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

Project ID ELT187

2021 US Department of Energy Vehicle Technologies Office Annual Merit Review

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Overview

Timeline

- Start – November 2016
- Finish – June 2020*

Percent complete: 85%

Barriers

- Insufficient Data on DER Applications
- Value of V2G integration as DER asset
- On and Off-Vehicle Hardware
- Cost, performance, communications, monitoring, and control
- Standards, interoperability

Budget

- Govt Share: $1,547,678
- Cost Share : $1,238,600
- Total Program: $2,786,278

Funding for BP1: $860,679

Funding for BP2: $631,826

Partners

- Lead: EPRI
- Partners: Flex Power Control, Stellantis, Kitu
- Collaborations: NREL, ORNL, and SAE

Focus on Open Standards Implementation of Vehicle-to-Grid as a BTM DER Technology

Relevance

Objective

- Develop and demonstrate power electronics and energy management controls system enabling vehicle-to-grid (V2G) bi-directional power flow (V2G) integrated with solar and stationary energy distributed resources
- ***Smart Power Integrated Node (SPIN)*** – single multi-functional modular unit integrating solar, stationary energy storage, and V2G power electronics with the localized DER Management System.

TI Goals

- *National Security* – Enable maximum local DER use behind the meter
- *Economic Growth* – Create a path for value from DER and V2G dispatchability enabled by SPIN to be available as incentives to EV owners.
- *Affordability to Consumers* – Reduce part and installation costs through system integration
- *Reliability/Resiliency* – Provide standby power to the premise in case of an outage, through synergistic application of Solar, Storage and EV

Impact

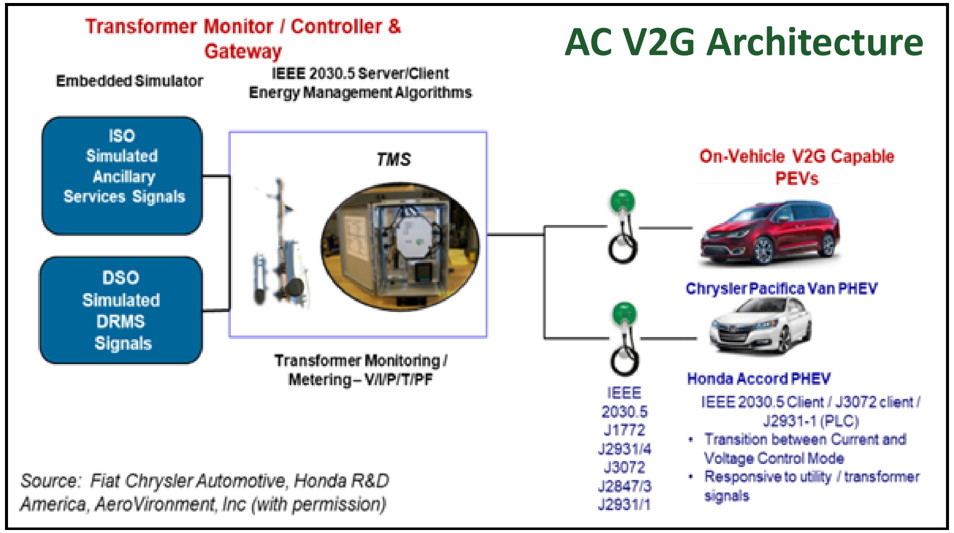
- Open standards implementation – SAE J1772, IEEE 2030.5, J2847/2 (DIN 70121), J2847/3, J3072, J2931/1, J2931/4
- Viability of V2G as DER resource and cost/benefit to consumer and utilities
- Battery durability impacts from V2G

V2G Technology Viability, Value and Battery Impacts – Key Enablers of a DER Ecosystem

