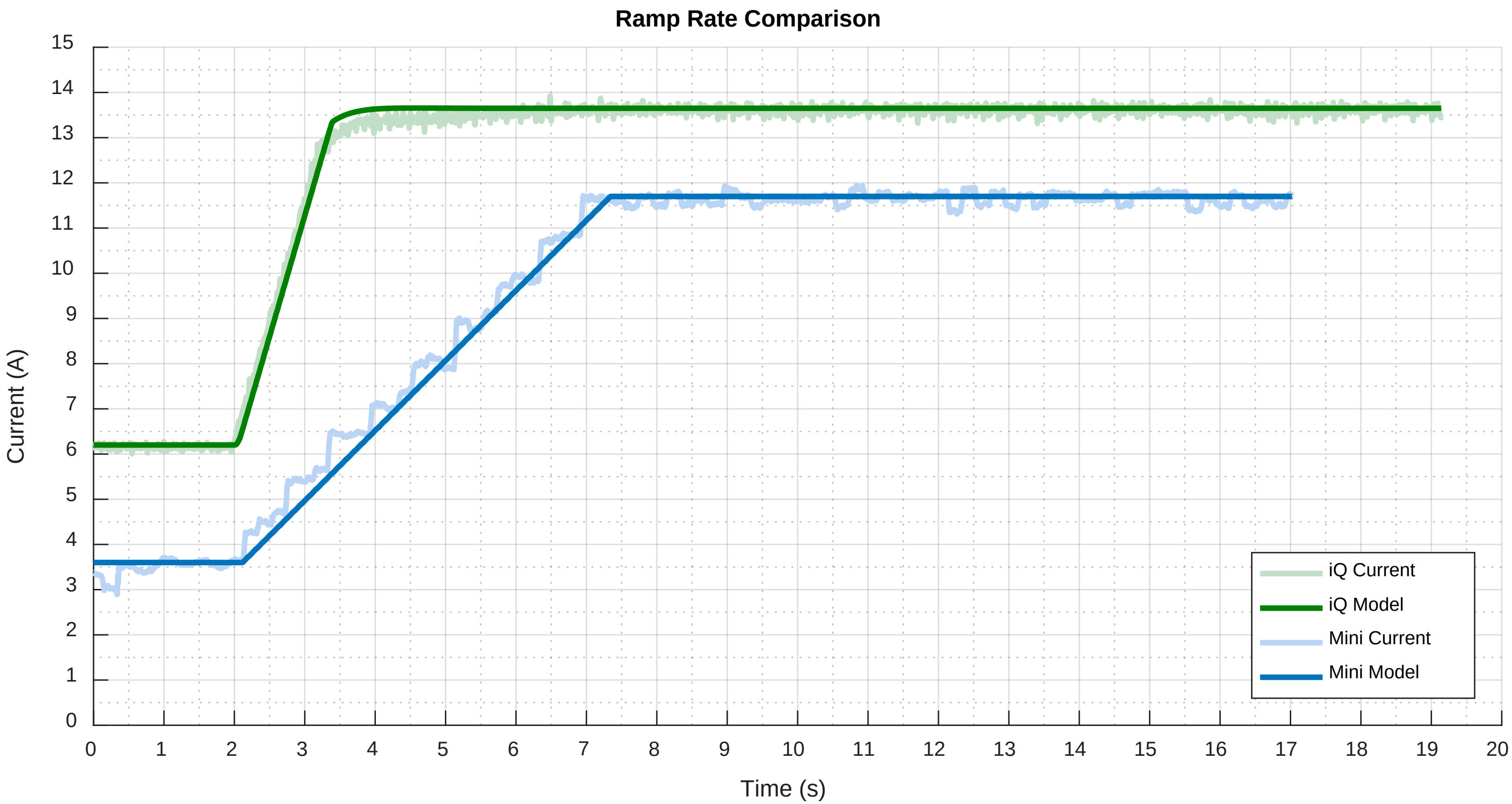
Unidirectional Charging Characterization

- ~0.56 s communication delay using Modbus protocol
- Different vehicles respond with different transfer functions
- SAE J1772 specifies a 5 s maximum response time (from CP change)



