Electric Vehicle Grid Integration

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Project ID #VSS156

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

Overview

Timeline

- **Project start date: 5/2014**
- **Project end date: 9/2016**
- **Percent complete: 35%**

Budget

- **Total project funding:**
    - DOE share: 100%
    - Contractor share: in-kind resources
- **Funding received in FY14:** $1.4M
- **Funding for FY15:** $900K

ANL = Argonne National Laboratory
GITT = Grid Integration Technical Team
INL = Idaho National Laboratory
LBNL = Lawrence Berkeley National Laboratory
ORNL = Oak Ridge National Laboratory
PNNL = Pacific Northwest National Laboratory
VSST = Vehicle & Systems Simulation and Testing

Barriers

- **Risk aversion of new tech (VSST – A)**
- **Cost and value proposition (VSST – B)**
- **Enabling tech and Smart Charging Systems (GITT – 2, 3)**

Partners

- **Project lead – National Renewable Energy Laboratory (NREL)**
- **Interactions/collaborations**
    - **ANL, INL, LBNL, ORNL, PNNL**
    - **Univ. of Delaware, PGE**
    - **GE, Grid2Home (Kitu)**
    - **NextEnergy, Coritech**

Relevance – Grid Modernization Alignment

- **10% reduction in economic cost of power outages by 2025**
  - Ability for a vehicle to be a “friendly” element of a microgrid
  - Export power function with grid-awareness
- **33% decrease in cost of reserve margins while maintaining reliability by 2025**
  - Ability of a vehicle/driver to forecast demand, reserve, and flexibility
  - In aggregate, manage local variability of renewable generation
- **50% decrease in the net integration costs of distributed energy resources by 2025**
  - Standardization, standardization, standardization
  - Accelerated testing and demonstrate

Vehicles Program Relevance

Integration of features that enhance the plug-in electric vehicle (PEV) value proposition

