Comprehensive Assessment of On-and Off-Board V2G Technology Performance on Battery and the Grid

Project ID #elt187

Principal Investigator: **Sunil M. Chhaya, Ph. D.**
Technical Executive
Electric Power Research Institute (EPRI)

Annual Merit Review
21 June 2018

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Outline

- Overview
- Project Objective
- Approach
- Milestones
- Project Accomplishments / Progress
- Collaboration and Coordination
- Market Impact and Sustainability
- Remaining Challenges and Barriers
- Summary Slide
- Technical Back Up Slides
- Critical Assumptions/Issues

Overview

Timeline

- Start – November 2016
- Finish – November 2019

Percent complete: 65%

Barriers

- Lack of Data on DER Applications
  - Value of V2G integration as DER asset
- On and Off-Vehicle Hardware
  - Cost, performance, communications, monitoring, and control
- Standards verification for V2G application
  - Interoperability and Certification

Budget

- Govt Share: *$1,547,678.00*
- Cost Share : *$1,238,600.00*
- Total Program: *$2,786,278.00*

Funding for FY 2017: $860,679
Funding for FY 2018: $631,836

Partners

- Lead: Electric Power Research Institute (EPRI)
- Partners: Flex Power Control, FCA, Kitu Systems, LG Chem
- Collaborations: NREL and ORNL

Project Objective

Objective

- Develop and demonstrate power electronics and energy management controls software solution to integrate vehicle bi-directional power flow (V2G) with solar and stationary energy distributed resources for both on-vehicle (AC) and off-vehicle (DC) bi-directional inverter technologies.
- Key Enabler is ***Smart Power Integrated Node (SPIN)*** – single multi-functional modular unit integrating solar, stationary energy storage, and V2G into a localized DER Management System.

TI Goals

- **Energy Security** – improves energy efficiency and utilization of renewables
- **Economic Growth** – enable accelerated adoption of electric vehicles by proving viability and cost benefit of V2G as useable dispatchable DER
- **Affordability to Consumers** – system integration of hardware/software reduces installation costs and upfront investment; Ongoing optimized energy efficiency saves on cost of energy
- **Reliability/Resiliency** – system interaction with utility distribution systems supports grid reliability, - integrated dispatchable DER w/V2G can support grid resiliency

Impact

- Verify application/interoperability of Standards Based Communication Protocols – SAE J1772, IEEE 2030.5, J2847/2, J2847/3, J3072, J2931/1, J2931/4
- Address viability of V2G as DER resource and cost benefit to consumer and utilities
- Address automaker concerns for battery durability impacts

Approach-Two Open Standards Based Architectures for V2G Implementation

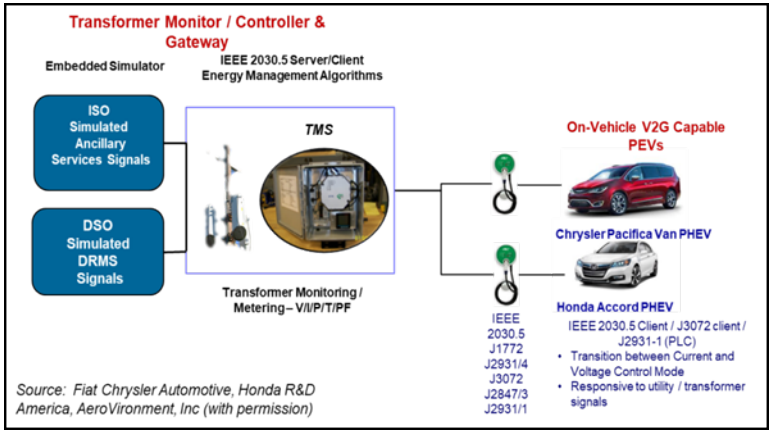
On-Vehicle AC V2G

- Incorporates ***Transformer monitoring and controls*** to manage multiple connected V2G capable PHEVs
  - Transformer Management System w/IEEE2030.5
  - L2 EVSE Bridge w/J3072 Authentication S/W
- Chrysler Pacifica Van PHEV and Honda Accord PHEV w/IEEE2020.5 /J3072 S/W