Unidirectional Charging Characterization

- Different vehicles respond with different transfer functions
  - iQ ramp response in this example is ~5.3 A/s
  - Mini-E ramp response in this example is ~ 1.5 A/s



Wireless Power Transfer Grid Integration Testing

Grid Simulator

200 to 240 VAC
50/60 Hz

Infrastructure Inverter

0 to 600 VAC
@ 85 kHz

Transmitter Coil

Receiver Coil

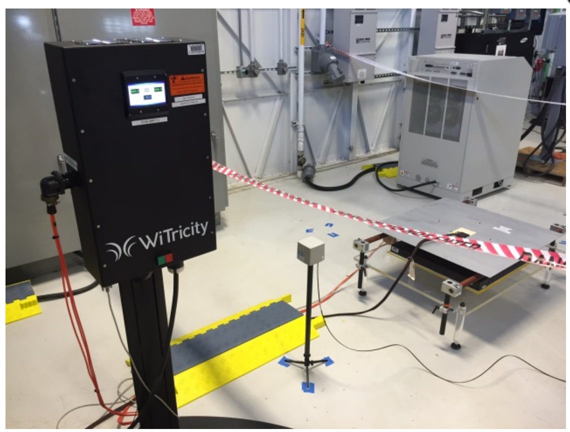
0 to 600 VAC
@ 85 kHz

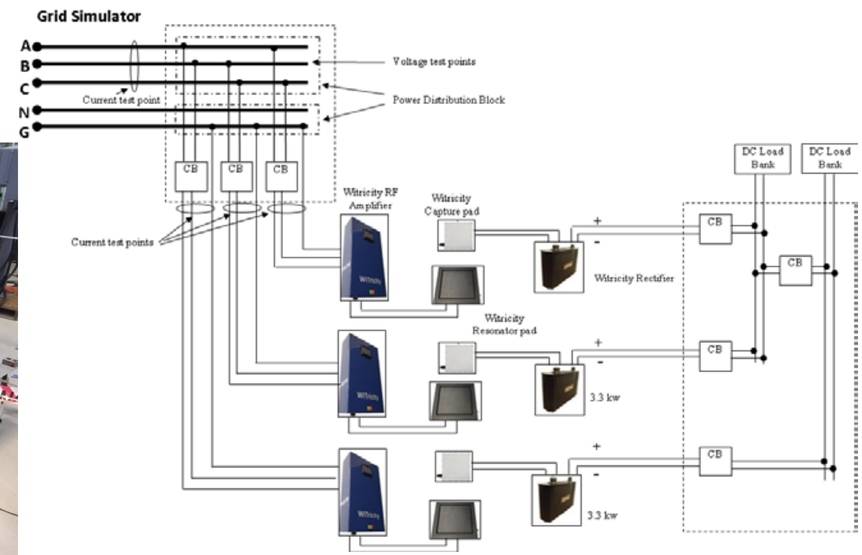
Vehicle Rectifier

0 to 400 VDC

DC Electronic Load

- Power quality testing for different grid voltage/frequency, receiver alignment, and battery charging power conditions
  - Current harmonics
  - Battery ripple current
  - Power factor
- Management with renewable and L2 EVSEs
- Three-phase implementation in a microgrid study





Source NREL, Andrew Meintz

Bi-directional Power Flow and Emergency Power Back-up

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

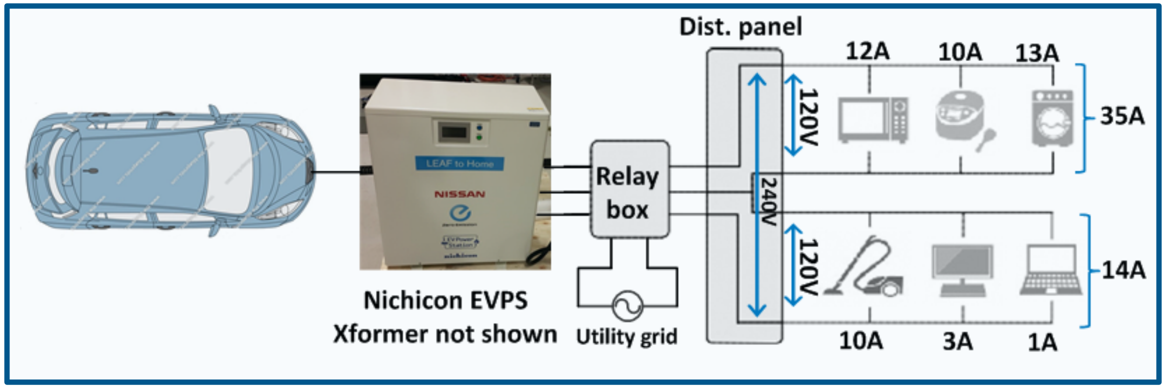
- Nichicon EV Power Station
  - 6-kW off-board charging capability
  - 120 V / 240 V, total 50 A@120 V V2H power capability
  - Runs with Chademo-compatible PEVs (Leaf, Mitsubishi i-MiEV)
  - Switching from grid-connected to grid-isolated operation

