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PEV / Grid Integration Study

RICK PRATT, P.I.

Pacific Northwest National Laboratory

Project ID # VSS142

PNNL-SA-109462

▶ Timeline

- Start – Oct. 2014
- Finish – Sept. 2015
- 75% Complete

▶ Budget

- Total project funding
 - DOE share – \$455K
- Funding Received in 2014
 - DOE share – \$400K

▶ Barriers and Targets

- Analyze opportunities and methods that facilitate the energy and economic benefits of grid connected PEVs
- Quantify PEV impact on the electricity grid

▶ Partners

- Society of Automobile Engineers: J2847/1, J2847/2, J2847/3 and J2836/5 committees
- NREL, ORNL, INL, ANL, LBNL



Objectives and Relevance

- ▶ The grid and distribution system network is a key conduit for enabling PEVs to contribute to national and regional petroleum and greenhouse gas reduction goals

- ▶ Problem: The electrical distribution system infrastructure is a potential limitation to maintaining or expanding the plug-in electric vehicle (PEV) adoption rate.
 - The projected effects of expanding PEV adoption can be evaluated by performing distribution feeder simulations of electric vehicle charging calibrated against measured EvProject data.
 - The PEV owner charging behavior is regionally biased with utility rate structures (time-of-use tariffs) and shifts the PEV charging demand profile on the distribution system. The projected economic value associated with tariffs can be calibrated against EvProject data.

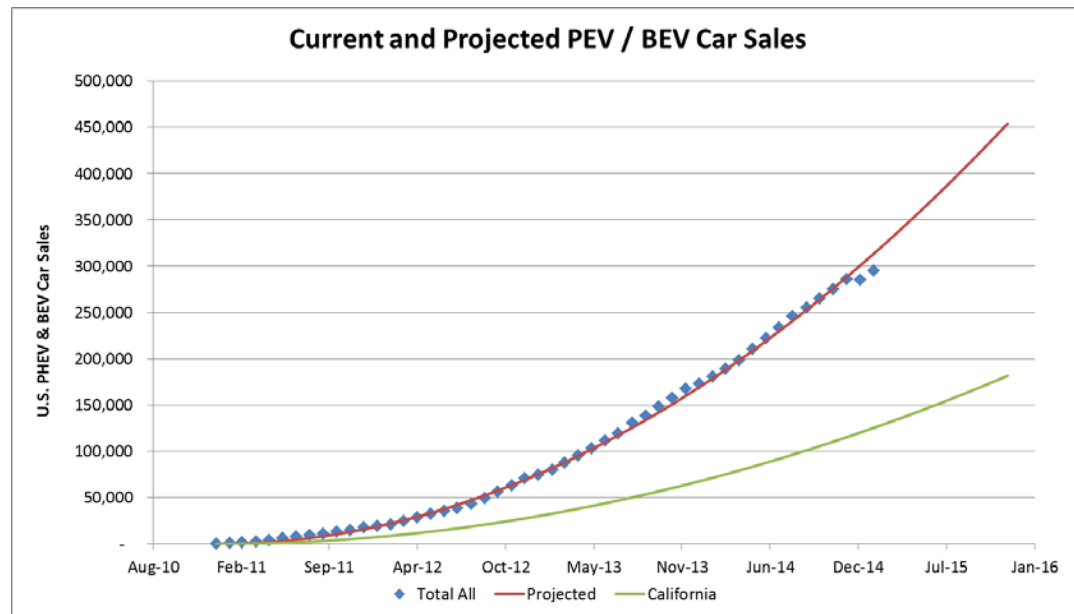
Milestones

Date	Milestone and Go/No-Go Decisions	Status
December 2014	Submit "PEV Smart Grid Integration Requirements and Opportunities Study"	Complete
March 2015	Complete a plan for developing a demonstration of an identified high value task from the "PEV Smart Grid Integration Requirements and Opportunities Study"	Complete
July 2015	V1G PEV Integration to Grid optimized value report	In-progress
August 2015	Collaborate and develop a demonstration of a high value task from the "PEV Smart Grid Integration Requirements and Opportunities Study"	In-progress
September 2015	Report outlining the V1G PEV / Grid communication requirements	In-progress
September 2015	Complete technical contributions to J2847/3 and J2847/5 SAE Standard documents	In-progress

Motivation: PEV / Grid Integration and Petroleum Consumption Reduction

Will PEV adoption enable petroleum and GHG reductions?

- 300,000 PEVs & BEVs sold¹ (Feb. 2015)
- 40% of PEV & BEV sales are in California
- 6,474 EvProject vehicles consumed 17,552.6 MWh in 2013².
- Average annual PEV/BEV energy consumption: ***2.7 MWh / vehicle**
- Annual transportation gasoline not used: ***340 gallons / vehicle @ 25mpg & 0.32 kWh/mile**
- Annual transportation gasoline not used: ***3.2 million barrels**
- 2015 estimated annual PEV / BEV energy consumption (assume 400K vehicles): ***1,084GWh**
- 2014 National Solar Generation³: **15,874 GWh**
- 2015 Annual PEV & BEV tailpipe GHG averted⁴: *** 980,000,000 kg**



- **National solar generation capacity adequate to charge all PEVs and maximize petroleum displacement and GHG averted.**
- **But, what grid infrastructure is needed?**

¹<http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952>.

²<http://avt.inel.gov/pdf/EVProj/EVProject%20Infrastructure%20ReportJan13Dec13.pdf>

³http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a

⁴<http://www.fueleconomy.gov/feg/Find.do?zipCode=94101&year=2015&vehicleId=34918&action=bt3>



Strategy: PEV / Grid Integration

- ▶ Quantify distribution system effects from PEV owner response to a tariff structure:
 - Identify and model projected PEV / Grid integration distribution feeder effects
 - Identify and model projected PEV / Grid integration value opportunities
 - Identify and plan high value PEV / Grid integration demonstrations including communication requirements, use cases and standard's gaps
- ▶ Background work on maximizing PEV V1G (one-direction charging) economic charging value and minimizing distribution feeder impact :
 - Demonstrations have shown the bi-directional (V2G) regulation services value proposition, but most PEVs and EVSEs have no V2G charging capability
 - PEV charging studies typically evaluate the effect of a single grid service
 - Stationary energy siting studies¹ have indicated strong economic value from system upgrade deferral and outage reduction. PEV charging is a form of distributed energy storage
 - Most California TOU tariffs have demonstrated strong PEV owner adoption of TOU programs
 - The concentration of simultaneously charging PEVs on a distribution feeder has not been analyzed to determine the number of PEVs/home that exceed feeder limits
- ▶ A tool² for evaluating stationary energy storage economics has been updated for V1G PEV charging application. This tool provides temporal power inputs needed by GridLAB-D, a distribution feeder analysis tool.

