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

Project ID ELT187

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DoE VTO Annual Merit Review
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Overview

Timeline

- Start – November 2016
- Finish – June 2020*

Percent complete: 75%

*Program extended from Nov 2019

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
  - 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: $631,826

Partners

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

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

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Relevance

Objective

- Develop and demonstrate power electronics and energy management controls software solution integrating vehicle bi-directional power flow (V2G) with solar and stationary energy distributed resources for on-vehicle (AC) and off-vehicle (DC) bi-directional inverter technologies.
- ***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

- *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, 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 to be a Part of the DER Ecosystem

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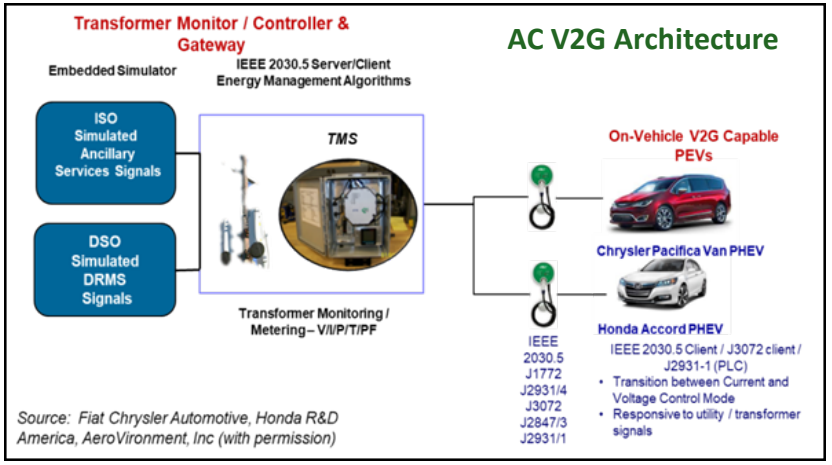
Approach: Open Standards-Based V2G

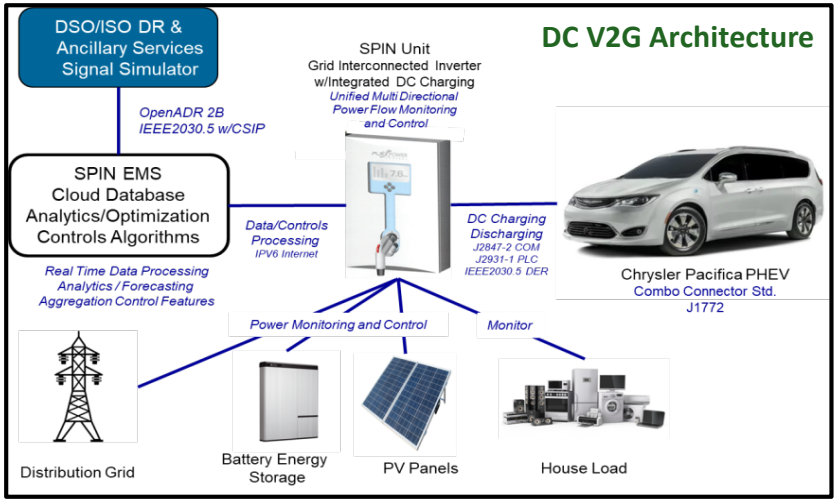
1. On-Vehicle AC V2G

- 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



2. Off Vehicle DC V2G

- ***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 Com and 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

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Milestones

Budget Period 2
Nov 2017 – Mar 2019

Description	Type	Completed Task Detail
SPIN Functional Testing and Verification	Mar 2018	Completed functional testing with cloud based analytics/optimization software
Converter Enhancements	Apr 2018	Completed updates to SPIN system and component technical, and software specifications
V2G Economic Evaluation	Jun 2018	Completed based On-Vehicle V2G development and demonstration
POC SPIN converter and software design upgrades	Oct 2018	Completed upgrades to Version 5 and testing based on operational power mode / configurations test criteria
System Lab Test Plan and Set Up/Test at NTRC (ORNL)	**Feb 2019**	**Go/No Go milestone for transition to BP3 - Approved**