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.

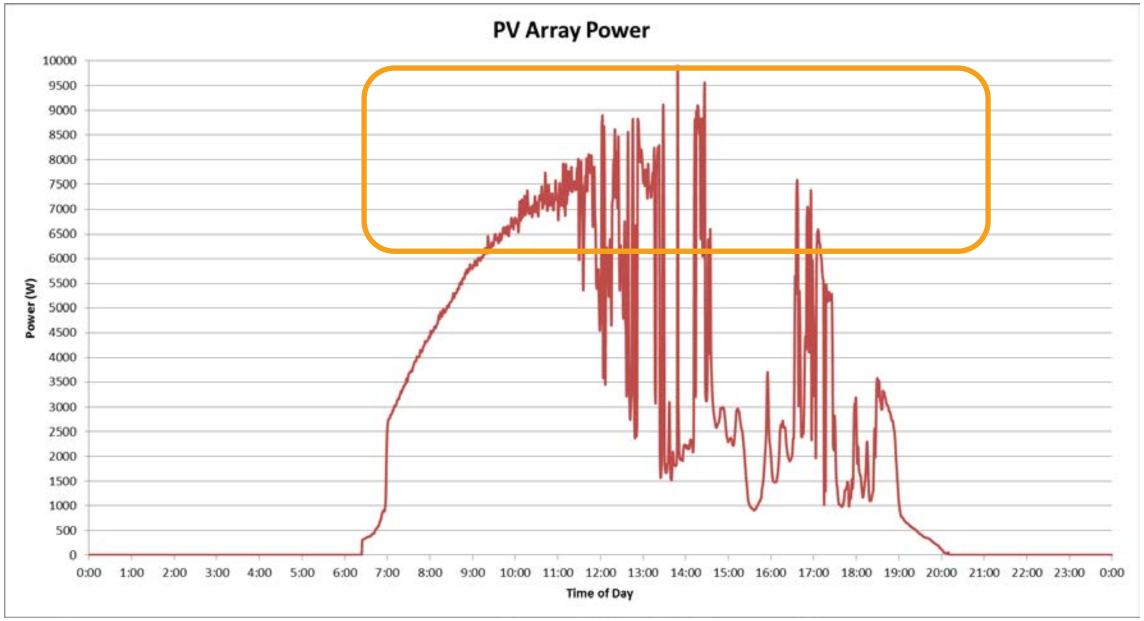
Via export power port

Source NREL, Mithat Kisacikoglu



Leaf-Nichicon power export

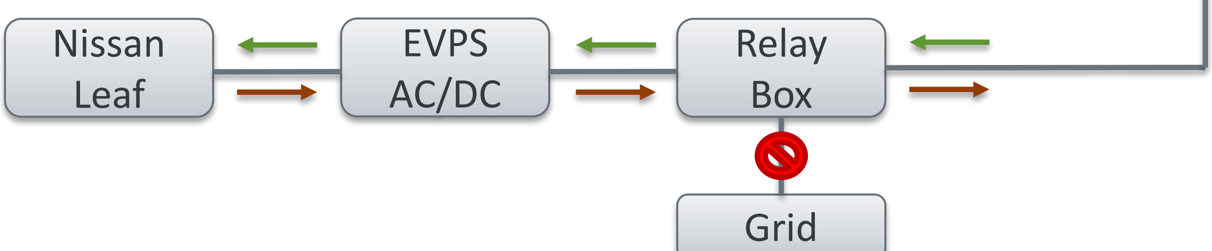
Emergency Power Backup