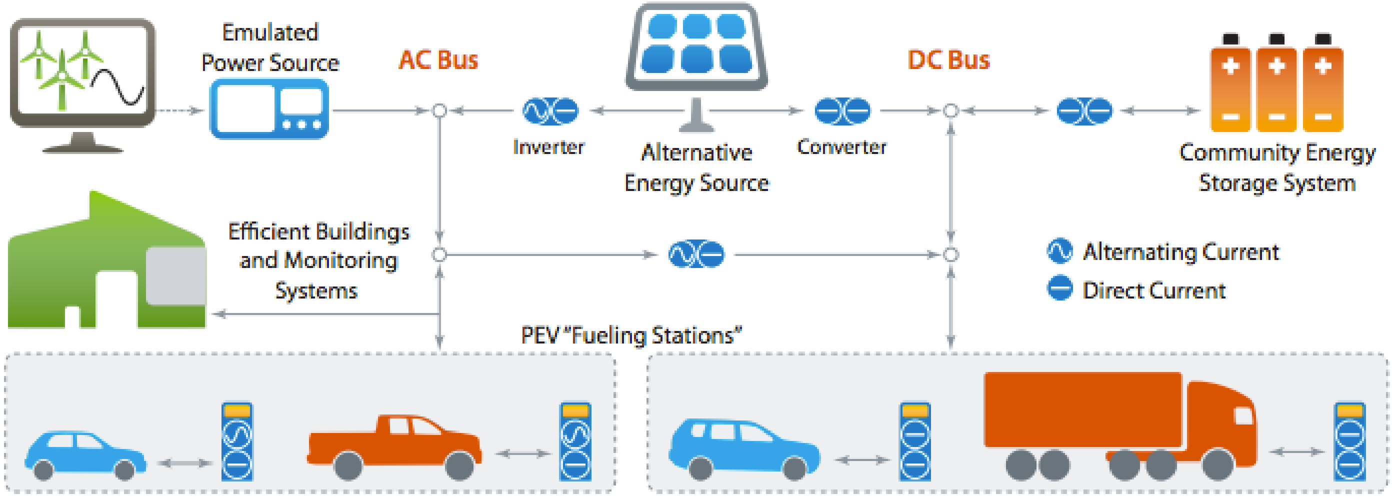
Milestones

Month / Year	Milestone or Go/No-Go Decision	Description	Status
12/2014	Multi-lab Smart Grid requirements study report	Leverage lab expertise to develop an EV Smart Grid Integration guidance document	Completed draft report 12/30/2014; published 5/2015
12/2014	Task 1 – Characterization	Develop a vehicle-to-grid (V2G) systems testing plan including use scenarios for DOE review	Preliminary plan 12/30/2014
1/2015	Task 1 – Characterization	Provide a V2G battery life impacts analysis report to DOE	Analysis progress report 1/30/2015
2/2015	Task 3 – Holistic System	Report on identified values of electric vehicle grid integration (EVGI) strategies	Delivered draft report 2/28/2015
4/2015	Task 2 – Communications and Control	Deliver summary report on existing V2G demonstrations controls and communications architectures	Delivered report 4/30/2015
Quarterly	Quarterly Progress Reports	Summarize progress on the collective task activities	Ongoing
9/2015	Annual Report	Summarize completed tasks and progress at end of fiscal year	In process

Approach

Electric Vehicle Grid Integration at NREL

Vehicles, Renewable Energy, and Buildings Working Together



Developing Systems Integrated Applications

Managed Charging

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

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

Emergency Backup Power

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

Bi-Directional Power Flow

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

Vehicle-to-Grid Challenges

Life Impacts

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

Information Flow and Control

How is information shared and protected within the systems architecture?

Holistic Markets and Opportunities

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

Approach – Multi-lab EV SG Requirements Study

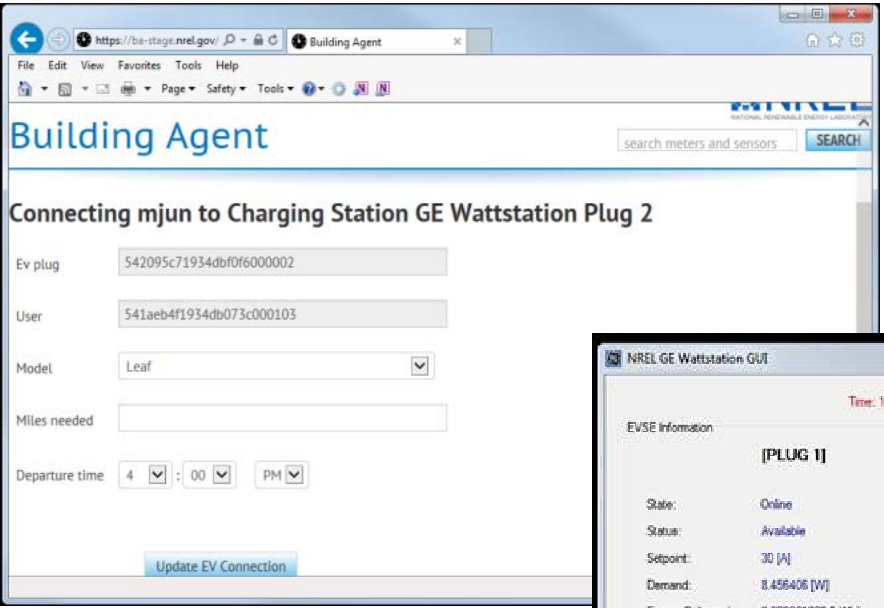
- **Leverage the expertise of multiple national laboratories to evolve the implementation scenarios and requirements for PEV integration with smart grid systems**

- **Produce a guidance document for DOE that details PEV grid integration system implementation methods and remaining research gaps**