Approach: Open Standards-Based V2G

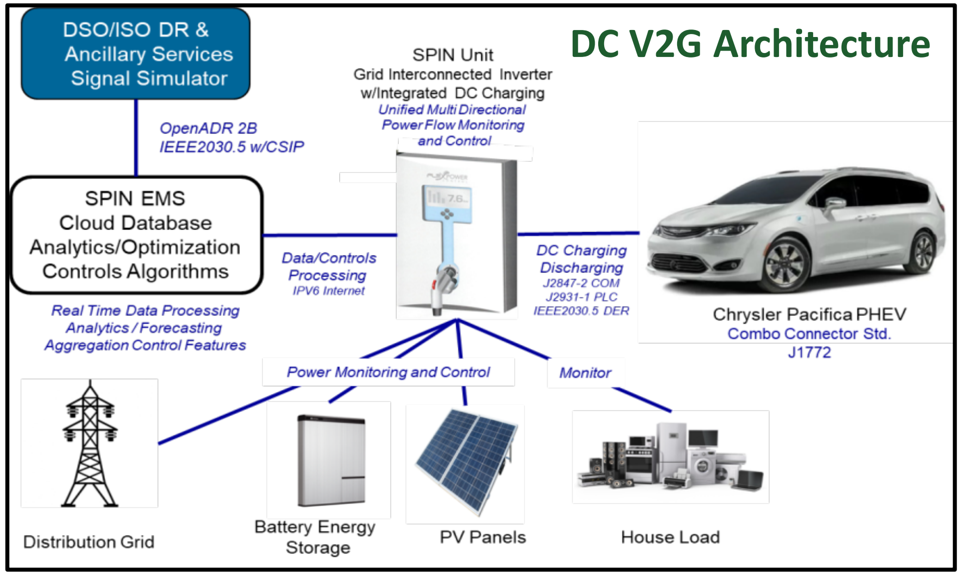
1. <u>On-Vehicle AC V2G</u>

- 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



2. <u>Off-Vehicle DC V2G</u>

- ***Smart Power Integrated Node*** **(SPIN)** for integrating off-board V2G with PV and storage
- J1772 CCS DC Charging w/J2847-2/J2847-3/ IEEE2030.5 Control
- Chrysler Pacifica PHEV with J1772 CCS, J2847-2/J847-3/IEEE2030.5 implementation
- SPIN Integrated DER energy management system
- Monitoring and controls through cloud data analytics and optimization algorithms



Source: EVSE Images – AeroVironment, Inc, Transformer Monitoring System (TMS): EPRI Technology, Battery Storage LG Chem, PHEV Images – Fiat Chrysler Automobiles and Honda R&D America

On-Vehicle: Distribution Services and Value; Off-Vehicle: BTM DER Integration, Storage Test

BP4 Milestones

Budget Period 4
Apr 2020 – Jun 2021

Description	Date	Planned Task Detail
Complete OEM Vehicle / SPIN DC V2G Communications Implementation and Verification	Jan 2021	• Development, implementation and testing of SPIN DC Communications Control Module (CCM): DC V2G based on SAE standards (J2847/3, DIN Spec extended, IEEE2030.5) • Interoperability DSO Server / SPIN / Vehicle (MY 2021 FIAT 500 EV) communications
Complete V2G Lab Demonstration	April 2021	Perform Vehicle/SPIN integrated demonstration.
Complete Demonstration Report	June 2021	Report covering the demonstration and data from characterization and use case functional testing..
Complete Battery Pack Durability Test Report	May 2021	Assessment and evaluation of impact from effectively V2G cycle operations. Pack impedance/capacity will be evaluated before and after the testing. (Delayed)

BP4: System Integration and Battery Performance Assessment

Project Accomplishments/Progress

On-Vehicle V2G Development

The work resulted in four publications:

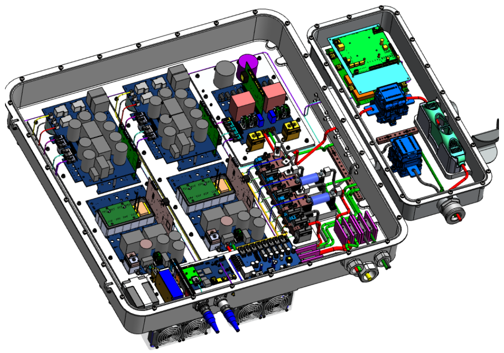
- ‘Open Standards-Based V2G: Technology Development’, EPRI:3002014770, 2018
- ‘Open Standards-Based V2G: Integrated Resource Planning Considerations’, EPRI:3002014801, 2018
- ‘Open Standards-Based V2G: Value Assessment’, EPRI:3002014771, 2019
- Chhaya, S., et al, ‘Distribution System Constrained Vehicle-to-Grid Services for Improved Grid Stability and Reliability’, California Energy Commission, CEC-500-2019-027, 2019
- ***Success Story:*** *SCE, Stellantis, EPRI, Kitu collaborating under an SCE project to define interconnection requirements for OEMs and EVSE manufacturers to include in the permitting process informed by the AC V2G work*. Honda are also participating.