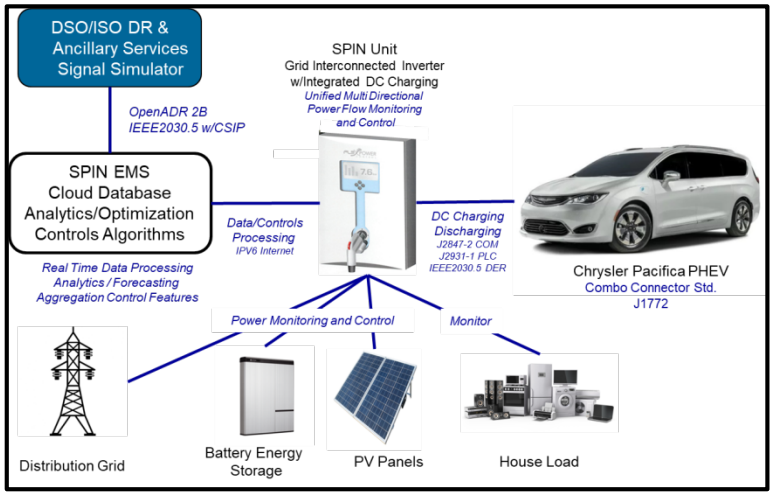
Off Vehicle DC V2G

- Incorporates ***Smart Power Integrated Node* (SPIN**) for integrating V2G as a distributed resource with solar and energy storage
- J1772 CCS DC Charging w/J2847-2/J2847-3/ IEEE2030.5 Com and Control
- Chrysler Pacifica PHEVs with J2847-2/J847-3/IEEE2030.5 implementation
- SPIN cloud based DER energy management system - data analytics and optimization algorithms

AC V2G Architecture



DC V2G Architecture



Source: EVSE Images – AeroVironment, Inc, Transformer Monitoring System (TMS): EPRI Technology, Battery Storage LG Chem, PHEV Images – Fiat Chrysler Automotive

Milestones

Budget Period 1 – Completed

Milestone	Type	Description
Use cases defined	Technical	Use cases are defined and prioritized.
Bi-directional converter design complete	Technical	The initial design for the bi-directional converter is completed.
SPIN build complete	Technical	SPIN assembled and is functional
SPIN HIL testing complete	Technical	The Hardware in the Loop (HIL) testing is complete
Critical Design Review Complete	Go/No Go	The Critical Design Review confirms device meets requirements and can proceed.

Budget Period 2 – In Progress, On Track

Milestone	Type	Description
Test plan complete	Technical	The system test plan is completed and ready
SPIN performance analysis complete	Technical	Analysis of characterization testing complete
Vehicle communications implemented	Technical	The SAE communication protocols are implemented.
Economic evaluation complete	Technical	Economic analysis completed
SPIN certification achieved	Go/No Go	The SPIN unit is system tested for full integrated functionality

Project Accomplishments/Progress

On-Vehicle V2G Technology Development

Completed Honda and FCA PHEV V2G communications/control integration

- Verified TMS to PHEV V2G com and control
- 2 separate vehicle com module implementations verify standards application
- Honda uses University of Delaware (UofDel) Vehicle Smart Link (VSL) module
- FCA uses EPRI Electric Vehicle Communications Controller (EVCC) module

Site Demonstration initiated at University California San Diego (UCSD)

- 1 Honda/3 FCA PHEVs deployed
- Site modifications – 75KVA Transformer, 400A Panel, Solar Inverter 12kW

Data modeling ongoing for circuit impact and V2G cost benefit assessment

- Simulation results indicating significant benefit from V2G for load balancing and improved energy efficiency at the Transformer circuit level
- Demonstration data collected from use case testing being used for correlation and validation with simulations test results
- Final reports due end of June 2018

Off-Vehicle V2G Technology Development

Conducted SPIN Design Review (Milestone)

- Completed Component Technical Specification and Communication, Monitoring, and Control Sub System Specification Document

Completed SPIN POC design and functionality testing

- 18 DC Power Flow configuration / operation modes/73 parameter metrics

Completed server/SPIN integration and simulation testing

- Data analytics and optimization algorithms/controls
- Algorithms focus on cost and energy efficiency within applied power electronics and customer constraints
- Forecasting model implemented – imputes utility pricing, grid conditions, and weather conditions
- Simulations indicate significant customer savings achieved with V2G added as DER