¹"Assessment of Energy Storage Alternatives in the Puget Sound Energy System", Volume1, "Financial Feasibility Analysis", Pacific Northwest National Laboratory, PNNL-23040, December 2013.

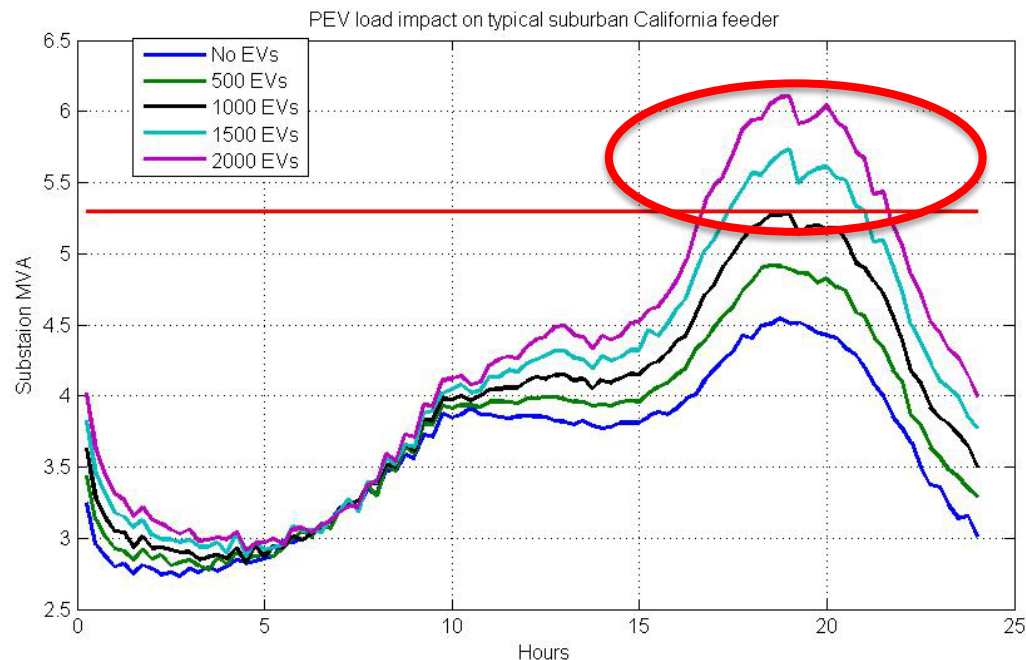
²"Assessment of Energy Storage Alternatives in the Puget Sound Energy System", Volume 2, "Energy Storage Evaluation Tool", Pacific Northwest National Laboratory, PNNL-23039, December 2013.

Approach: Model PEV / Grid integration

uncontrolled charging on distribution feeder

Uncontrolled Charging and feeder effects

- Uncontrolled charging occurs when the PEV charges as soon as its plugged in. It is simple to implement and maintain.
- Prototypical Suburban California distribution feeder simulations using 1000 homes reaches the substation transformer limits with ~1000 PEV or **~1.0 PEVs/home**
- Analysis assumes 3.3kW PEV charging rate and uses 2013 EvProject PEV energy requirements
- California PEV adoption rate²: ~1.5PEVs / home by 2022
- Estimated time for daytime feeder overload: ~7 years
- 30 states have only uncontrolled charging options



Uncontrolled charging will be at design limits with ~1.0 PEVs/home.

¹http://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_vehicles/electric-car-global-warming-emissions-report.pdf

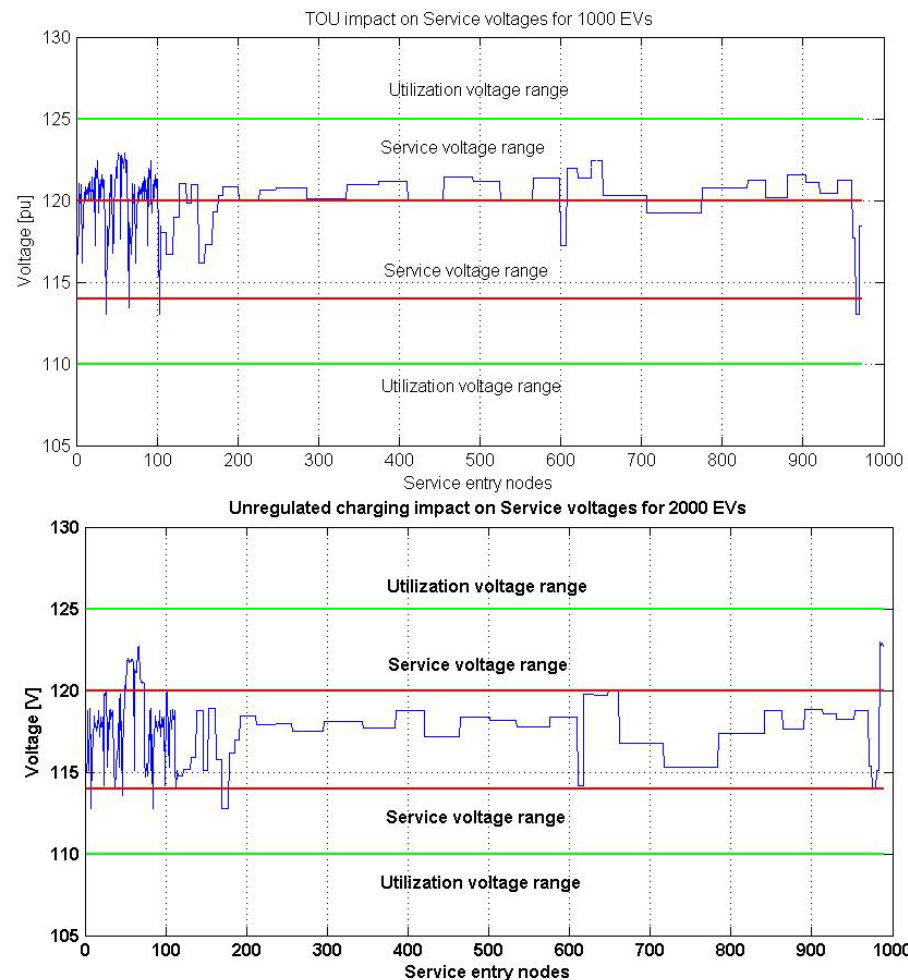
²"Southern California Plug-In Electric Vehicle Readiness Plan", UCLA Luskin School of Public Affairs, downloaded from http://164.67.121.27/files/Downloads/luskincenter/ev/PEV_Readiness_Plan.pdf, using Table s 4.1 and 14.1, December 2012.