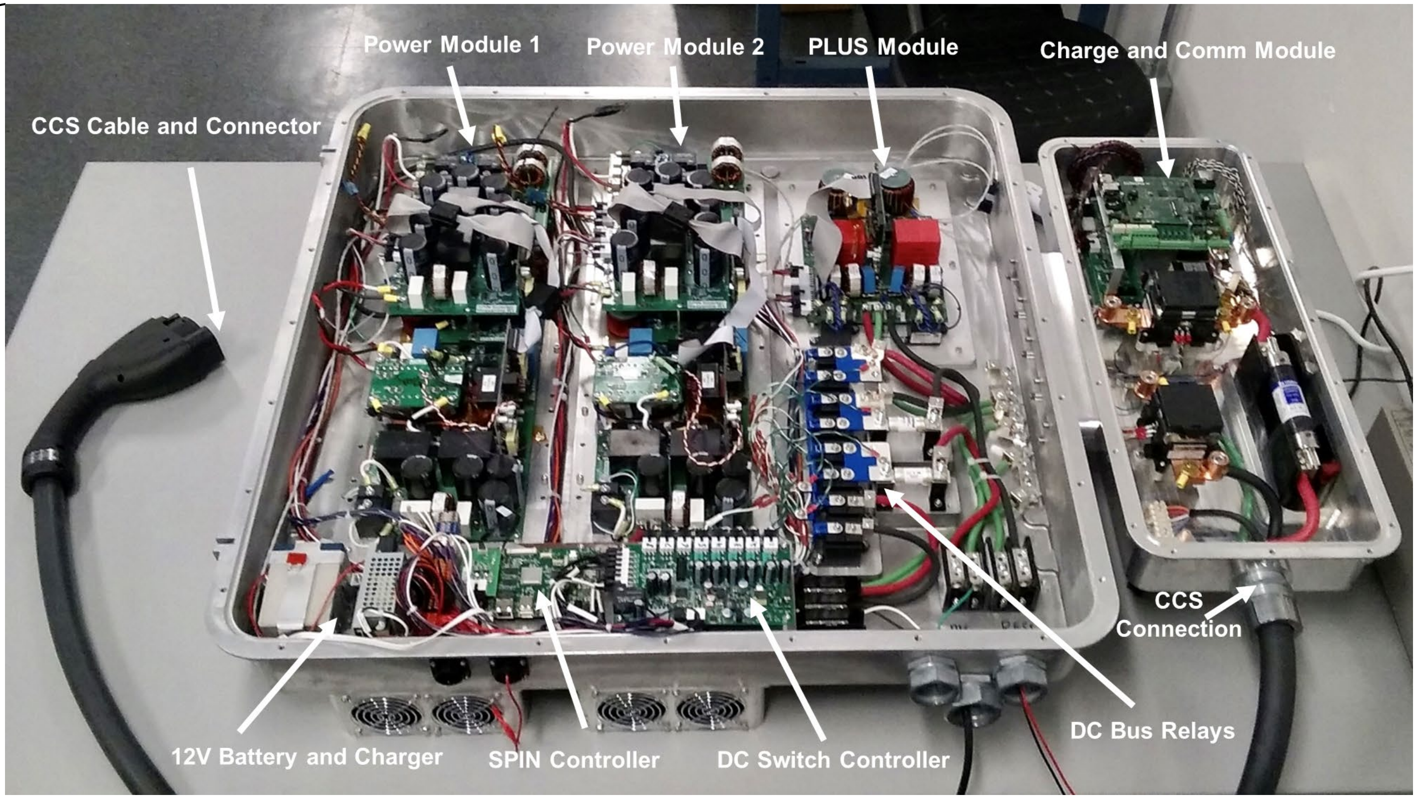
Off-Vehicle V2G Development

- BP 3 extended (COVID19), team made the best of the extension, *despite COVID19*
- Battery testing commenced at NREL July 2020 in autonomous mode, has accomplished equivalent to 2.7 years of performance testing, *Excellent Results*
- Coordinated V2G DC Subsystem and System Integration
  - End to end communication verification on bench
  - DSO Server – SPIN
  - SPIN to Active DC Load with Bidirectional Power through DIN 70121 – at San Diego
  - EV to DC Charger, bidirectional DIN 70121 software – at Auburn Hills
- SPIN System design-intent build completed
- Full System Integration at Rhombus, San Diego
- *Significant learnings, informing DC V2G implementation requirements*

On-Vehicle: Completed System Demo, Published Public Results, Standards Revision, Formalizing Requirements
Off-Vehicle: Subsystem Integration Verified, System Integration Performed, Partial Data
Battery Impacts Testing: Significant Meaningful Data Available, Testing Continuing