Budget Period 3
Apr 2019 – Jun 2020

Description	Type	Planned Task Detail
Complete OEM Vehicle / SPIN DC V2G Communications Implementation and Verification	Oct 2019	• Development, implementation and testing of SPIN DC Communications Control Module (CCM): DC V2G based on SAE standards (J2847/3, DIN Spec harmonized, IEEE2030.5) • Interoperability DSO Server/SPIN/Vehicle (FCA Pacifica Van PHEV) communications
Complete V2G Lab Demonstration	Dec 2019	Perform Vehicle/SPIN integrated demonstration.
Complete Demonstration Report	Feb 2020	Report will be generated covering the demonstration and data from characterization and use case functional testing..
Complete Battery Pack Durability Test Report	Jun 2020	Assessment and evaluation of impact from 6 month V2G cycle operations. Pack impedance/capacity will be evaluated before and after the testing.

BP2: Full Functional Verification Complete; BP3: System Integration and Battery Evaluation

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Project Accomplishments/Progress

On-Vehicle V2G Development

- ***Completed On-Vehicle V2G (AC) Implementation and Demonstration- Final Report submitted Jan 2019***
  - Validated end to end standards based implementation (J3072, J1772, IEEE2030.5, J2847-3, J2931-1/-4)
  - Interoperability verified - separate and independent vehicle V2G communications modules
    - Honda Smart Link and FCA Pacifica Van with EPRI Vehicle Communications Controller (EVCC)
    - EVSE V2G module (AeroVironment/Kitu Systems) compatible with both vehicle versions.
  - **Site Demonstration conducted at University California San Diego (UCSD) – 4 EVSEs/1 Honda/3 FCA PHEVs deployed and demonstrated**
- ***Data modeling revealed 3X benefit of V2G versus V1G***
  - **V2G Value benefit assessment estimates $407/EV/Year improvement over V1G ($155/EV/Year)**
  - V2G benefit of $1725/EV/Year relative value estimated if EV participate in Ancillary Services market with no constraints on battery degradation or SOC

Off-Vehicle V2G Development

- ***Completed POC SPIN System upgrade***
  - Resolved reliability and robustness issues – updated specifications
  - System power modules/software upgraded from Version 3 to 5
  - Completed transition of SPIN System to ORNL/NTRC lab
  - NTRC Lab integration and testing completed Feb 2019
- ***BP3 Go-Ahead Approved***
- ***Re-defined Battery Durability task – FCA/NREL SOW approved***
- ***Coordinated V2G DC Component/Software Implementation***
  - DSO Server (Kitu Systems)
  - SPIN Master Controller (FPC/EPRI)
  - DC Control Communications Module/ CCS Connector/SECC PLC Module (Rhombus/FPC/IoTecha)
  - EVCC/PLC Module (FCA/IoTecha)

On-Vehicle: Completed System Demo, Published Public Results
Off-Vehicle: Power Electronics, Local Control, Analytics and UI Prototypes Verified

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NTRC Lab Set Up with SPIN Rack System

Source: Oak Ridge National Lab (ORNL)

ORNL/NTRC Power Testing Setup for Off-Vehicle V2G System Integration and Test

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Response To Reviewers Comments

Reviewers Comments

- *"progress towards the battery durability impact study is not identified."*
- *.."the approach does not consider all available open standard architectures, such as ISO 15118, which is already a reference standard for J1772 CCS DC charging. "*
- *"no proposed future research is called out, and the evaluation is based on the remaining tasks listed for Budget Period 2. "*
- *"…the project team has identified a detailed list of important remaining challenges and barriers. The reviewer added that, at this time, it is unclear how many can be addressed under this project, but it is a useful list to have."*
- *"…Underwriters laboratories (UL) qualification, or gap analysis, is essential for determining the industrialization path."*

