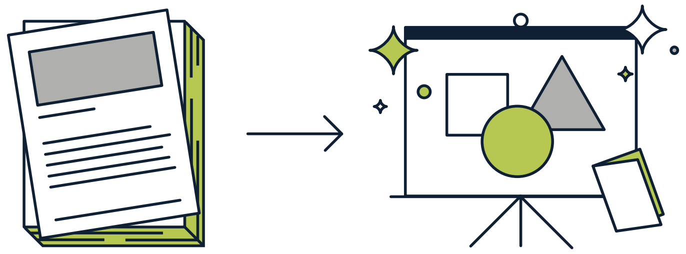
What is TA&D?

TA&D is a process developed by Electric Power Research Institute (EPRI) for sharing the story of the California Energy Commission's (CEC) Electric Program Investment Charge (EPIC) projects funded by Southern California Edison (SCE) rate payers.

TA&D presents learnings and opportunities from each project, distilled into engaging presentations and materials that provide real-time updates on the latest advancements from EPIC integrated demand side management (IDSM) and distributed energy resource (DER) technologies.



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Technology Assessment & Delivery

EV-Grid Solution

Distribution System Aware Vehicle to Grid Services for Improved Grid Stability and Reliability.

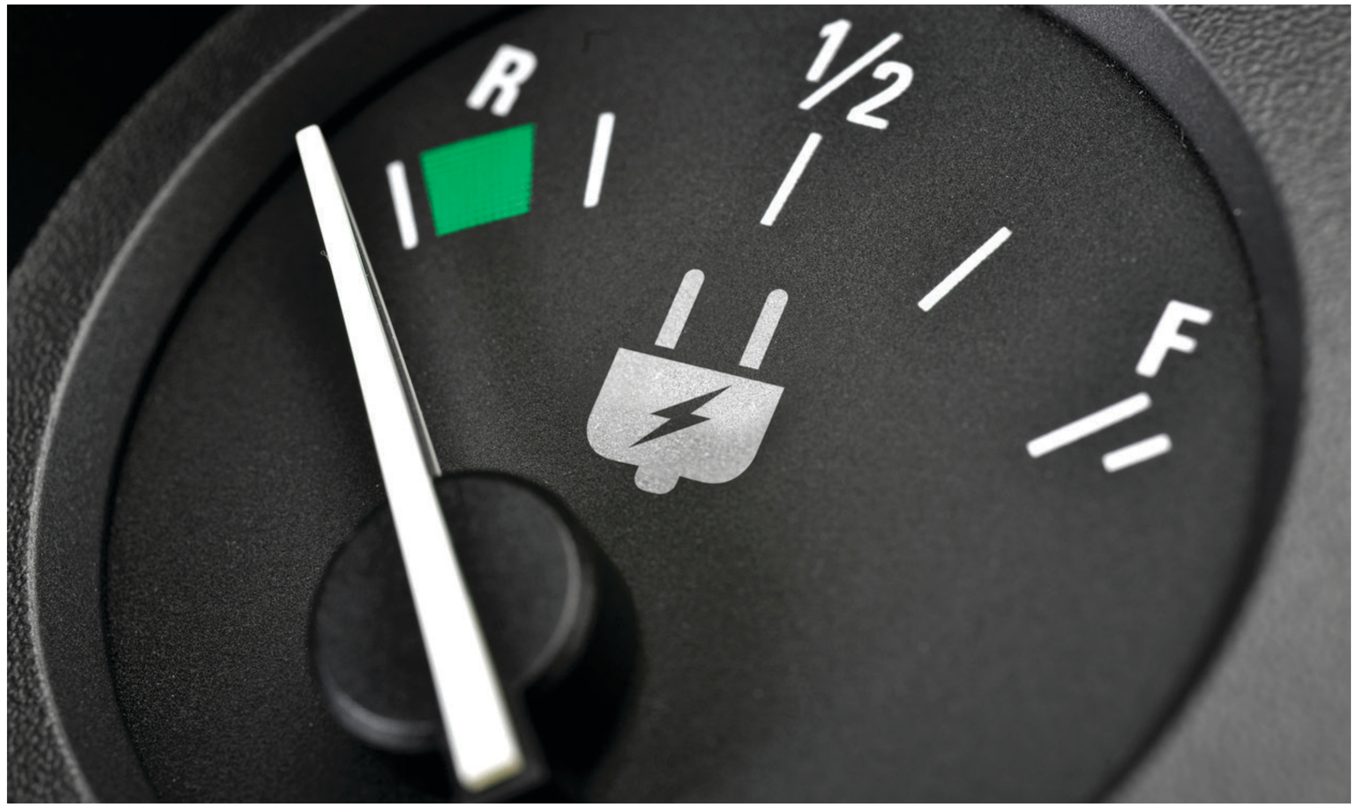
CEC EPC 14-086

June 2019

Suggested Next Steps

The technical feasibility of and the potential for value creation from engaging V2G-capable PEVs for grid services are significant enough to warrant focusing on the following key activities in the future:

1. Define SAE J3072 interoperability, certification requirements and harmonized labeling.
2. Develop V2G incentive structures that are acceptable to customers.
3. Define clearer electrical integration standards.
4. Develop next-gen ‘edge of grid’ computing technology.
5. Address adoption of J3072 by utilities for application to Rule 21 interconnection requirements.
6. Test capability of on-vehicle V2G inverters to meet Rule 21 revisions.