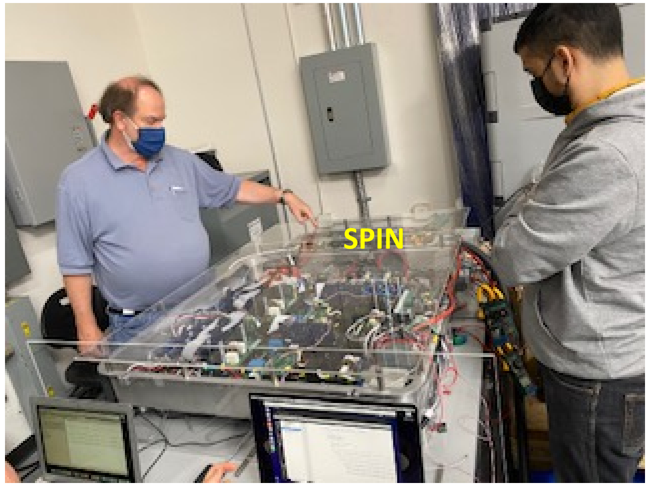
SPIN Design-Intent System Built (DOE EE8352 Supported)

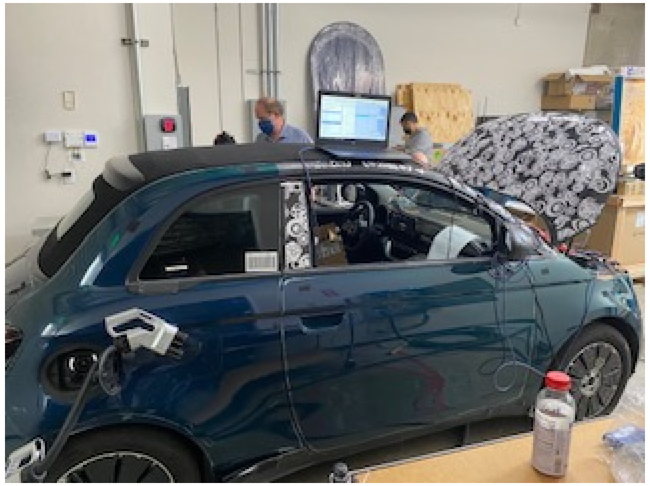


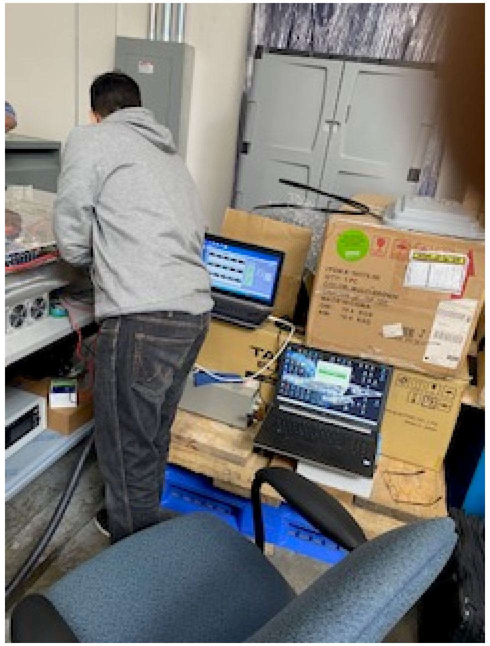


Dimensions:
Main Unit:
L900mm x W900mm x D250mm
DC CCM:
L600mm x W 275mm x D 125mm