Response

- The Battery Durability Impact Study: redefined SOW between FCA and NREL; Work to commence in BP3
- US implementation of SAE DC CCS based on DIN 70121 as referenced in J2847-2. Updates pending IEC 15118 ED2 completion and release – DIN 70121 is harmonized with IEC 15118
- Future research will be related to application verification of V2G to support utility DER grid services such as frequency and voltage management, and balancing generation and demand for islanded grid or microgrid configurations to help improve utility distribution reliability and resiliency. Reference DOE FOA 2064.
- Agree that not all challenges and barriers listed will be accomplished under this program. Effectiveness for ZNE/Microgrid operations/benefits and affects on Total Cost of Ownership will require follow-on research funding.
- UL qualification for commercialization is understood, as well as UL 1741SA and IEEE 1547-2018 compliance to qualify SPIN for utility interconnection. Engaged in the California Public Utilities Commission (CPUC) Smart Inverter Working Group.

Hardware Development Challenges → Reprioritization of Focus: Product to Technology
Two Additional Programs Focused on Extending Technology into Product

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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

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Remaining Challenges and Barriers

Power electronics development

- SPIN POC System verification of DER and V2G control utilizing server data analytics and optimization control algorithms within ORNL lab demonstration environment
- Addressing design gaps for UL 1741SA and IEEE 1547-2018 compliance and determinations for IEEE 2030.5 for Smart Inverter Communications/Functions

Understanding of impact to vehicle battery durability and cycle life

- Assessment of PEV Battery impacts from V2G within specified SOC boundaries to mitigate or avoid degradation of capacity, impedance, etc. based on PEV battery capacity constraints

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

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

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

- Assessment of ZNE and Microgrid operational capabilities and benefits – follow on research funding required

Challenge: Integrate End to End V2G System Functions on Grid, SPIN System and PEV with evolving SAE V2G Standard

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Future Work

BP3 – DC V2G End-to-End Verification

- Integration of SPIN DC charging / discharging – and SPIN to vehicle V2G interface/control communications
- Demonstration and functional validation to control DER/V2G power flow for maximum local utilization of PV generation
- Validation of analytics/algorithms to maximize V2G/DER
- Verification of battery impacts from utilization for V2G
- Correlate AC and DC V2G project findings

Proposed Future Work

- Smart Inverter Communications and Functions for AC and DC Charging / Discharging applications
- Expanded evaluation of integrated V2G/DER attributes and cost effectiveness with utility stakeholders – leverage SPIN product development program (DOE 1740) to extend into utility supported evaluation pilot programs
- Assessment of ZNE and Microgrid operational capabilities and benefits from V2G/DER – research funding needed

Future Work Ongoing on Two Additional Follow-on Projects: CEC 16-054 (Ecosystem Software); EE0008352: Proof-of-Design

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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)
- 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 integration progressing

- Completed version upgrade of SPIN power modules and electronics control software – transition to ORNL NTRC Lab – set up and power mode operational testing completed
- Finalized controls software architecture for SPIN DC Control Communications Module (CCM) and EV V2G communications module interoperability
- Achieved GO decision into Period 3 of program
- BP3 milestones are completion of SPIN V2G/CCM integration with FCA PHEV and NTRC lab testing/demonstration - and evaluation/assessments of FCA PHEV Battery Packs for durability by NREL

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

On-Vehicle V2G Technology Demonstrated, Grid Interface Comms Leveraged for Off-Vehicle V2G Integration; Learnings Applied to Follow-on Projects