Approach: Model PEV / Grid integration uncontrolled charging on distribution feeder

Uncontrolled Charging and local feeder impact

- The local voltage effects of 1.0 PEVs / home and 2.0 PEVs/home is very similar in the uncontrolled charging scenario when observed at the aggregated peak charging rate.
- ¹Service Voltage Range – fully satisfactory equipment operation within the range including infrequent excursions outside the range
- ¹Utilization Voltage Range – outside this range, equipment may not operate satisfactorily or protective devices may operate to protect equipment.
- Utilities actively regulate distribution voltages by means of tap changing transformers and switching capacitors to follow load changes.

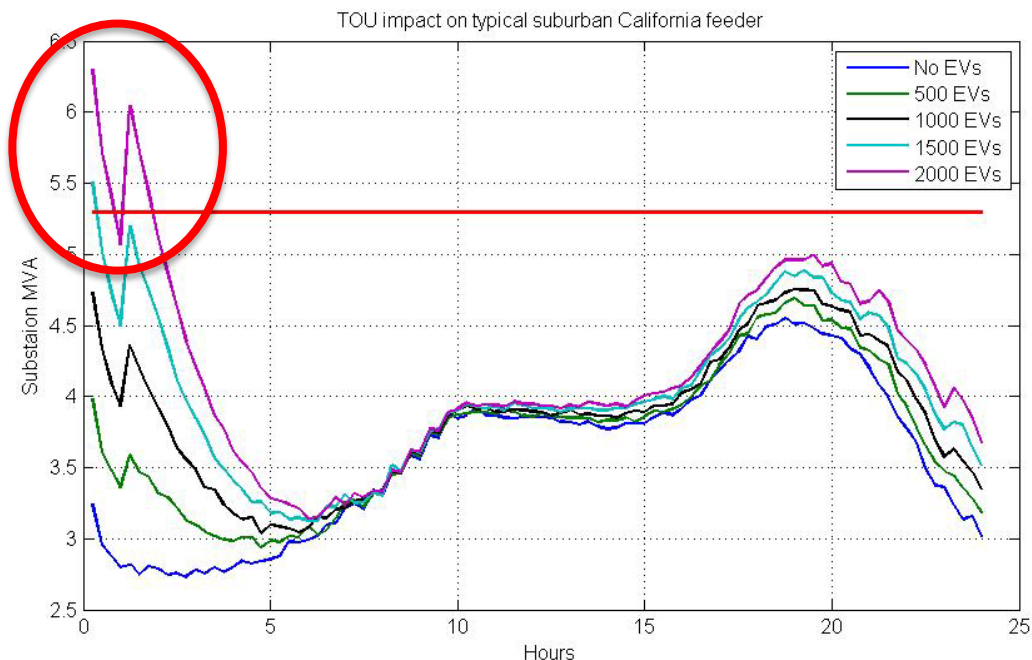
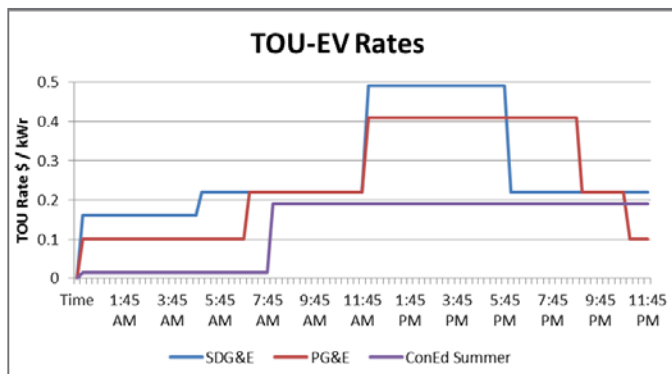
The local feeder voltage impacts are minimal using uncontrolled charging at 2.0 PEVs / home @ 3.3kW charging.



Approach: Model PEV / Grid integration TOU charging on distribution feeder

Time of Use (TOU) Charging and feeder effects

- TOU EV charging tariffs offer lower electricity prices during approved program times
- The PEV owner must subscribe to a utility program and may need to install a separate electricity meter
- 33 utilities in 20 states offer Time-Of-Use PEV charging rates¹
- TOU Rates can vary by utility and time of year



- TOU Charging GridLAB-D simulation on 1000 homes on prototypical Southern California suburban distribution feeder
- TOU charging allows greater PEV penetration and lengthens time before distribution transformer exceeds design limits, but at ~1.5PEVs/home & 3.3kW charging power the design limits are exceeded