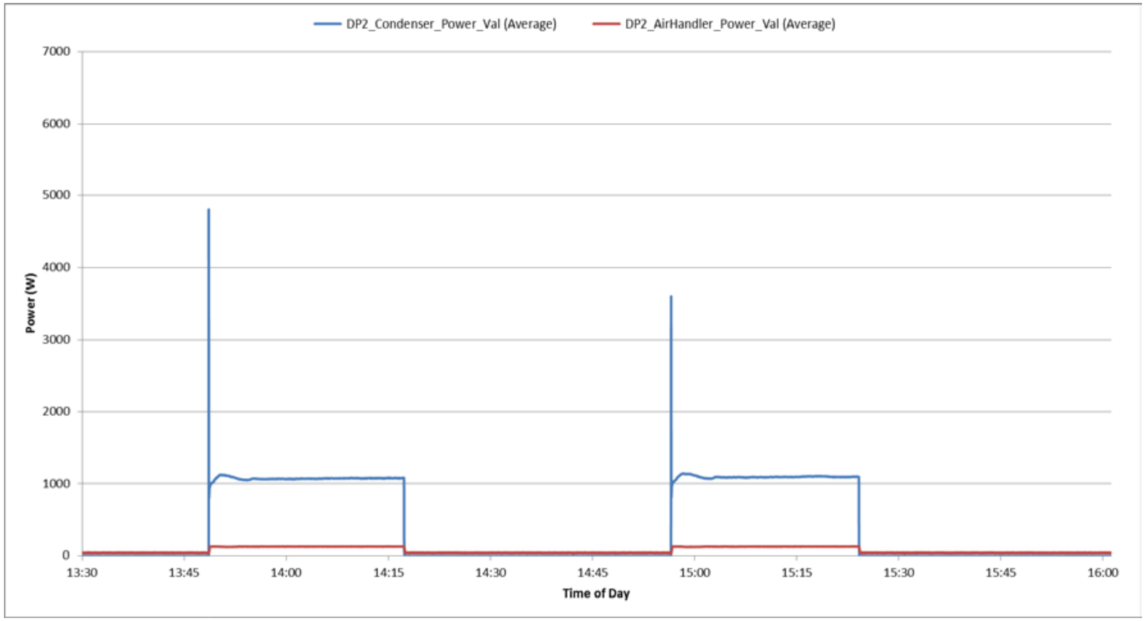
PV Generation

	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

Home Loads



Emergency Power Backup



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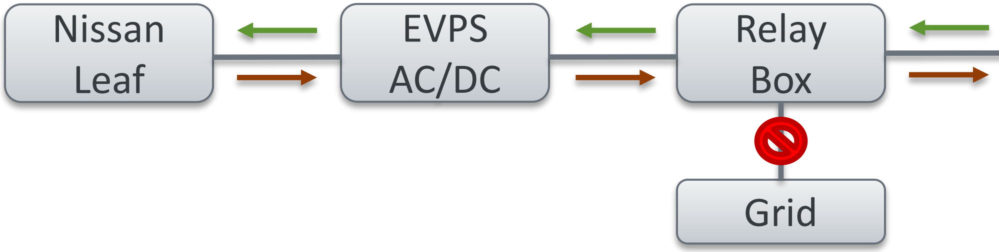
PV Generation