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Technical Back-Up Slides

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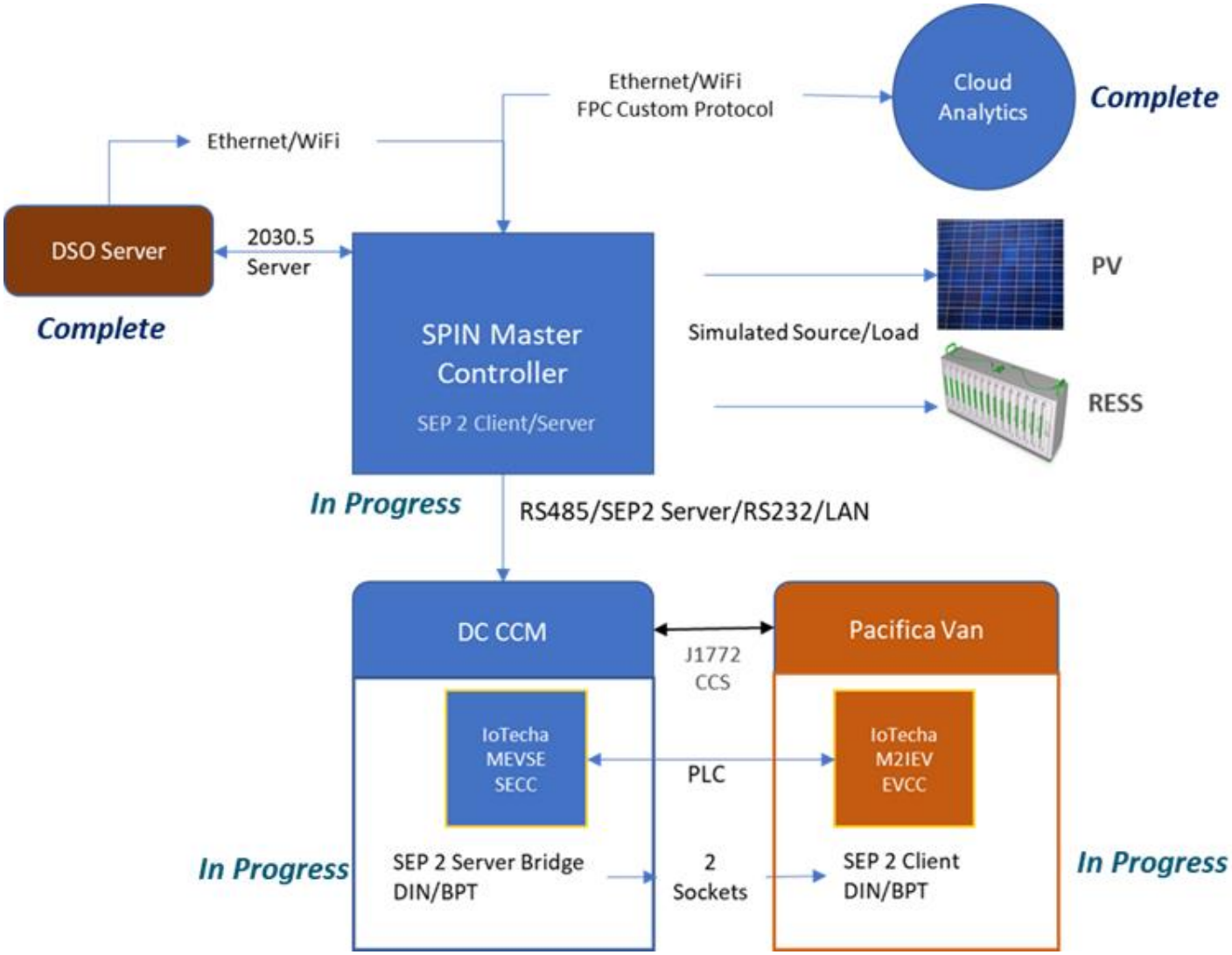
Integrated DC V2G System Layout



Source: EPRI

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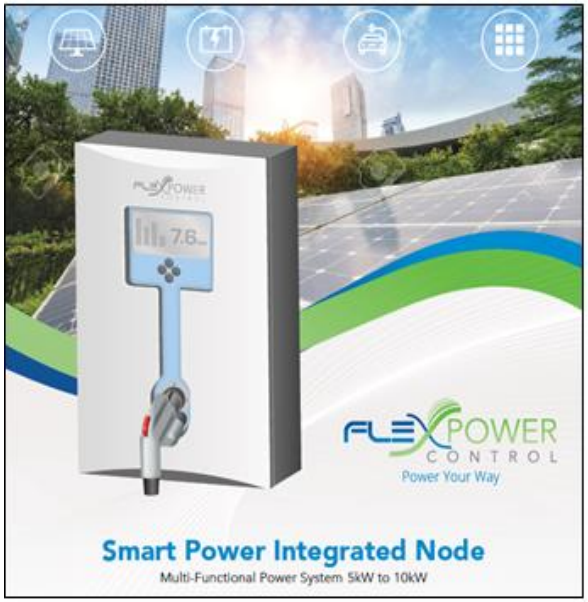
SPIN System Functional Diagram