Coordinating with FCA

- DC charging / discharging SPIN to PEV interface
- Control communications specifications

Coordinating with LG Chem

- SPIN interface and control of RESU10H Storage

Project Accomplishments/Progress

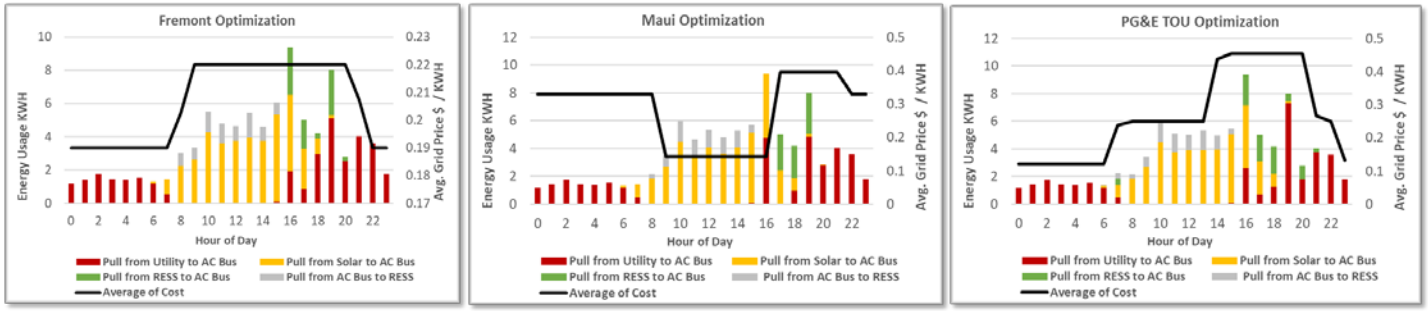
SPIN Analytics / Optimization Development

- Advanced **forecasting** algorithms based on usage from the SPIN unit database, providing energy usage predictions
- Sophisticated **optimization** modeling providing SPIN user the ability to maximize cost savings or renewable energy usage
- Detailed analytics summarized by **device**, allowing users to drill down and analyze SPIN unit's decisions based on each device's energy usage
- Real-time energy and **cost savings** metrics

Cost Savings Scenarios

- **Objective: Maximize cost savings**
  - Fremont, CA pricing: higher price from 9am – 10pm
  - Maui, HI pricing: half the price from 9am-5pm
  - PG&E TOU pricing: lowest early morning, highest in the evening
- **In each scenario, the optimization changes depending on when grid prices are the cheapest**
- **Cost savings metrics are passed onto the customer so they can see their potential savings each day by following the SPIN optimization**

Type	Forecasted Cost with No Solar	Forecasted Cost with Solar	Optimized Cost with Solar
Fremont	$15.25	$8.53	$6.81
Maui	$19.76	$14.02	$10.92
PG&E TOU	$24.04	$13.24	$9.62



Simulated Cost Optimization Scenarios using actual load and Utility tariff data

Collaboration and Coordination

Prime	EPRI ELECTRIC POWER RESEARCH INSTITUTE
Smart Power Integrated Node (SPIN)	FLEXPOWER CONTROL Power Your Way
IT Communications	KITU SYSTEMS
Power Electronics & Test	OAK RIDGE National Laboratory
Field Test	NREL NATIONAL RENEWABLE ENERGY LABORATORY
On-Vehicle Integration	FCA FIAT CHRYSLER AUTOMOBILES
EV Battery – Durability Assessment	LG Life's Good; NREL NATIONAL RENEWABLE ENERGY LABORATORY

Market Impact and Sustainability

The program is designed to evaluate the technical viability of V2G and to assess the value and cost benefit for V2G as a DER source.