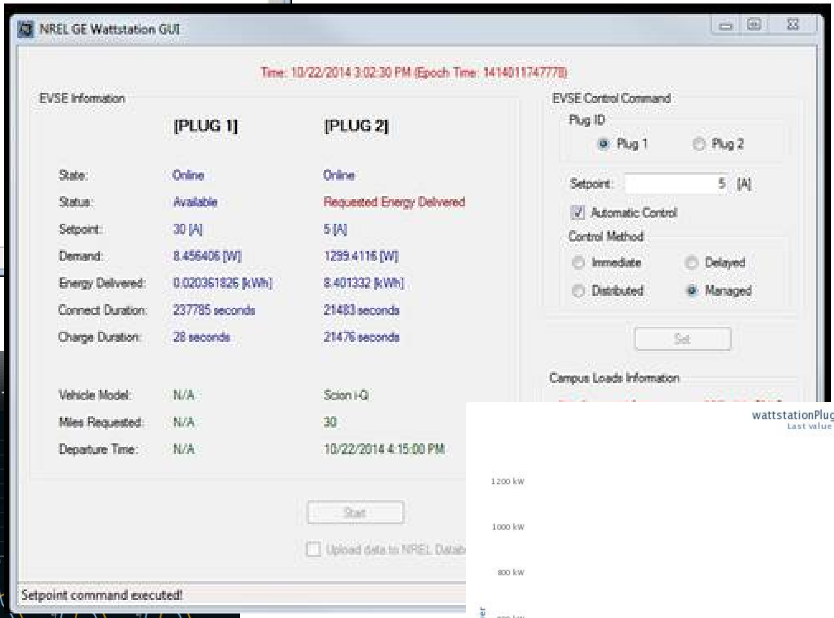
Technical Accomplishment and Progress

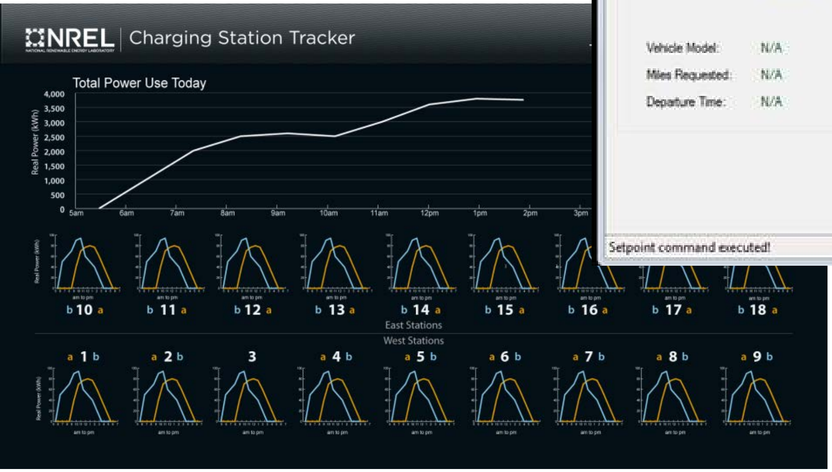
Charge Management System Integration

Driver Entries

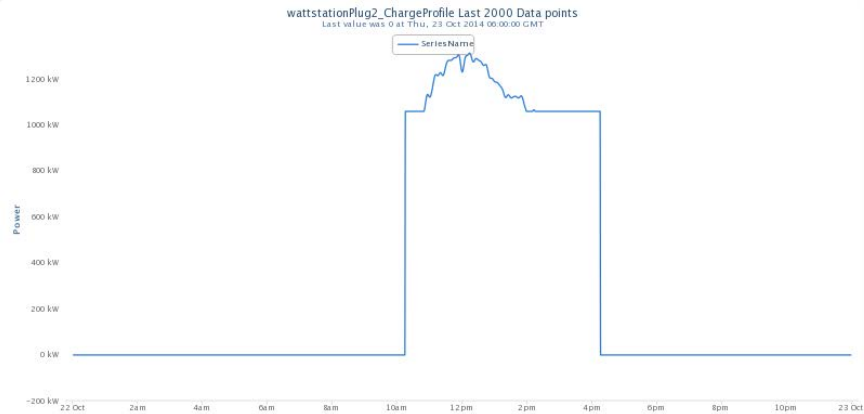


Management Tool





Databus Schedule



Technical Accomplishment and Progress

Mini-E with Export Power Capability

- **19 kW of AC export power**
- **Communication between electric vehicle supply equipment (EVSE) and vehicle supports enhanced features**
- **Central management aggregating vehicle demands/resource and EVSE attributes to meet driver and grid expectations**
- **Completed much of IEEE 1547.1 test procedures – ensures grid safe operations**