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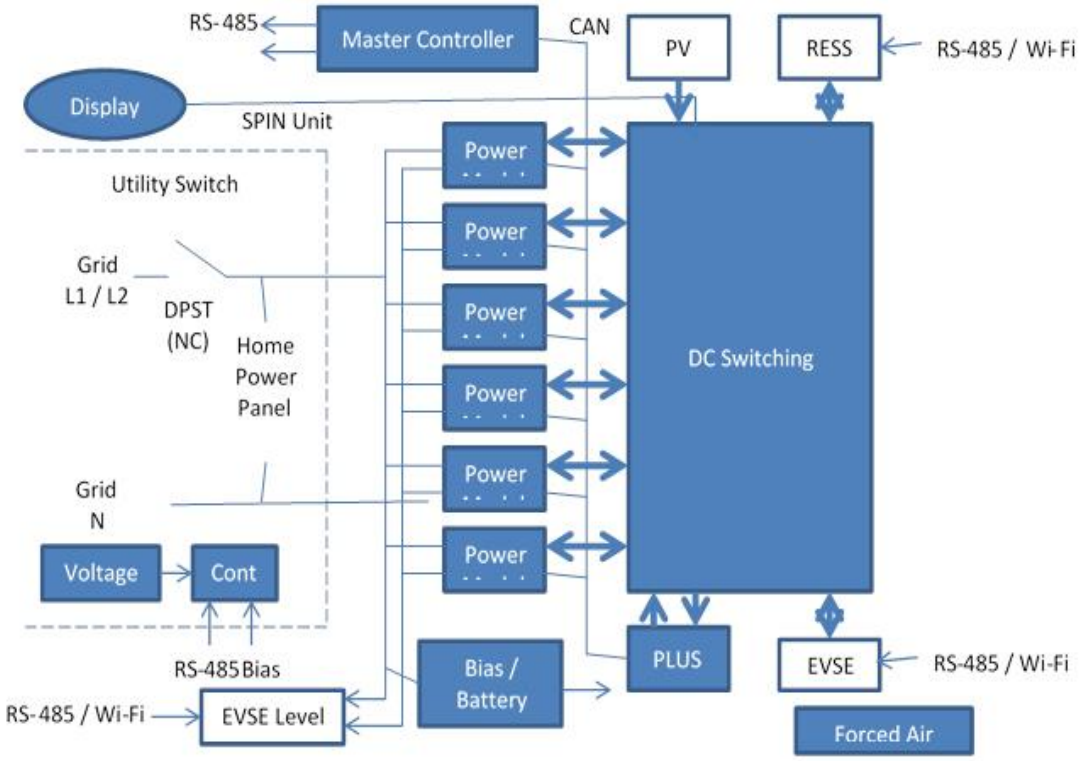