Home Loads



Emergency Power Backup

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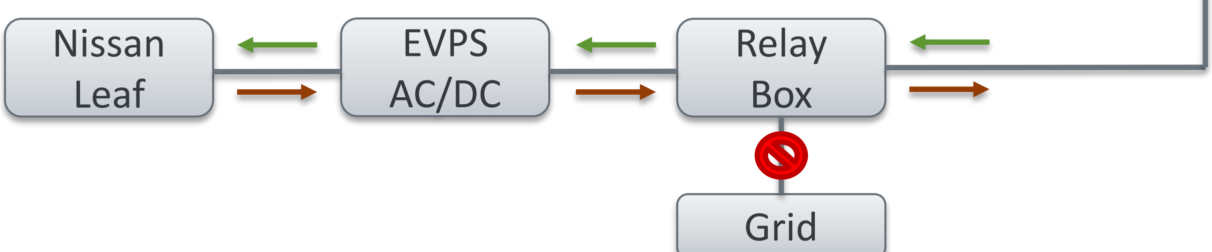
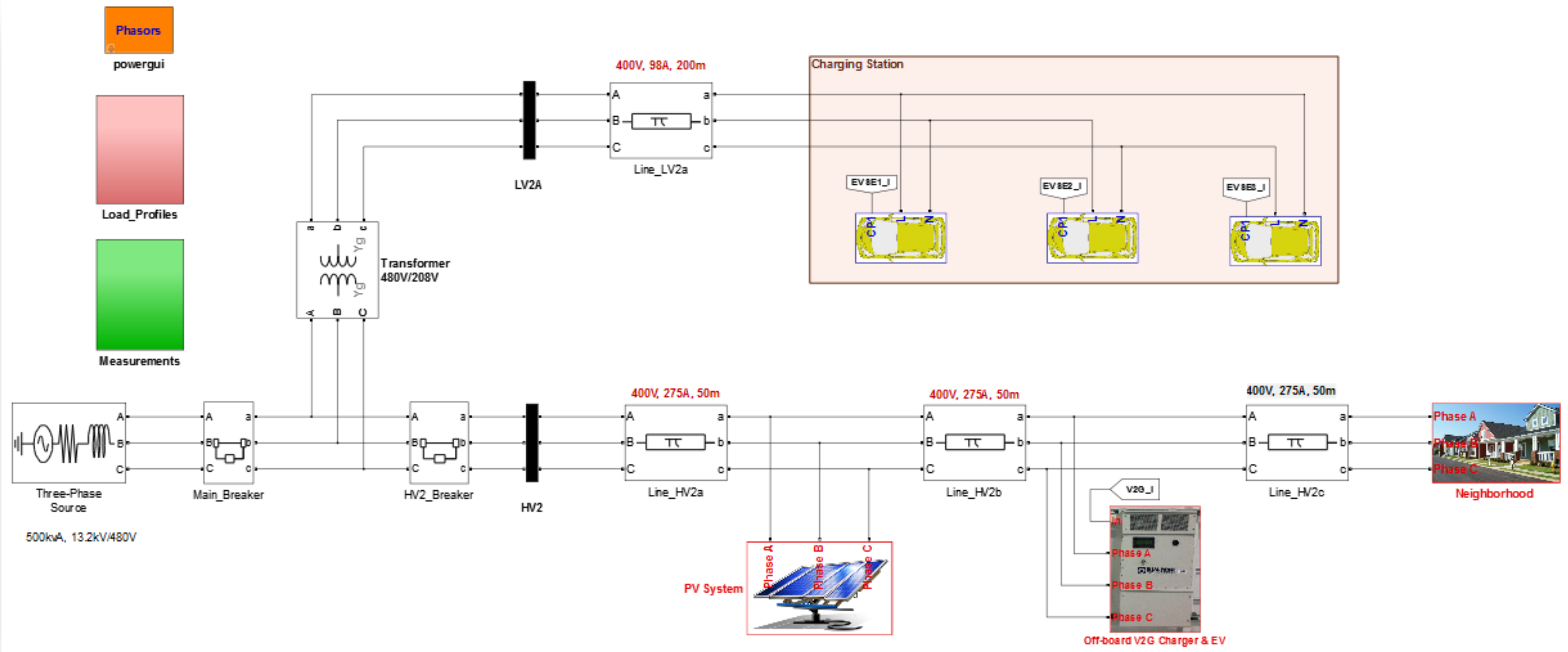
PV Generation