Source: JC Zhang, NREL

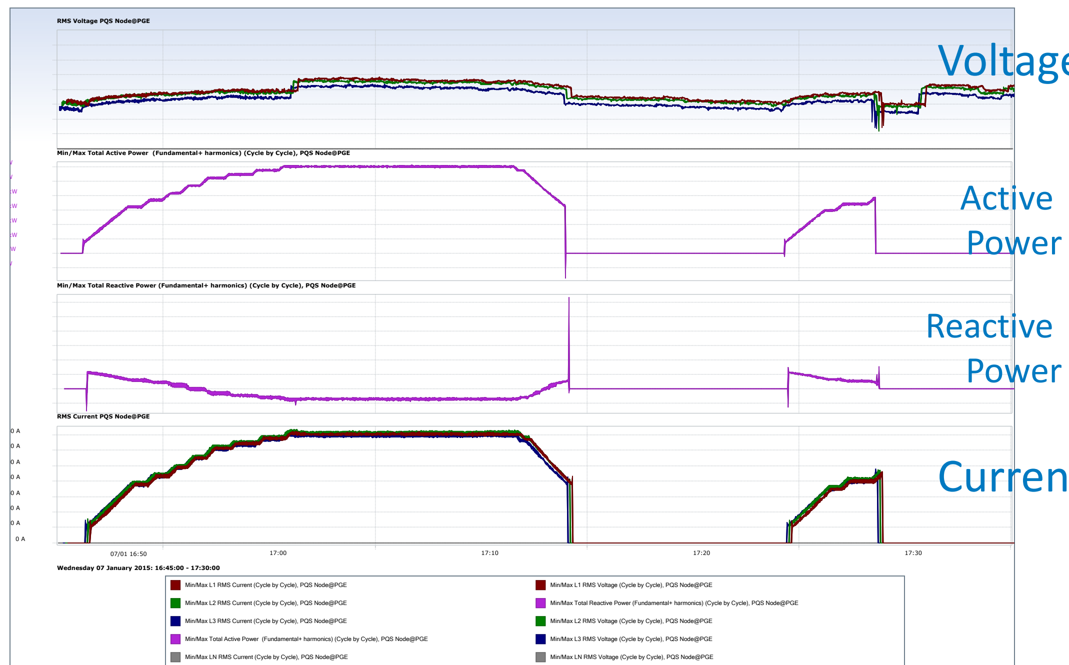
Source: Tony Markel, NREL

Technical Accomplishment and Progress

PGE/EDI V2G Truck – Electrical Characterization

Photo by Dennis Schroeder, NREL 32537

- Provided test support for EDI to perform PF control tuning of inverter software
- Islanded power-up testing utilizing load banks
- Demonstrated grid synchronized export at 120 kVA
- Completed export tests from 0.97 to 1.03 PU grid voltage using grid simulation.
- Initial results of testing to PGE support RFP development



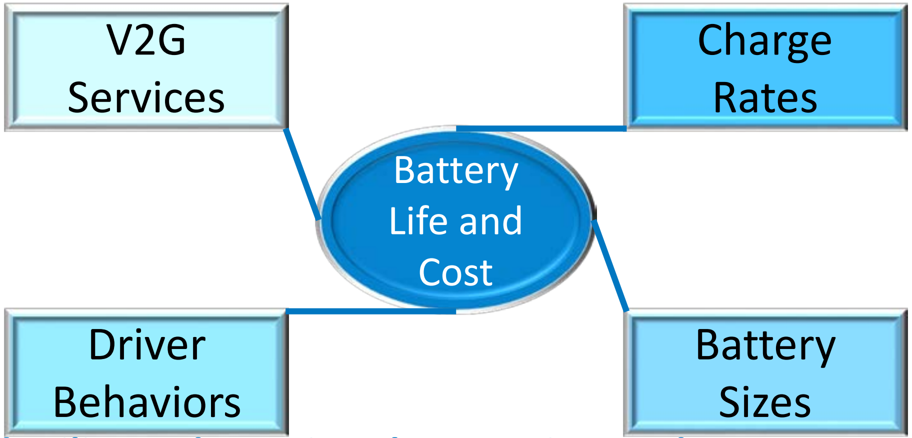
Time (~50 min)

PF – power factor
PU – per unit

Technical Accomplishment and Progress

Grid Services Battery Life Impacts Assessment

- **Impact Definition**
  - Life: Percentage of resistance rise and capacity fade to the values at the beginning of battery life
  - Cost: Total cost of gas, electricity, and battery degradation
  - Utility: Ratio of annual miles driven by battery (charge depleting) to the total annual travel miles
- **Impact of V2G on battery life, cost, and utility under various grid services, driver behaviors, and battery sizes**
  - Grid services
    - Mini-E data
    - Regulation profile
    - Peak demand profile
    - Spinning reserve profile
  - Driver behaviors: 317 driving cycles
  - Battery sizes
    - Plug-in hybrid electric vehicle (PHEV)-20
    - PHEV-40
    - PHEV-80