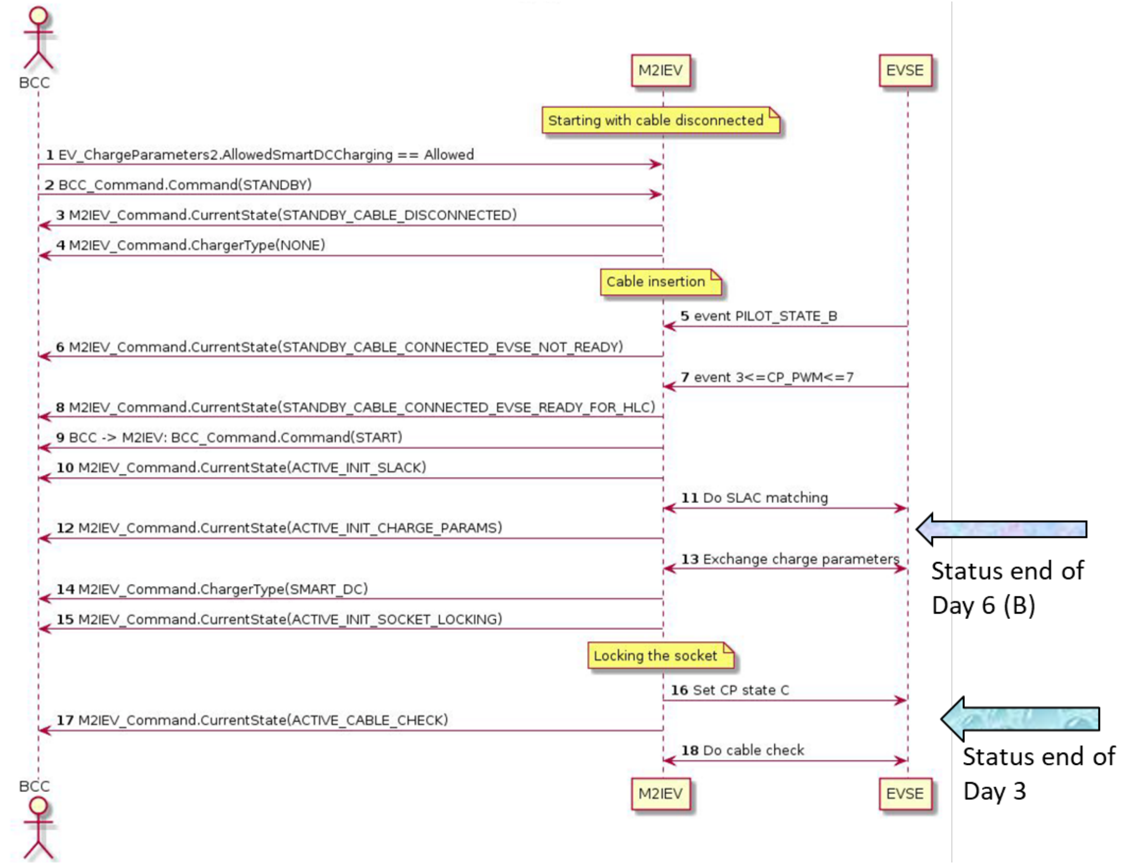
EV – SPIN System Integration Testing

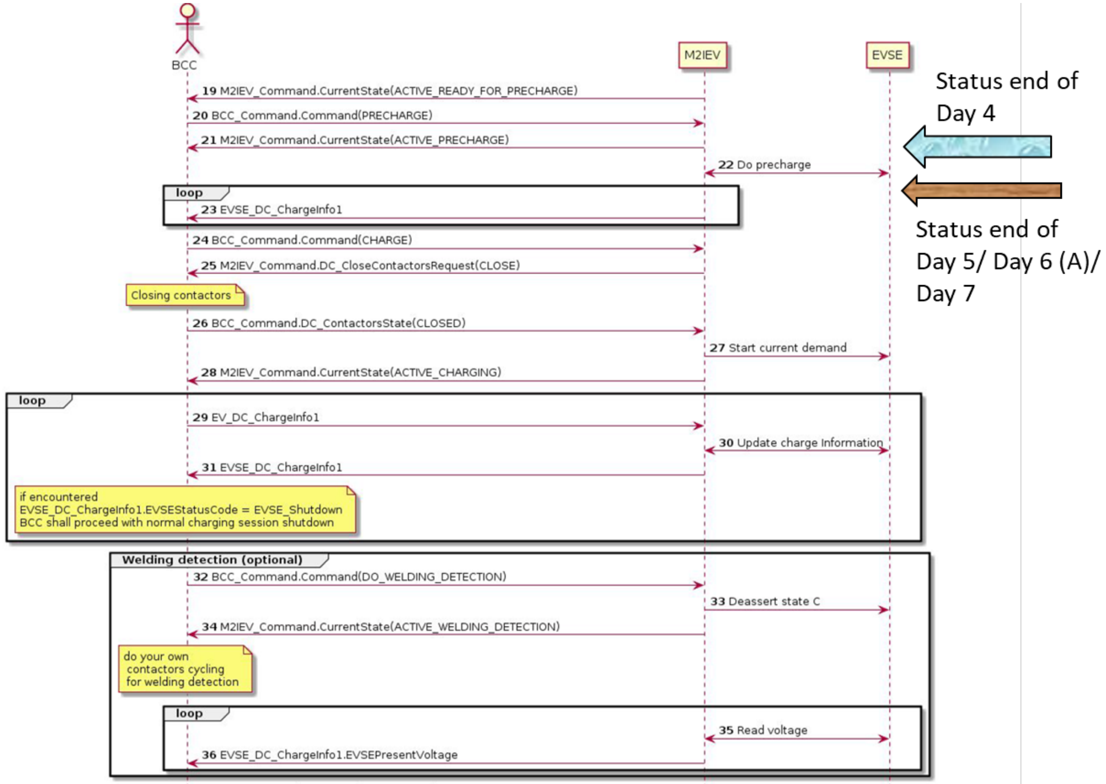






SPIN Integration Testing Sequence Diagram and Status



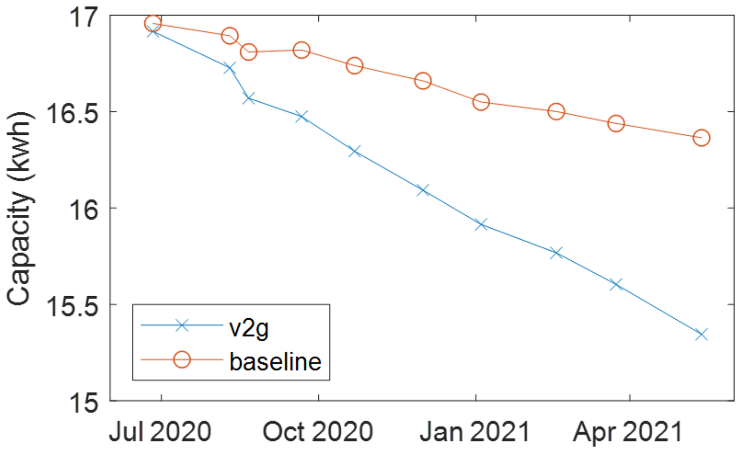


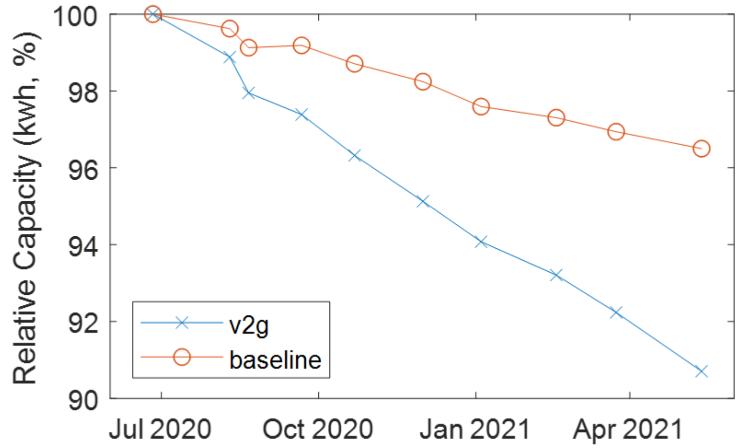
Power Flow Control Tested Separately, but the DIN 70121+PLC Control Card Being Replaced

Battery Testing Results

Reference Performance Test – Lifetime Capacity (kWh)