Home Loads



Modeling and Testing of Microgrid

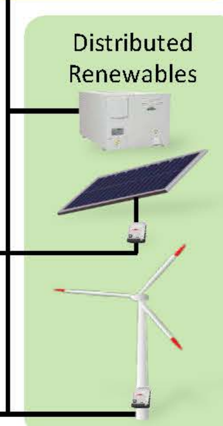


Power hardware-in-the-loop testing

Grid Modernization Efforts

Grid Modernization Initiative

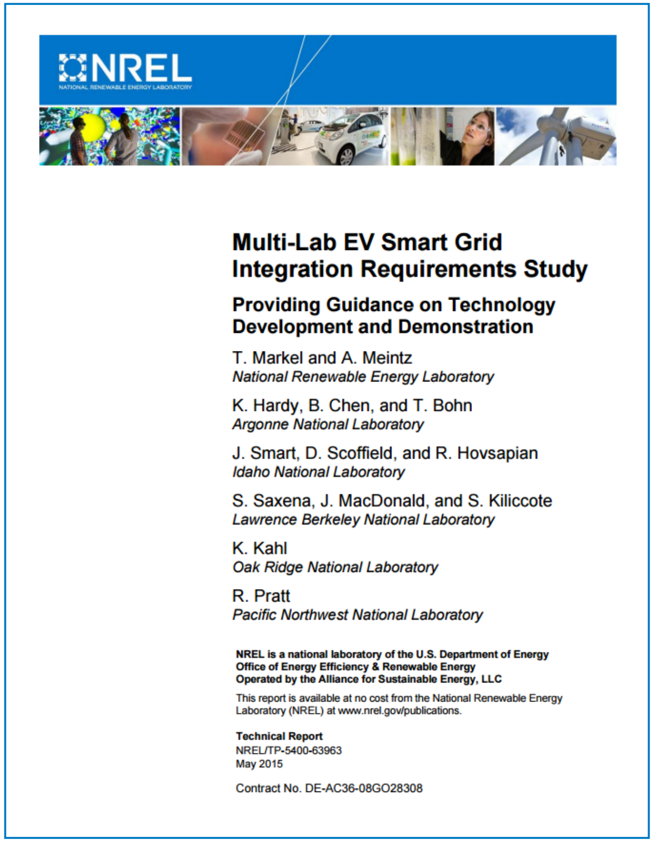
- This new crosscutting effort will build on past successes and current activities to help the nation achieve at least three key outcomes within the next ten years:
  - > 10% reduction in the societal costs of power outages
  - > 33% decrease in cost of reserve margins while maintaining reliability
  - > 50% cut in the costs of wind and solar and other DG integration
- If achieved, these three key outcomes would yield more than $7 billion in annual benefit to the U.S. economy
- Grid Modernization Lab Consortium
  - Mitigate adverse impacts of EV deployment
  - Leverage existing synergies between EVs and the grid, building energy management systems, distributed renewables, and other smart grid assets.



Grid Modernization Lab Call Overview

- Funding for research at National Labs to define and develop integrated systems supporting Grid Modernization Initiative objectives
- EERE Solar, Wind, Buildings, Vehicles, Fuel Cells program supporting along with Office of Electricity
- Proposals are intended to be multi-year and include collaboration across multiple labs
- Category 1 – Foundational efforts; cross-cutting
- Category 2 – Program-specific technologies with interfaces to Category 1 activities

Multi-Lab EV Smart Grid Working Group delivers guidance report to DOE - May 2015


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Multi-Lab EV Smart Grid Integration Requirements Study

Providing Guidance on Technology Development and Demonstration

T. Markel and A. Meintz
National Renewable Energy Laboratory

K. Hardy, B. Chen, and T. Bohn
Argonne National Laboratory

J. Smart, D. Scoffield, and R. Hovsapian
Idaho National Laboratory

S. Saxena, J. MacDonald, and S. Kiliccote
Lawrence Berkeley National Laboratory

K. Kahl
Oak Ridge National Laboratory

R. Pratt
Pacific Northwest National Laboratory

NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Operated by the Alliance for Sustainable Energy, LLC