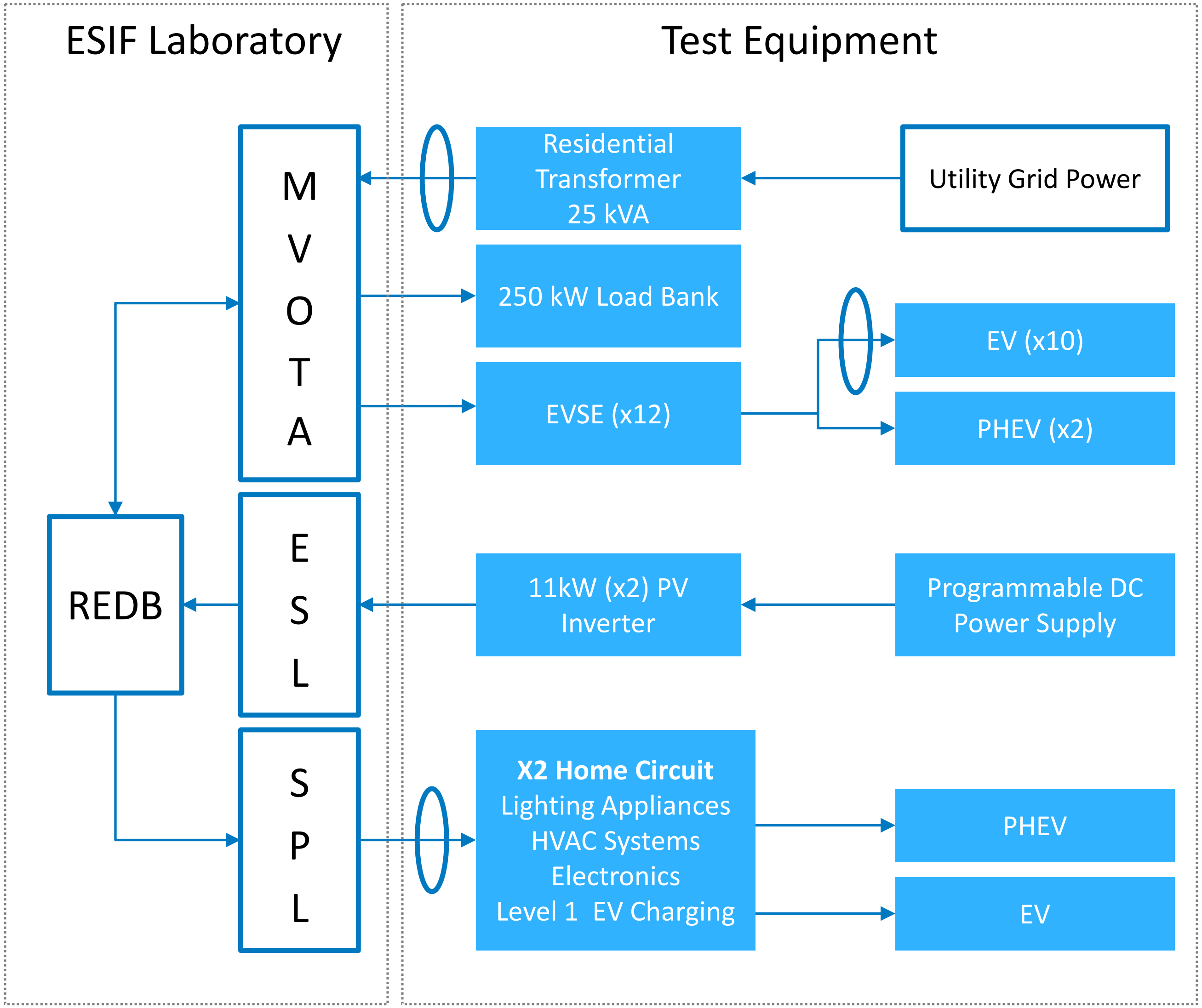


- **Impact of charging rates on battery life , cost, and utility under various battery sizes and driving cycles**
  - Battery sizes
    - PHEV-20
    - PHEV-40
    - PHEV-80
  - Driver behaviors: Three typical driving cycles from 317 driving cycles will be selected for this simulation
    - Aggressive driving cycle (>12,000 miles/year)
    - Average driving cycle (12,000 miles/year)
    - Unaggressive driving cycle (<12,000 miles/year)