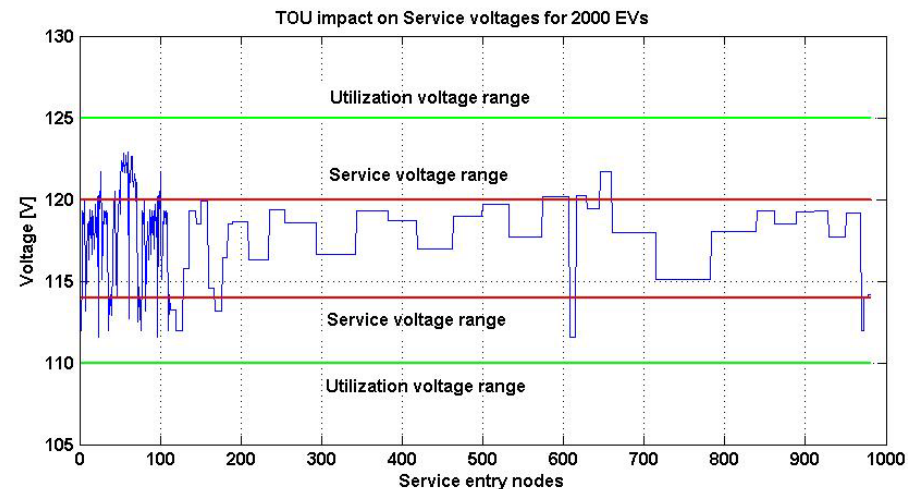
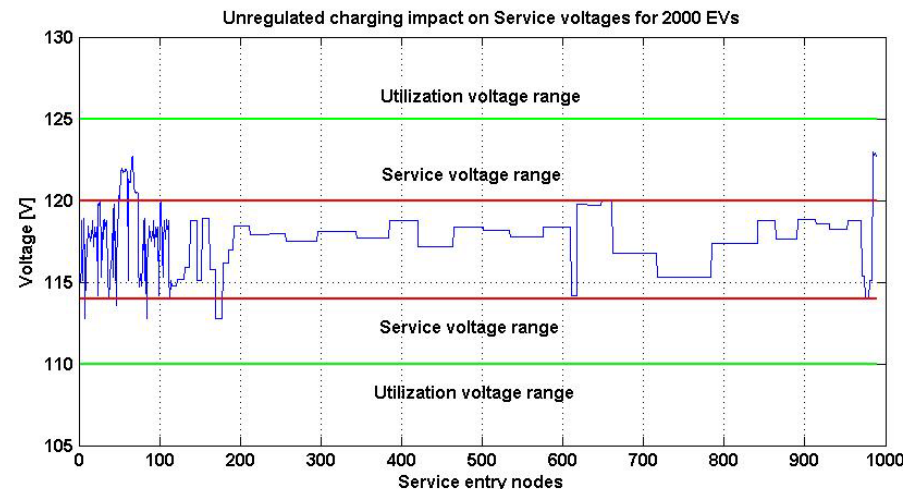
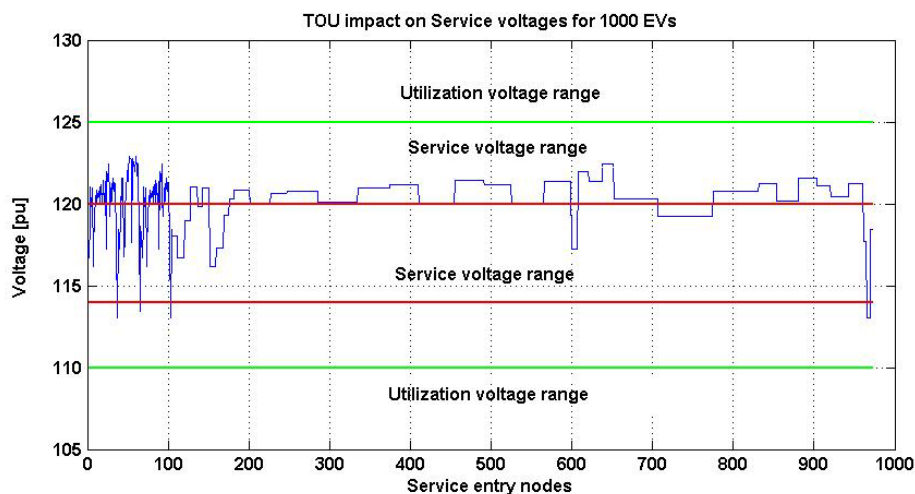
¹http://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_vehicles/electric-car-global-warming-emissions-report.pdf

Approach: Model PEV / Grid integration TOU charging on distribution feeder

TOU Charging and local feeder response

- The local voltage effects of 2.0 PEVs/home for TOU charging has more nodes experiencing larger fluctuations outside of the Service Voltage Range.
- Reducing the number of PEVs / home significantly reduces the numbers and magnitude of Service Voltage excursions.

The local feeder impacts are greater using TOU charging @ 3.3kW, but within tolerances.



Method: Economic value proposition calculations

Simulation Inputs

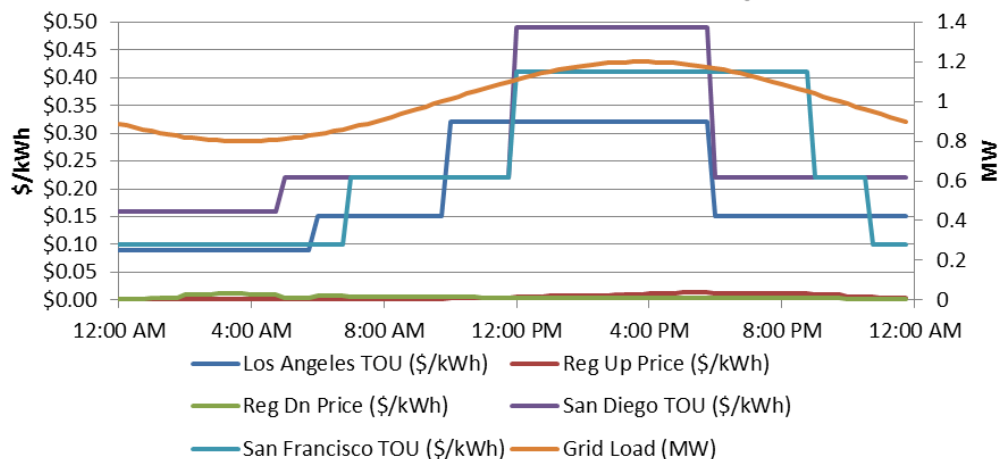
- ▶ Energy price (TOU-EV from SCE, PG&E & SDG&E)
- ▶ Regulation Services value (average from June 2014 CAISO data)
- ▶ Grid load curve peaking at 3:45PM and minimum at 3:45AM
- ▶ NHTSA travel data for 5 groups of 100 vehicles for uncontrolled charging PEV distance and charging times.
- ▶ EvProject Nissan Leaf temporal charging power data from Q4, 2013 for TOU charging times and power
- ▶ Vehicle range, charging efficiency and maximum charging power