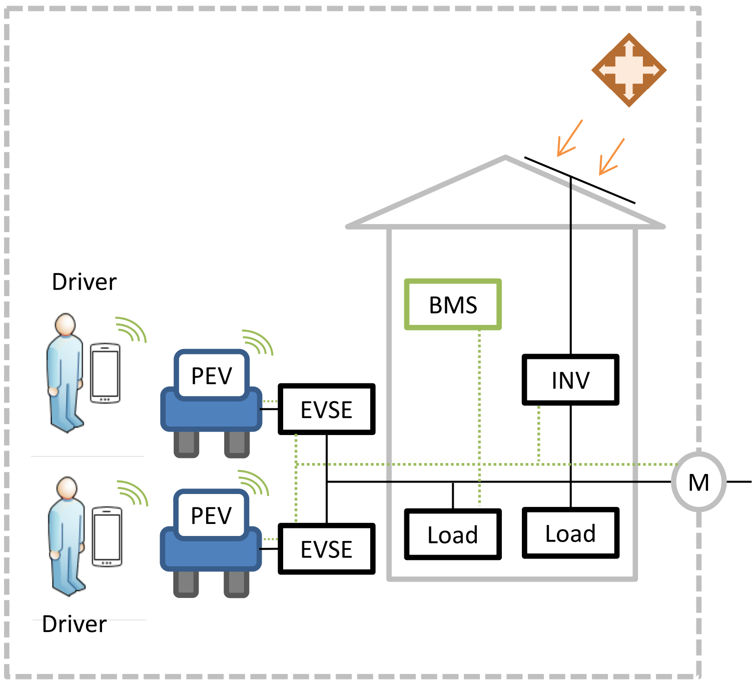
This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-5400-63963
May 2015

Contract No. DE-AC36-08GO28308

Multi-Lab EV Smart Grid Working Group
DOE Vehicle Technologies Office

Vehicle to Building Integration Pathway



Description

- Enable workplace charging and promote broader PEV adoption through the **development and demonstration of an interoperable communication pathway and control system architecture** that connects

  [1] Plug-in Electric Vehicles (PEVs)

  [2] PEV drivers

  [3] Electric Vehicle Support Equipment (EVSE)

  [4] Building Energy Management System (BEMS)

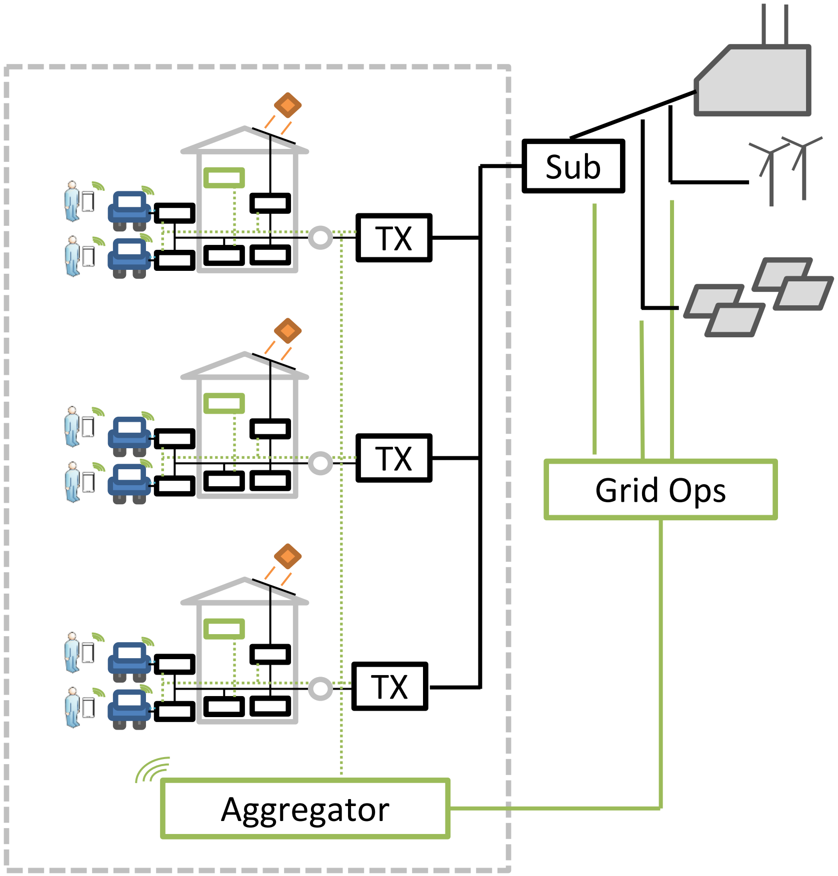
  in order to create value for all parties.
- Demonstrate scalable communications and control system will enable managed energy use between dissimilar grid-connected devices that will mitigate demand charges.
- Establish a physical platform to develop and test the technical requirements needed for standards development and interoperability.