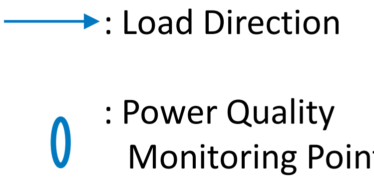
Leverages the development of BLAST-V tool by ES Program

Technical Accomplishment and Progress

ESIF Vehicle Grid Integration Capabilities Development

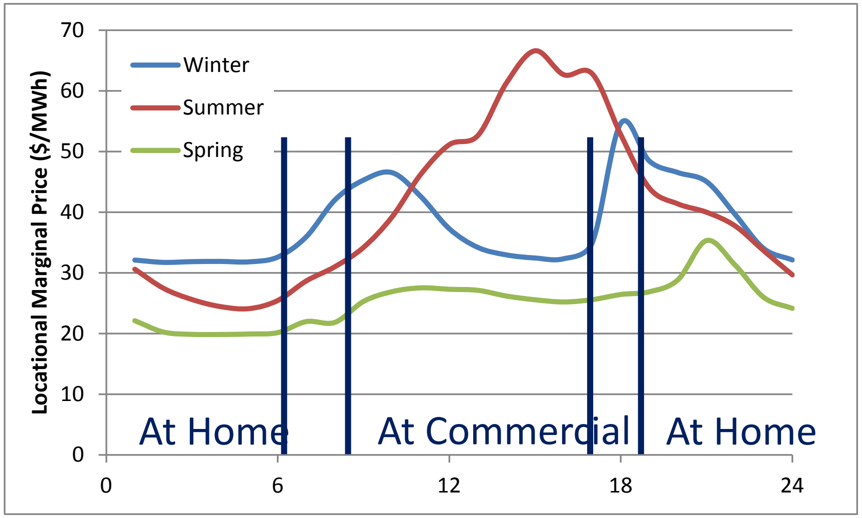


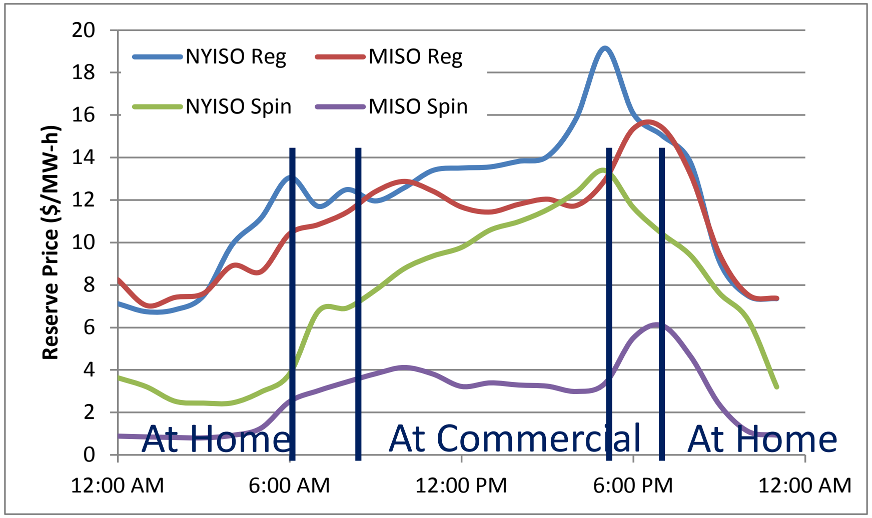
ESIF: Energy Systems Integration Facility
ESL: Energy Storage Laboratory
MVOTA: Medium Voltage Outdoor Testing Area
REDB: Research Electrical Distribution Bus
SPL: Smart Power Laboratory



Technical Accomplishment and Progress

Holistic System – Market Opportunities and Challenges





Daily and Seasonal Variability will Impact Value Proposition

Thoughts on Market Integration

- **EV charge management should first be focused on minimizing or eliminating the capacity costs and optimized around energy cost**
- **The provision of ancillary services from EV charging has the potential to provide some additional value, but is small relative to avoiding capacity costs**
- **The unknown path forward on Distributed Energy Resource participation in markets makes assessment challenging and may differ by region**