Observations

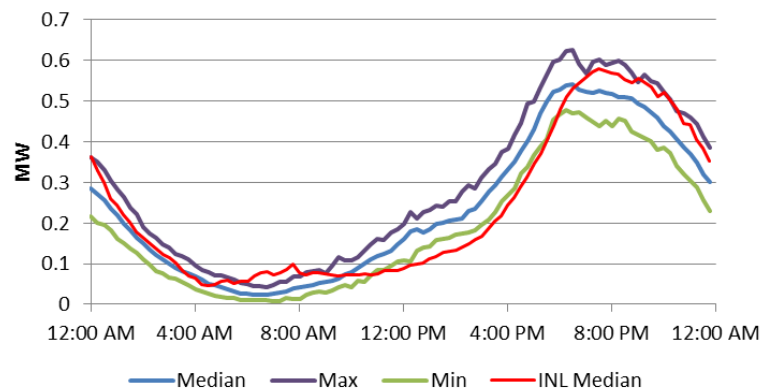
NHTSA travel data adequate for temporal uncontrolled charging power simulations

- Residential charging behavior differed in evenings and early morning

Simulation Price & Grid Load Inputs



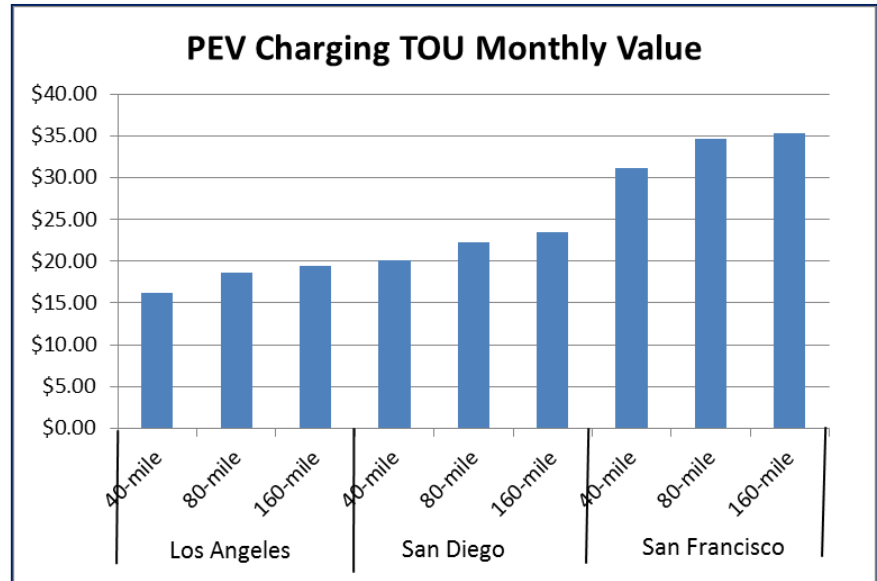
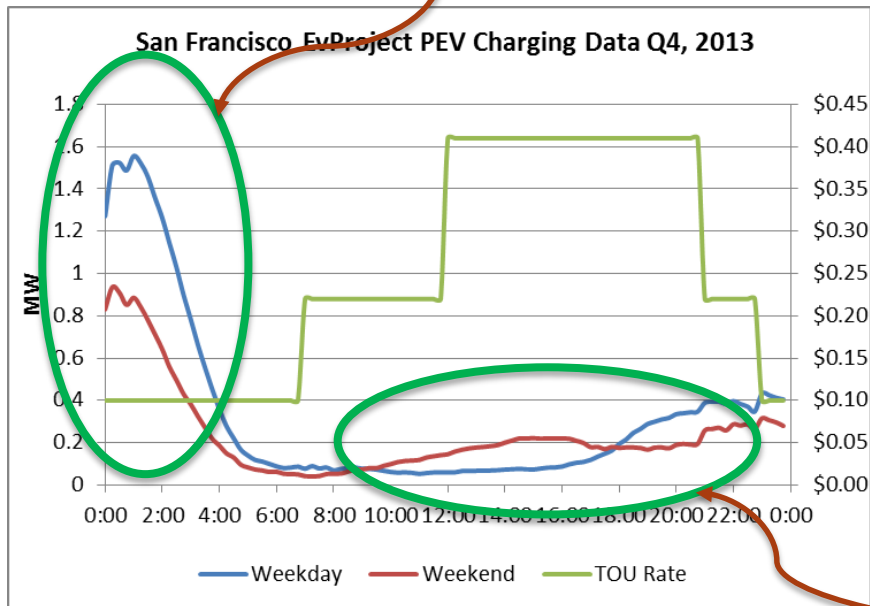
Seattle Oct-Dec 2013 NHTS vs INL Weekday



Approach: Model PEV / Grid integration TOU charging value

Time of Use (TOU) Charging Value

- An average 80-mile PEV range customer subscribing to TOU-EV charging tariffs could expect to pay \$18 to \$35 per month less than uncontrolled charging
- San Francisco EvProject data shows effect of Nissan Leaf owner behavior shifting to gain \$35 per month value