Participating labs (lead lab first): PNNL, ANL, INL, LBNL, NREL
Partners: AeroVironment, Bonneville Power Administration, University of Delaware, DTE Energy, California Energy Commission

Funding: $3.4M over three years

Multi-Lab EV Smart Grid Working Group
DOE Vehicle Technologies Office

Systems Research Supporting Standards and Interoperability



Description

- **Develop a distributed vehicle/grid integration platform** to determine the feasibility of PEVs providing grid services and renewable energy integration without negatively impacting the PEV customer experience
- Perform **distribution-level hardware-in-the-loop demonstrations** involving a variety of vehicles and other distributed energy resources at numerous facilities
- Trial multiple communications pathways to **accelerate standards development** and understand how to prioritize the needs of the PEV customer, facility, third-party aggregator, and grid operator in multiple use cases

Participating labs (lead lab first): INL, ANL, LBNL, NREL, ORNL, PNNL

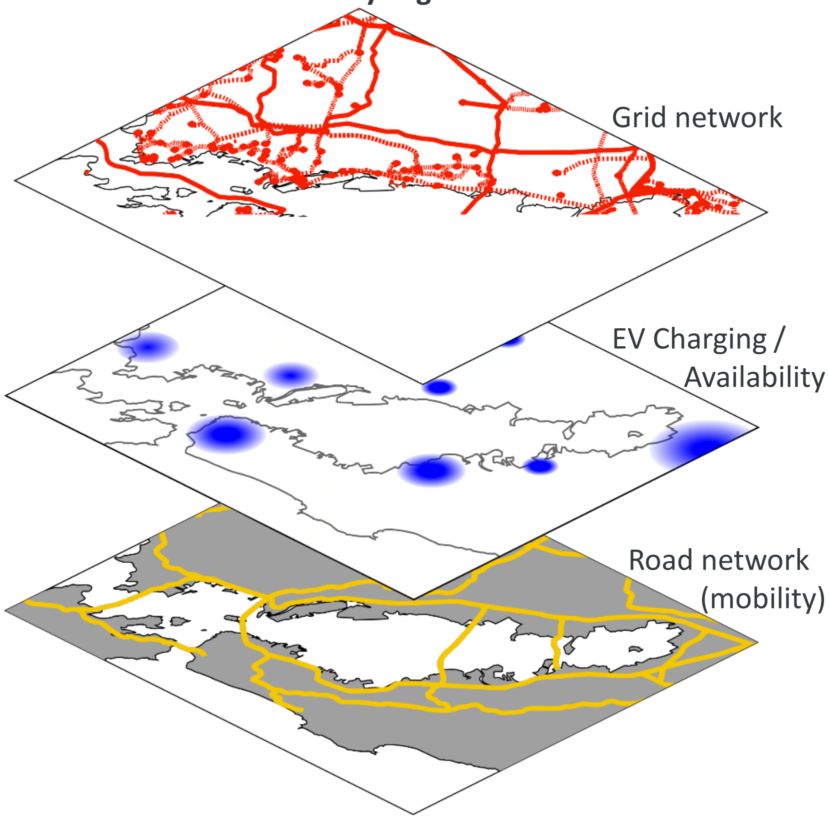
Partners: Bonneville Power Administration, DTE Energy, Eversource, University of Delaware, Siemens, California Energy Commission, USDRIVE Grid Interaction Technical Team

Funding: $3.6M over three years

Multi-Lab EV Smart Grid Working Group
DOE Vehicle Technologies Office

Modeling and Control Software to Support V2G Integration

Simulations & data to quantitatively understand interactions and opportunities between mobility & grid networks



Description:

Develop advanced *modeling and simulation tools* to:

1. **Understand how much renewables integration is enabled by vehicles**, and developing operational frameworks so clean vehicles enable a clean grid.
2. **Understand the value available for vehicles** to serve as a grid resource under different VGI approaches.
3. Provide tools and understanding to **guide effective decision-making on VGI pathways** for all stakeholders.

Participating labs (lead lab first): LBNL, ANL, INL, NREL, ORNL, PNNL

Partners: Bonneville Power Administration, California Energy Commission

Funding: $2.8M over three years

Multi-Lab EV Smart Grid Working Group
DOE Vehicle Technologies Office

Energy Benefits from Vehicles, Buildings, and Renewables Working Together

Questions:
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www.nrel.gov

NATIONAL RENEWABLE ENERGY LABORATORY