MISO – Midwest Independent System Operator
NYISO – New York Independent System Operator

Response to Reviewer Comments

- **Driver needs must be entered to successfully achieve V2G function value. Alternative methods?**
  - There are many pathways to interact with the driver today. Heuristics are being proposed for next year. The risk of failure is quite high.
- **Integration cost of bi-directional systems should be incorporated into the work plans.**
  - The strategies to date consider both on-board and off-board bi-directional power strategies, but the number of systems is quite limited to begin a reasonable cost analysis.
- **The reviewer felt that to know when and why the grid could make use of vehicle energy storage is seen as potentially having real benefit.**
  - A market assessment study was started this year to consider existing grid needs, opportunities, and challenges.
- **There is a need to understand the full cost to the vehicle owner when the battery capacity degradation may be accelerated due to added cycling of the battery.**
  - A battery application and degradation study was initiated this year.

Roadway to Multi-Lab Collaboration

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

<u>Leveraging shared resources</u>

- ESIF offers 1 MVA of grid simulation, 2.25 MW PV simulation, 1.3 MW real and reactive load banks, RTDS for HIL simulation, and High Performance Computing
- VTIF offers 30 kVA of grid simulation, 40 kW of real and simulated PV, 120+kVAR both AC and DC load banks
- EVSEs and vehicles with communications and control through INTEGRATE program

INL – Idaho National Laboratory

- Collaborate on PHIL development to improve INL-NREL RTDS connection at ESIF to leverage resources for large distribution bus simulation.
- Focus on PEV model development in the RTDS environment that account for power quality characteristics of multiple onboard charging systems.

Argonne National Laboratory

- Collaborate on PHIL development to ensure VTIF/ESIF capabilities align with ANL HIL efforts as they relate to PEV to EVSE communication
- Develop PEV V2G agent and reverse power control algorithms for critical load and export applications.

Oak Ridge National Laboratory

- Develop a dynamic wireless roadway simulation tool utilizing magnetic characteristics to understand grid and vehicle dynamics.
- Evaluate infrastructure roll out with capital cost mitigation through applying dual-use applications for power electronics

Berkeley Lab

- Utilize the TSDC statistics with V2G-Sim to develop an understanding of regional variation in unmanaged charging, V1G scheduling capability, and V2G resource capability.
- Evaluate V2G-Sim results through V1G manage charging in an ESIF microgrid environment.

Pacific Northwest National Laboratory

- Collaborate on VOLTTRON agent development for PEV V1G charging to provide building to vehicle control capability and for aggregator agents.
- Focus on a managed charging environment to ensure that EVSEs at workplace charging scenarios do not add to peak power and thus demand charges.

Key Concerns/ Questions to Address

- How does the system of components and controls work to generate value?
- What is the value opportunity, How big is it, What are the Regional differences, and What needs to happen to achieve functionality?
- How will specific functions affect battery life?
- How to enable interactivity across multiple communications and controls structures and implementation environments?
- Local optimization driven by tariffs not necessarily global optimal solution?
- How to make it simple and effective?

Future Plans

Grid Modernization Goals

- 10% reduction in economic cost of power outages by 2025
- 33% decrease in cost of reserve margins while maintaining reliability by 2025
- 50% decrease in the net integration costs of distributed energy resources by 2025

VT Activities

- Ability for a vehicle/infrastructure to be a "friendly" element of a microgrid
- Export power function with grid-awareness

- Ability of a vehicle/driver to forecast demand, reserve, and flexibility
- In aggregate, manage local variability of renewable generation

- Vehicle to home, building, meter, and driver strategy
- Standardization and interoperability
- Accelerated testing and demonstrate

Summary – Electric Vehicle Grid Integration

- **Interest in vehicle grid integration opportunities is high**
  - Significant work remains to make it functional and viable
- **Multi-lab collaborations have led to strategies to maximize benefit of laboratory resources**
- **Growing capabilities in Energy Systems Integration Facility will start to offer insights**
  - Charge management hardware and software solutions
  - Export power integration functionality
  - Communications and controls integration with buildings and homes
  - Fast charge and wireless system power hardware strategies
  - Mitigating renewables impacts both at distribution and operations levels
- **Efforts tie Vehicles Program activities to Grid Modernization**