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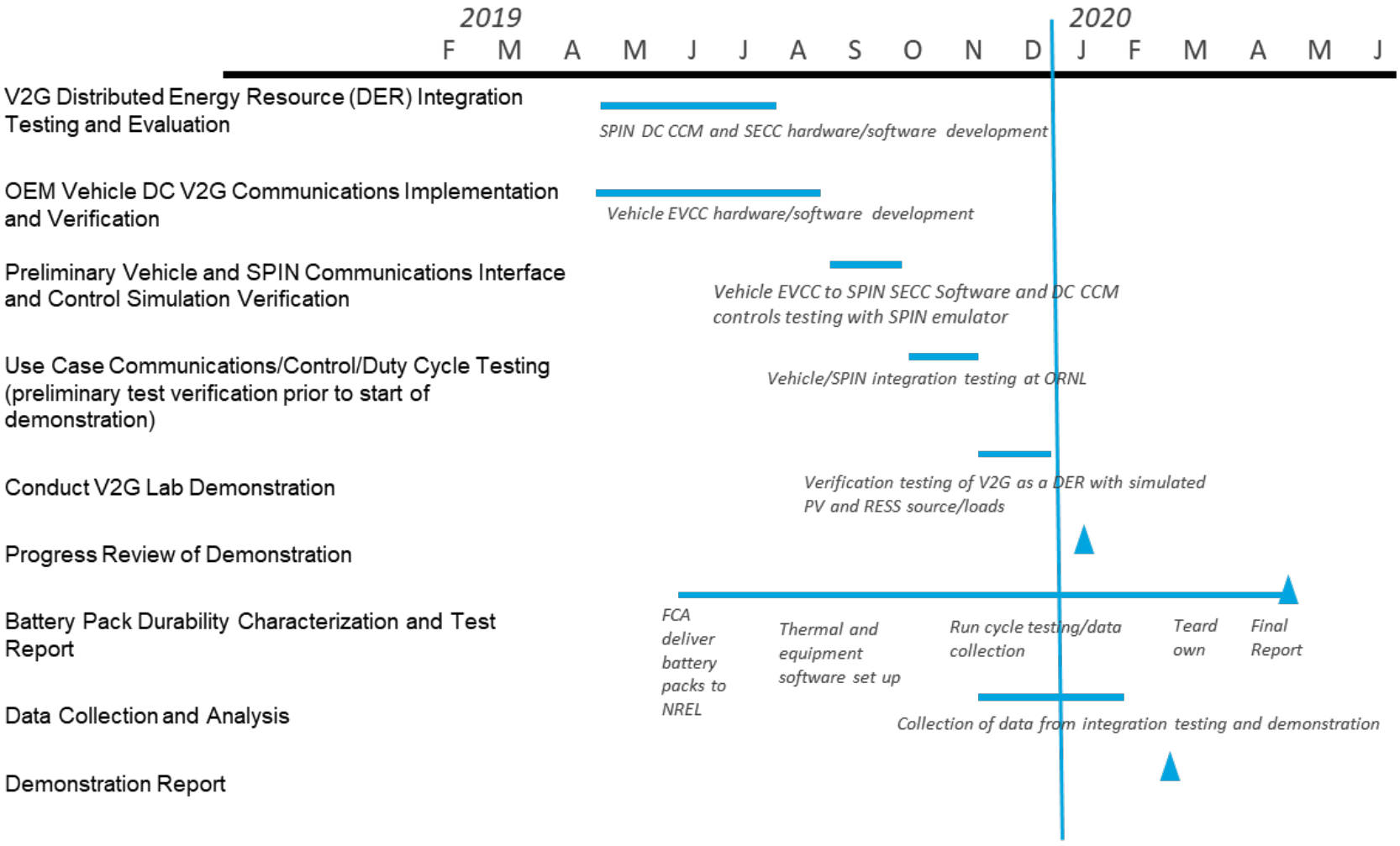
BP3 Task Schedule Overview



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UCSD Demonstration Site - On Vehicle (AC) V2G