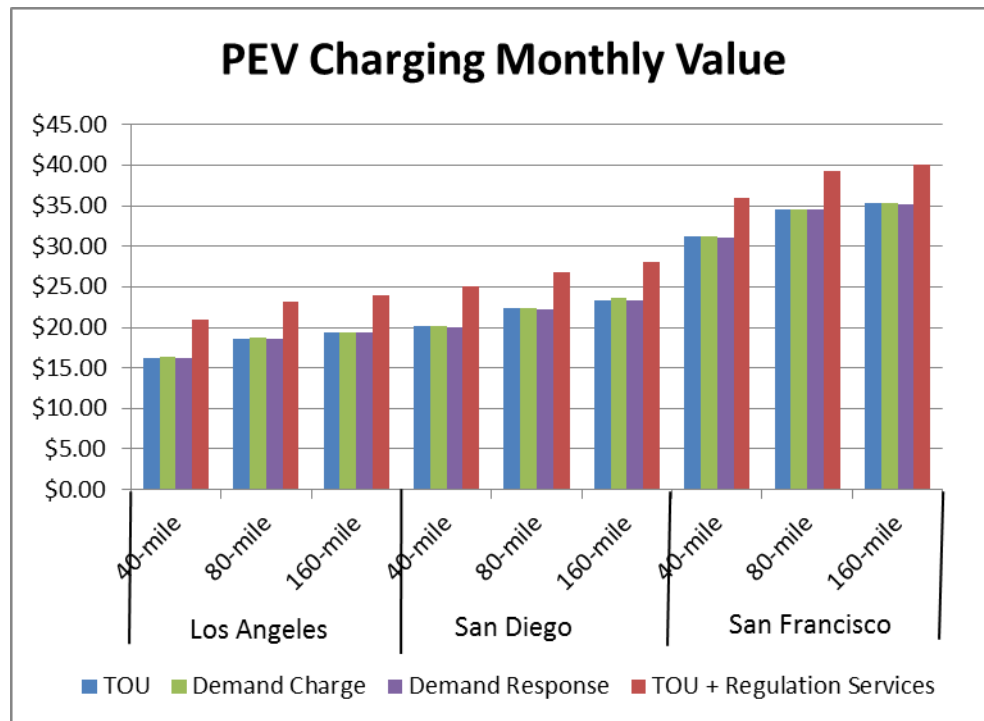


- **TOU charging causes measurable PEV response to tariffs.**
- **But, there is still significant residential charging throughout the day!**

Approach: Model PEV / Grid integration TOU charging

Will adding other grid services improve TOU's \$16-\$36 / month?

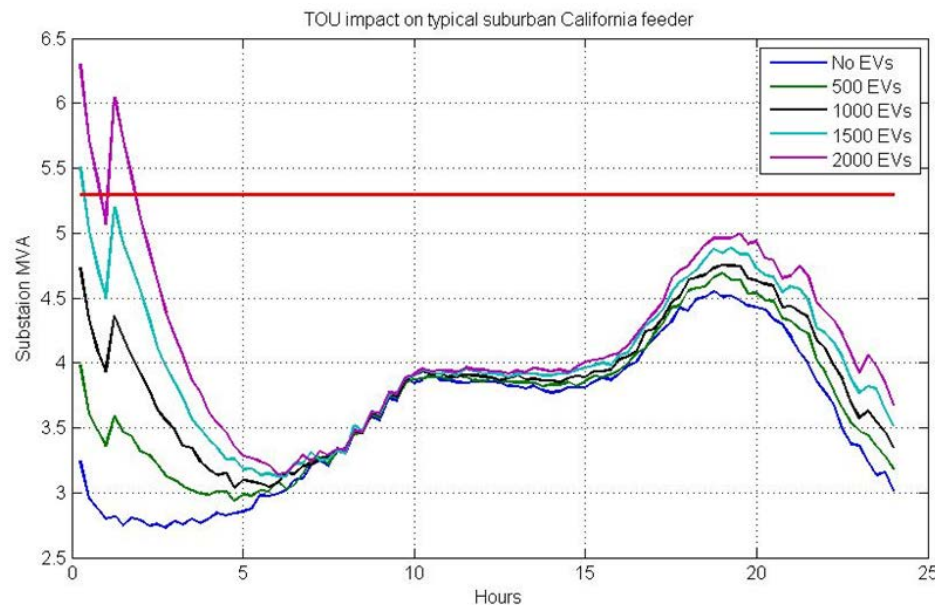
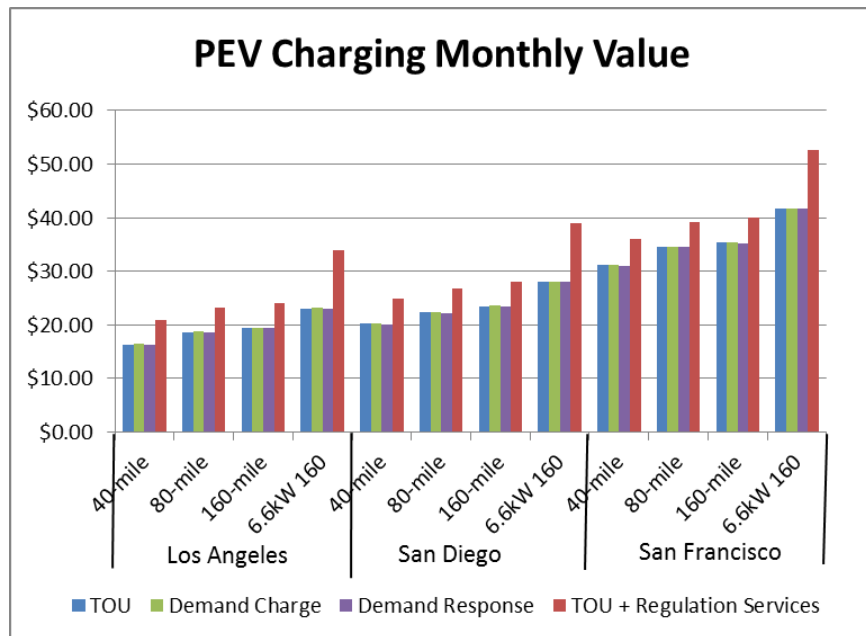
- All markets show an increasing value with battery capacity
- Participating in regulation services provides an additional \$5/mo.
- Demand charge aversion has a very small value
- Demand response value is difficult to determine. Value is available only to PEVs that charge during the DR periods, but current TOU rates are high during DR periods.
- Regulation Services, DR and demand charge aversion may require at least OEM Central Server communication to implement



- Demand Response and Demand Charge aversion could shift peak load, but require additional communication infrastructure
- Incorporating Regulation Services with TOU provides an additional 13% to 30% increase in revenue

Approach: Model PEV / Grid integration TOU charging on distribution feeder

What is the effect of increasing charging rate?