Missing Pieces

The project identified gaps in the technology application that will require further investigation and development. The primary gaps are:

- Acceptance and adoption of interconnection requirements for onboard inverters that interact with utilities for application to the distribution grid interconnection requirements (Rule 21) as a route to commercialization.
- Capability of on-vehicle V2G inverters to meet Rule 21 revisions relative to incorporation of the technical requirements for smart inverter communications and advanced inverter functions.
- Synchronization between different original equipment manufacturers (OEM) vehicles due to local site circuit voltage and frequency transients that may cause interruptions in communications.
- Reducing signal response times to support ancillary fast response services such as frequency regulation.
- The impact of increased cycling on battery life is not well understood and additional constraints on operation may be required to maintain battery health. In addition, V2G services may void OEMs and battery manufactures warranties.

EV-Grid Solution - Project 14-086

Supporting California's Clean Energy Goals

Plug-in electric vehicles (PEVs) are poised to become viable distributed energy resources, enabling improved grid stability and reliability. California, Assembly Bill 32 (Statutes of 2006, Pavley) drives the state's 2020 greenhouse gas requirements and has accelerated the widespread introduction of PEVs. Governor Edmund G. Brown Jr.'s Executive Order B-48-18 further codified the goal to electrify transportation to prepare the California grid for the introduction of five million EVs by 2030.

The California Public Utilities Commission (CPUC) and the California Independent System Operator's (California ISO) California Vehicle-Grid Integration (VGI) Roadmap states that vehicle electrification and smart grid technology integration present an opportunity for PEVs to provide valuable services for reliable electricity grid management. Managed or "smart" charging strategies (shifting or reducing PEV charging load during periods of high grid load) are necessary to ensure PEVs do not increase local or system peak load.

The Distribution System Aware Vehicle to Grid Services for Improved Grid Stability and Reliability project (EV-Grid) blends analysis, simulation, and implementation of an integrated vehicle to grid (V2G) system managed through a transformer management system. This integrated system uses open standards and interoperable protocols to provide connectivity and communications between the grid and the EV, operating as flexible energy storage, to enhance grid reliability and stability.

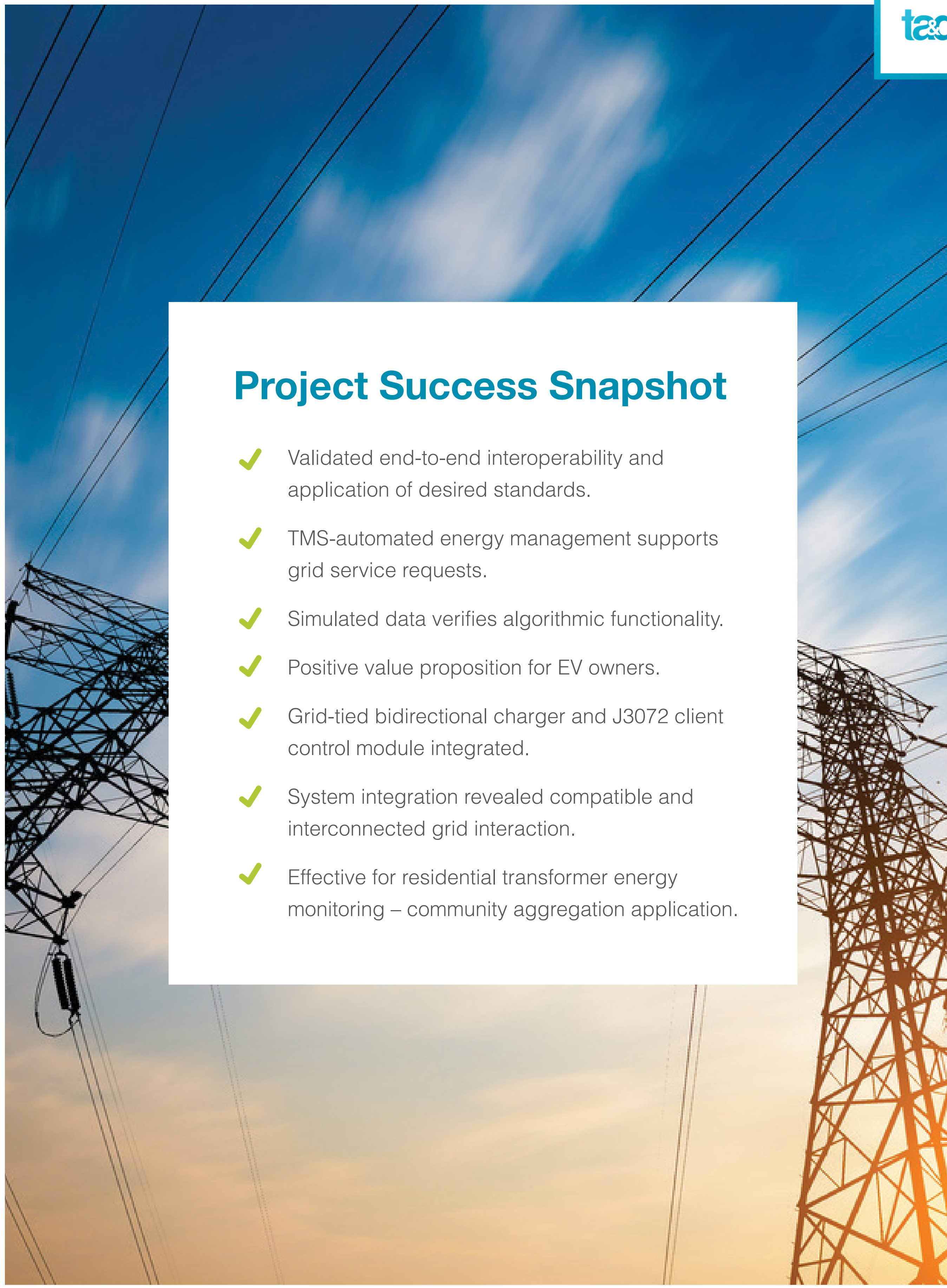
Led by the Electric Power Research Institute (EPRI) in partnership with contributors Kitu Systems, AeroVironment, FCA, E3, Clean Fuel Connection and additional PEV partners Fiat-Chrysler Automotive and Honda R&D America, the EV-Grid project tests protocols for verifying electric V2G interoperability and compatibility with CPUC interconnection requirements.