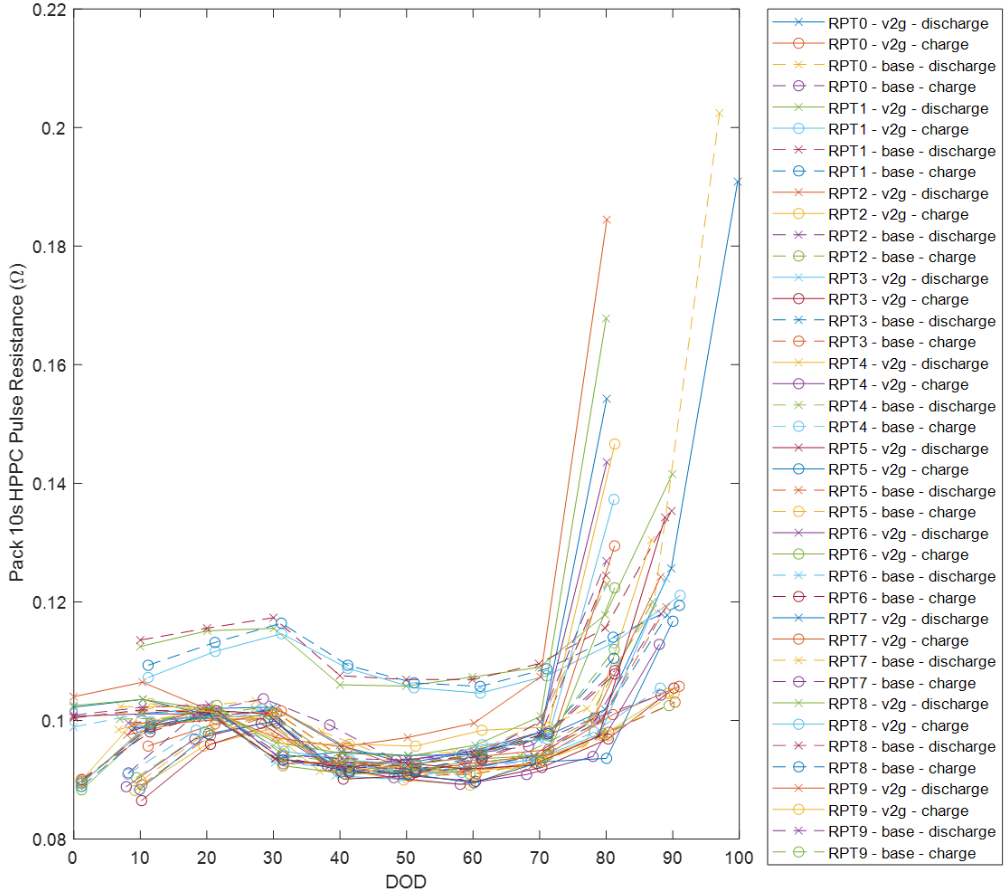
	V2G		Baseline	
RPT0	16.917kWh	100.00%	16.958kWh	100.00%
RPT1	16.728kWh	98.88%	16.894kWh	99.62%
RPT2	16.57kWh	97.95%	16.81kWh	99.13%
RPT3	16.48kWh	97.42%	16.82kWh	99.19%
RPT4	16.295kWh	96.32%	16.739kWh	98.71%
RPT5	16.093kWh	95.13%	16.666kWh	98.28%
RPT6	15.915kWh	94.08%	16.55kWh	97.59%
RPT7	15.768kWh	93.21%	16.50kWh	97.31%
RPT8	15.60kWh	92.24%	16.44kWh	96.94%
RPT9	15.35kWh	90.71%	16.36kWh	96.50%





3 year-Equivalent Data, 44% Charge/Discharge Cycle per Day, Marginal kWh Capacity Impact: 1.7%/year, Similar Ampacity Trend

Pulse Resistance Profile



- Consistent trend over SOC and life
- Remarkably tight – very little variance
- Indicates a highly efficient system – if the heat is minimized at the source…the best way to mitigate it
- 30-80% SOC band appears to be the most usable part, outside of which, battery charge/discharge power needs to be curtailed
- Stellantis confirms this is consistent with their understanding

Evidence of quantifiable value from PPEV battery capacity, *cooperatively* by SPIN and the PEV, with the PEV managing its battery to not violate the warranty.

Response To Reviewers Comments

Reviewers Comments

- “Delays have put the project behind schedule, COVID19 will add further delay”
- “Given the inception of project in 2016, more progress should have been accomplished.”
- “The remaining challenges appear highly significant and were downplayed by the presenter”

Response

- Timeline: The team worked within the constraints of shutdowns, created emulator based verification setups, and the battery testing, once on auto-pilot, did not require staff presence. In short, most of the progress was achieved despite COVID19 shutdowns, across system build, subsystem integration and battery testing.
- Project plows new ground on multiple frontiers – power electronics, vehicle and EVSE side system integration, standards verification and communications verification. Three major delays – core power electronics, communications integration and automated battery test setup – provided significant learnings
- The big unknown has been the supplier capability to deliver, and relative newness of the standards and ability for communications interface supplier to support. Once these issues were resolved, progress could be accelerated

Collaboration and Coordination

Prime	EPRI Electric Power Research Institute
Smart Power Integrated Node (SPIN)	FlexPower Control (Power Your Way); KITU Systems
Grid/SPIN/PEV Communications	EPRI Electric Power Research Institute
Power Electronics Test & Demonstration	Oak Ridge National Laboratory
On-Vehicle Integration	FCA Fiat Chrysler Automobiles
EV Battery – Durability Assessment	NREL National Renewable Energy Laboratory

Collaborative Team Includes Expertise from Subject Matter Areas and Proven Capabilities

Remaining Challenges and Barriers

Understanding of impact to vehicle battery durability and cycle life

- Continued assessment of PEV Battery impacts from V2G within specified SOC boundaries to understand extended impact on battery performance

Standards based end to end V2G/DER integrated system communications / controls

- More robust and stable communications physical medium (HomePlug GreenPHY or other) – the research is informing the limitations of the existing communications protocol

Determination and verification of value-added use cases for V2G/DER application

- Future applications will prove the value.