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

Source: EPRI

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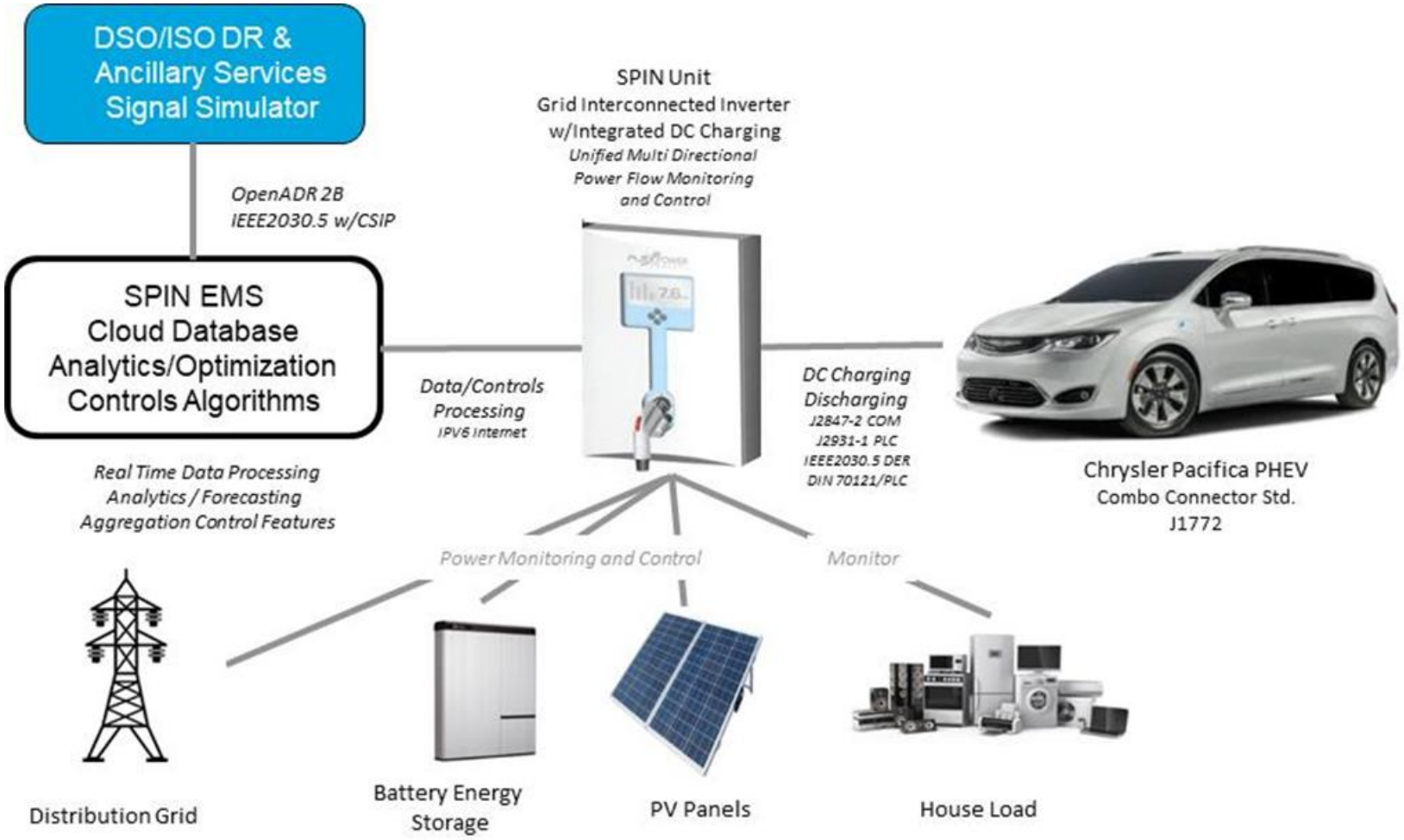
Off Vehicle DC V2G System Architecture