- Results of this program can provide important information to the Department of Energy, the utilities, the automakers, and the consumers about the potential attributes of V2G
- Provide a technical methodology for enabling those attributes
- Reasoning for pursuing commercial implementation

There is a clear market direction toward integration of solar and battery energy storage to maximize utilization and value of renewable energy

- V2G can be a viable energy storage resource
- Preliminary SPIN data analytics and optimization simulations indicate significant potential for improved energy efficiency and resiliency from integrating V2G with other constituent DER technologies

Utility challenge is the ability to monitor, predict, and control customer owned DER energy generation onto the grid

- Results of this program can inform the need and justification for continued development and collaboration on V2G value for grid reliability, resiliency, and market value

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

Remaining Challenges and Barriers

Power Electronics Development

- Level of fidelity and maturity of power electronics challenging for achieving UL qualification intent design within present timeframe and budget.
- Approach modified to proceed with SPIN POC Rack System for verification of DER and V2G control utilizing server data analytics and optimization control algorithms within ORNL lab demonstration environment
  - Foregoing intended field demonstration at NREL

Use Case value and cost benefit assessments

- Utility/ratepayer cost effectiveness benefit from optimization strategies for dispatching V2G as integrated DER
- Estimate benefit affects on Total Cost of Ownership (TOC) for PEVs

Understanding of impact to vehicle battery durability and cycle life

- Challenge is to determine limits for utilization of PEV for V2G within specified (i.e. plus 60%) SOC boundaries of the battery pack to mitigate or avoid degradation of capacity, impedance, etc.
- Identify V2G value and impact based on PEV battery capacity constraints (i.e.16kWH versus 85kWH packs)

Standards Based End to End V2G/DER integrated system communications/controls

- Testing and certification of interoperability needed for validation and wide adoption of V2G application standards

Determinations and validation of value use cases for V2G/DER application

- Assessment of ZNE and Microgrid operational capabilities and benefits

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

Summary

Off-Vehicle (DC) V2G/DER integration

- SPIN design and communications specifications completed – achieved GO decision into Period 2 of program
- Significant progress achieved in development of SPIN power electronics/software/controller integration with control algorithms for optimized V2G/DER management
- Next milestone is completion of SPIN V2G/DER integration and lab testing with LG Chem EV configured Battery Packs, RESU10H Storage Unit, and FCA PHEV
- Initiating Baseline characterization of EV Battery Packs for durability evaluation/assessments

On-Vehicle (AC) V2G technology development

- Completed vehicle V2G system communications and control testing with EVSE and TMS
- Transitioning vehicles and TMS hardware to UCSD for start of field demonstration week of 5 May 2018
- Progressing with formulation of data models and data collection parameters for circuit impact analysis and cost benefit assessment reports
  - Field demonstration data will be factored into data models

Emphasis on addressing V2G/DER Open Standards

- Protocol implementation and interoperability requirements and technology integration

Technical Back-Up Slides

UCSD Demonstration Site

Charging Island Front Side

400A Distribution Panel and Disconnect Box

Charging Island Back Side

Are two chargers located on each side of 75kVA transformer – See Side View

Charging Island Side View

Two chargers per pedestal – 4 total for 3FCA and 1Honda PHEV

V2G (AC) Communications Functional EVSE

Dual L2 AV EVSE

5V Power Supply

EVSE RS Control Board

IoTecha/Expansion Board

IoTecha Board contains the J3072 and IEEE 2030.5 software and connects to EVSE RS Control Board through UART (serial port). Pilot signal is generated by the EVSE RS Control Board. PLC signal is injected onto the pilot wire on the Expansion Board. The Pilot to the output cable to the EV Is connected to the Expansion Board.

Source: AeroVironment, Inc (EVSE)
IoTecha, Inc – Expansion Board (with permissions)

Transformer Management System (TMS)

Transformer Power Measurement Unit (TPMU)

- Measures Voltage, Current and Phase
- RS485 Communications Interface to the TC

Transformer Controller (TC)

- Linux based open Router Platform
- RS485 Communications Interface to the TPMU
- Communications to each EVSE(s) and PEV (s) via HomePlug AV Adaptor
- Performs Energy Management Algorithm

HomePlug AV Ethernet Adaptor

- Ethernet connected to the Transformer Controller
- Communicates to all connected Gateways via the premise drop

TMS Enclosure NEMA 3R Outdoor Mounted to L2 Charging Island 75KVA Transformer

Source: EPRI

SPIN System Functional Block Diagram

Source: Flex Power Control (with permission)