Increasing charging power will be needed for longer range batteries. This increases:

- regulation services revenues
- TOU charging rate peak

The width of the TOU peaks also increase as Vehicle Miles Traveled increases

- Substation PEV charging power for 500 PEVs shifts from the 500 EV line to the 1000 PEV line at the 6.6kW charging rate.
- **750 EVs (0.75 PEVs/home) exceed the distribution feeder design limits**

Process: V1G Economic Value Proposition

▶ Simulation Goals:

- Identify the maximum value for a combination of V1G grid services the PEV can provide while charging and still meet its transportation requirements
- Model the effect of uncontrolled and TOU charging on prototypical suburban CA feeder

▶ Economic Valuation Process:

- NHTS data for first set of 100 vehicles is used to obtain vehicle travel history
- Vehicle energy requirements & charge complete time determined
- Charging is conducted only when vehicle is home and:
 - When the customer value will be maximized by selecting times when the combination of
 - ◆ tariffs (energy rates) are minimized
 - ◆ Grid services value is maximized
 - When the energy required, maximum charging rate and charge time limitations can be met
- Simulation is run for 24 hours and terminated such that state of charge at end of day is the same as at the beginning of the day
- The economic value is reported as the difference between uncontrolled charging and controlled charging
- The temporal power for each PEV charger is output to feed the grid simulation software

▶ Grid Simulation Process:

- Obtain temporal charging PEV charging data and select spatial feeder locations to apply PEV charging load
- Execute GridLAB-D and evaluate nodes and distribution transformer performance



Technical Accomplishments

- ▶ Market and distribution feeder simulations identified:
 - Combinations of grid services provide additional revenue streams
 - Some combinations of grid services are not broadly compatible (i.e., DR and TOU)
 - Regional market variations require providing different combinations of grid services to optimize PEV owner value
 - Increasing battery capacity (range) can result in battery charging rate increasing to support travel requirements. This causes feeder limits to be reached more quickly, but regulation services revenue does increase

- ▶ Distribution feeder simulations identified:
 - Uncontrolled charging on moderately loaded feeders can exceed distribution transformer limits as PEV adoption increases
 - TOU charging on moderately loaded feeders can exceed distribution transformer limits as PEV adoption increases
 - Increasing PEV charger sizes and battery sizes will extend the charging rate AND increase the width of the TOU peaks

- ▶ System-Level observations:
 - TOU rate structures do NOT currently enable greater petroleum and GHG reductions since EV charging constrained to morning hours when wind and solar have lower impact
 - Larger batteries and higher charging rates will aggravate localized feeder issues by exceeding limits longer and farther

Technical Accomplishments – Develop Requirements and Use Cases

- ▶ Use Cases that could enhance PEV owner value:
 - Determining a distribution system upgrade deferral value is difficult since TOU tariffs delay most T&D upgrades. Distributed TOU times (maybe using even / odd house numbers for different TOU schedules) do not require communications, but could incentivize residential charging distribution
 - Duck Curve solar ramp rate is a seasonal issue that incentivized PEV charging behaviors could help mitigate
 - Renewables integration – economic value has not been attributed to specifically charging electric vehicles from renewable resources
 - Communications are required to manage aggregated PEV charging loads response to dynamic grid conditions

- ▶ Control and Communication Requirements
 - A number of different communication interfaces and protocols exist for utilities to communicate needed variations in generation or load
 - Network security requirements must be met and maintained
 - Duke Power and Light's "Distributed Intelligence Platform" and PNNL's VOLTTRON are designed to bridge between communication interfaces (including utilities) and PEV charging control interfaces
 - The communication latency from utility to controllable generation or load must be less than 1 second in order to participate in regulation electricity markets
 - Customer preference (e.g., departure time) and PEV information (e.g., energy required) communications must be developed and tested (SAE-J2847/5)
 - Current electricity markets require aggregation of either 100kW or 1MW to participate in the market¹⁷



Path forward – FY2015

▶ Simulation – economic / distribution feeder

- Report PEV value-optimized V1G grid integration use cases
- Quantify potential PEV market value and renewables integration potential.
- Report the communication and technology requirements needed to support value-optimized use cases
- Develop collaboration teams to validate and extend methods developed

▶ Hardware

- Develop and test reference designs needed to support communication and control technology development using VOLTTRON (distributed control platform) that lead toward implementing PEV charging control into a transactive control system
- Specify communication latency and bandwidth needed for fielded control system
- Identify gaps in standards (ANL / PNNL)

Path forward - Multi-Lab collaborative identified three research areas

▶ Simulation

- Identify PEV value-optimized grid integration use cases using V2G-Sim (LBNL), EvProject data (INL), and GridLAB-D (PNNL) to quantify potential PEV market value
- Develop simulated basis for VGI business models
- Perform analysis needed to articulate benefits to OEMs, PEV owners, utilities and policy makers
- Develop hardware and information requirements for agent controllers
- Identify simulation areas / capabilities needing additional R&D