The project ends in June 2021, but the Application and Integration Work Continues

Future Work

- Continue maturing the product through certifications (UL, IEEE1547, IEEE2030.5, IEC/ISO 15118)
- Expanded evaluation of integrated V2G/DER attributes and cost effectiveness with utility stakeholders
- Extend the resiliency angle of SPIN through field trials

Summary

On-Vehicle (AC) V2G technology demonstration completed

- Completed demonstration and verification of AC On-vehicle V2G application of SAE/IEEE2030.5 protocols
- Standards interoperability verified between TMS/EVSE (Bridge)/EV (Honda & FCA PHEVs)
- Follow-up discussions to incorporate AC V2G in the California DER discussions underway, with this project being the primary technical foundation (CPUC Rule 21 Working Group 2)
- Final report submitted Jun 2018 /Released Mar 2019 through CEC https://www.energy.ca.gov/2019publications/CEC-500-2019-027/index.html

Off-Vehicle (DC) V2G/DER system integration marginally successful

- Implemented controls software architecture for SPIN DC Control Communications Module (CCM) and EV V2G communications module interoperability
- Completed subsystem level testing successfully
- System integration and test achieved at power electronics level, controls/communications between EVSE and EV being tested

Emphasis on verifying V2G/DER open standards with key use cases

- Validation of V2G functionality as a viable DER asset through application of SAE/IEC/IEEE standards – R&D results already generating significant learnings about co-existence of IEEE, IEC/ISO and SAE standards

Technical Back-Up Slides

SPIN – Ongoing Technology /Product Development Commercialization Pathway

EPRI Technology Innovation Program

SPIN Concept Design / Spec

CEC EPC-14-086: Distribution System Constrained V2G Services

- Core V2G Functionality refined, implemented, verified
- OEM Interfaces Defined for V2G and Smart Inverters
- Projects involving on-vehicle V2G planned
- Within SIWG, learnings being transferred for on-vehicle inverters to be Rule 21 compliant

DoE EE0007792: On- and Off-V2G Performance and Grid/Battery Impacts

- SPIN Hardware and Base Software Developed
- Power Flow Verification
- Verified for DC V2G implementation
- Battery test protocol and impacts assessment

CEC EPC-16-054 – Ecosystem Integration

- External System Integration,
- End to End Functionality Development
- Integration and Test for DSO, Microgrid, and Standalone BMS integration
- Off-board DC inverter as smart inverter, integrated with PV and Storage
- Leveraging SPIN developed from DOE EE7792 Program

DoE EE0008352: SPIN Productization

- SPIN as a product with Rhombus as the technology developer
- Wide Bandgap devices – high efficiency, broader temperature range, compact
- PV/EV/Storage Integrated Package
- Significant partner interest in offering this package. Prime application for addressing distributed resilient systems

Scope of EPC-16-054

V2G Pack Test Cycle

Two Pacifica PHEV Battery Packs for testing.

Pack 1: Runs driving duty cycles
Pack 2: Driving + Residential V2G cycles to provide a comparison.

Notes:

- Pack 1 is the V2G pack.
- Pack 2 doesn't discharge at home so only takes an hour to recharge.
- Cycles are run continuously 24/7
- 1 cycling day = 3 days of use; 30 days = 4.5 months' data

	Pack 1	Pack 2
	hours	
Work	-	-
Drive home	0.5	0.5
Discharge at home (10kW)	1	0
Charge to 100%	2	1
Wait (key cycle – contactor open)	1	3
Drive to work	0.5	0.5
Charge (50% to 100%)	1	1
Total time/cycle	6	6

Cycle Discharge ~ 15 mi					
	Cycle	Time (hrs)	Distance (mi)	Energy Throughput (kWh)	Net Energy (kWh)
CD	CD1 City	0.3811	7.44	3.96	2.24
	CD US06	0.1667	8.01	5.27	2.81
CD total		0.5478	15.45	9.22	**5.05**
Total pack kW					11.8
Usable energy after both drive cycles (kW)					**6.75**
Proposed discharge power (kW) - available for DER					2
DER duration (hrs)					3.375

RPT* every 28 days (4 weeks)
RPT includes C/3 capacity cycle and HPPC

**RPT = Reference Performance Test*