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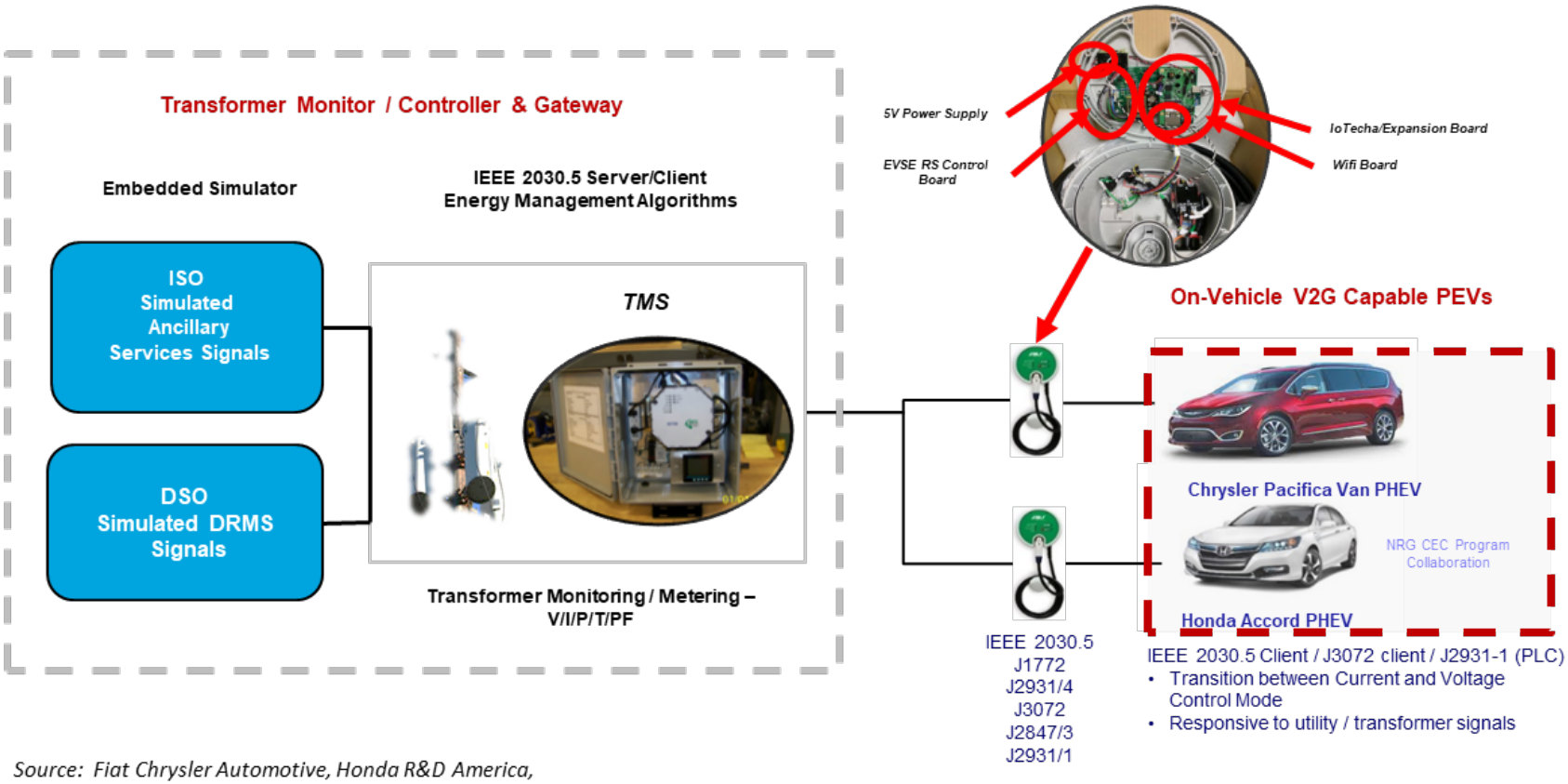
On-Vehicle V2G System Architecture



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Critical Assumptions and Issues

- ***Future implementation of Wide Band Gap technology into SPIN power electronics (DE-EE0008352)***
  - Leverage advantage for improved efficiencies, thermal performance, and reliability
  - Assessment of cost impact for commercialization
  - Understanding of implications to controls development
- ***SPIN optimization V2G/DER energy management strategy/requirements (CEC EPC 16-054)***
  - Customer control/preference priorities versus utility grid needs
  - Effectiveness of Local energy management to provide grid reliability, resiliency, and renewables ramping support
- ***Standards V2G application/interoperability verification***
  - Determine and inform standards organizations on gaps for functionality and interoperability
- ***Expanded pilots for assessment of ZNE and Microgrid applications***

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