▶ Emulation

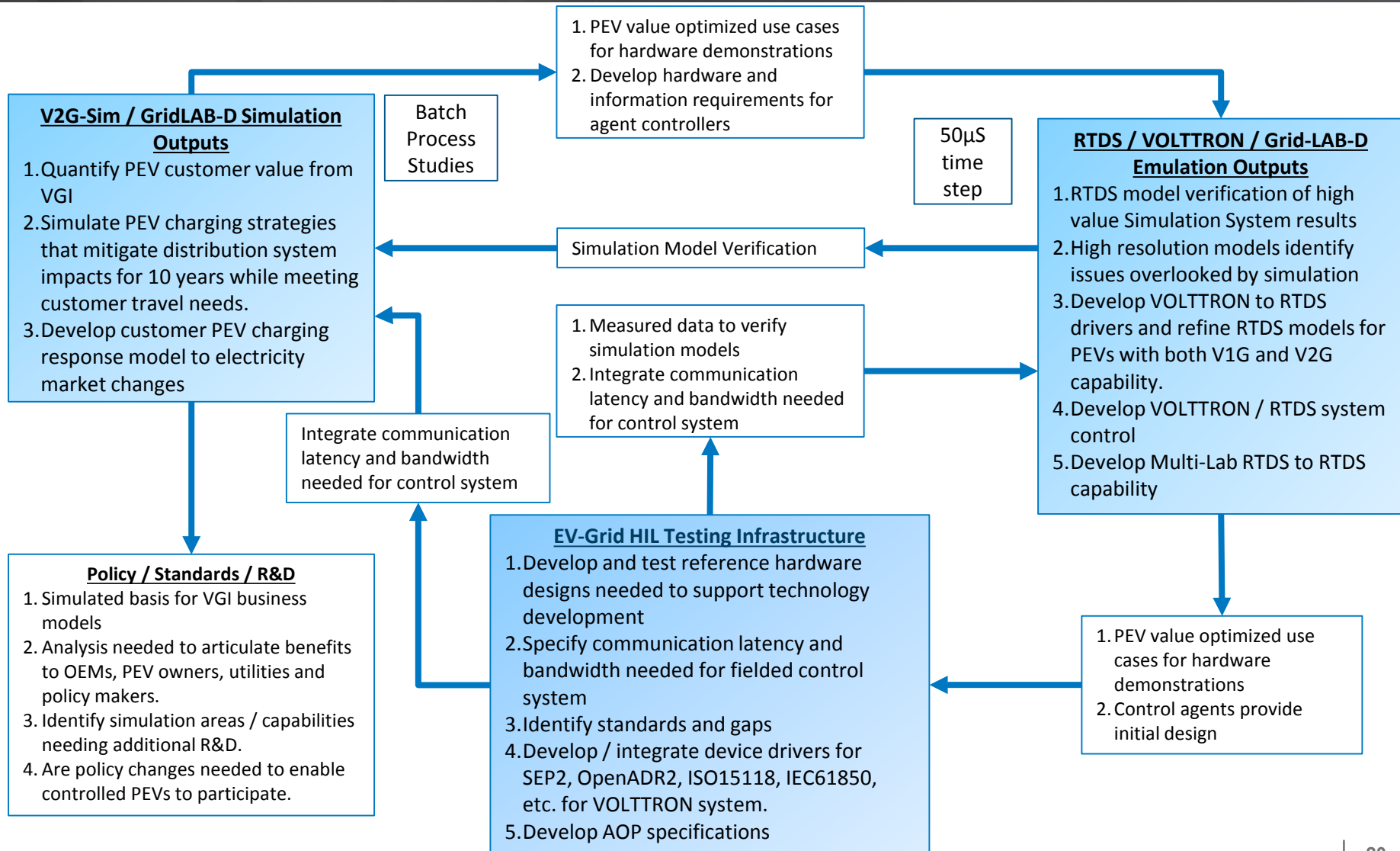
- Verify simulation models and results using emulation models (INL) and GridLAB-D (PNNL)
- Analyze high resolution emulation data to identify harmonic and transient issues
- Develop VOLTTRON (PNNL) / emulation drivers and system control approaches
- Develop Multi-Lab emulation capability

▶ Hardware

- Develop and test reference hardware designs (PNNL / ANL) needed to support technology development
- Provide real-time measured data to verify simulation and emulation models
- Specify communication latency and bandwidth needed for fielded control system
- Develop / integrate VOLTTRON (PNNL) device drivers for SEP2, OpenADR2, ISO-15118, etc.
- Identify gaps in standards (ANL / PNNL)



Integrated Multi-Lab FY16-17 Proposal





Responses to Review Comments

Review Comments being addressed

- ▶ Question 1: Approach to performing the work - the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.
 - Integrating additional use cases and expanding external collaboration
- ▶ Question 3: Collaboration and coordination with other institutions.
 - The reviewer added that it seemed the project should have more extensive collaboration, including utilities, as well as additional EVSE manufacturers and potentially home energy control systems partners such as Johnson Controls. It is mentioned under Gaps that utility incentives for coordinated charging are beginning to appear in several regions.
- ▶ Question 4: Proposed future research – the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways.
 - One concern the reviewer had is whether enough collaboration and communication is being undertaken with those entities which would ultimately have to accept and implement recommended control strategies. Additionally, it seems that having a few additional use cases would be beneficial instead of relying on one case with three EVs and a single determination of when each one would be back ready to charge, before drawing peak load reduction conclusions
 - The reviewer observed that the PI would benefit from a more comprehensive future research strategy. Presently, he has investigated frequency regulation and coordinated charging. The reviewer added that future research efforts involve further coordination with the utilities; however, limited details were provided.

The review comments have identified two general areas of concern:

- Extending the research scope (use cases, external collaboration partners, etc.) beyond the current boundaries to enable broader conclusions and create opportunities for research to be commercialized. It was an accomplishment to implement the demonstration in hardware and exciting to hear the encouragement to develop collaboration teams. The FY15 project scope began to establish broader collaboration efforts, first through more active collaboration with other Labs including LBNL, INL, ANL, and NREL and in FY16 with utilities. FY15 efforts included visits to Chrysler, DT Energy, and Mercedes to begin to establish relationships with these organizations. An NDA was put in place with Chrysler to discuss a technical solution to an issue brought up in a GITT meeting. In addition, the stationary storage economic tools developed through relationships with LBNL and PG&E and adapted for use in the PEV V1G market will be tested with utility partnerships currently being established.
- Develop a multi-year research program building upon Laboratory technology and connections that enables wider PEV adoption and identifies opportunities for PEV / grid integration. The PNNL FY15 and future plans realize this objective beginning with PNNL and LBNL PEV economic tools integrated with GridLAB-D. FY16 plans include enhancing the PNNL Lab Homes physical test bed through connectivity with PNNL buildings using PNNL's VOLTTRON and live grid data feeds as well as enabling ANL and INL to develop VOLTTRON HIL applications.

Questions ?

Other references:

“PEV / Grid Integration: Value Proposition and Charging Optimization”, Pacific Northwest National Laboratory, PNNL-23801, October 2014.

Contact:

▶ *Rick Pratt* at (509) 375-3820
rmpratt@pnl.gov