EV-GRID SOLUTION

Project Overview

The project will develop an integrated V2G system that can be tested and demonstrated to be distribution-aware, self-regulating, interoperable, secure, and open as well as scalable and flexible. Real-world tests and demonstrations will provide confidence that the V2G system can provide grid support functions and possibly influence investor-owned utilities (IOUs) to add them to their Assembly Bill 2514 Storage Mandate compliance plans.

The data gathered will also enable validation of cost-effectiveness models through direct engagement with the IOUs' existing infrastructure and distribution networks, combined with simulated independent system operator interaction.



Project Success Snapshot

- ✓ Validated end-to-end interoperability and application of desired standards.
- ✓ TMS-automated energy management supports grid service requests.
- ✓ Simulated data verifies algorithmic functionality.
- ✓ Positive value proposition for EV owners.
- ✓ Grid-tied bidirectional charger and J3072 client control module integrated.
- ✓ System integration revealed compatible and interconnected grid interaction.
- ✓ Effective for residential transformer energy monitoring – community aggregation application.

EV-Grid Project Results

This project successfully implemented an open standards-based, on-vehicle V2G-capable technology that met cyber secure, end-to-end requirements specified by industry standards associations. The project team collected use case data from the integrated system software and use case parameters that included message verification and responsiveness, PV over-generation balancing, reverse power flow to mitigate peak load ramping, and demand response.

The use case implementation verified actual system performance with the assumptions initially made during the value assessment using steady-state conditions. This team validated that the assumptions used for the vehicles were accurate and met their performance limits. The verified testing results did not require changes to the value assessment modeling.

The diverse nature of California's distribution system necessitates that similar studies be conducted in the future for a wider range of selected scenarios across broader types of distribution system segments. Performing such studies across additional scenarios and analyzing hundreds of actual vehicles and their charging behavior across California will ensure V2G benefits are thoroughly validated.

Project Objectives

Develop and implement an end-to-end V2G communications system using applied open standards:

- SAE J1772, J2836/3, J2847/3, J3072, J2931/4, J2931/1 (Vehicle Requirements)
- IEEE 2030.5 (SEP 2.0 DRLC feature set and control algorithms)
- OpenADR 2b (Utility/DSO protocol)

Implement dynamic V2G management use cases that demonstrate:

- Automated local transformer condition monitoring and control communications
- DSO aggregated PEV DR and Load dispatch control (sync with transformer constraints)
- ISO ancillary services dispatch control (using simulated AGC signal)

Assess the cost/benefit for the customer, the utility and CA as a whole using:

- E3 DER Avoided Cost and Cost Effectiveness methodology adopted by the CPUC
- EPRI/E3 Energy Storage Evaluation Tool to assess V2G energy capacity and ancillary services value
- OpenDSS for distribution circuit impact analysis to quantify costs and deferred capital expense

Implement data collection and performance analysis through:

- Simulated and field demonstrations
- System performance review for stability and reliability

Potential Benefits of this Technology

- ✔ Improve grid reliability by providing ancillary services at the aggregated level
- ✔ Balance the “Duck Curve” through bidirectional power flow capability
- ✔ Provide lower costs for ratepayers due to extensible and scalable V2G systems
- ✔ Allow grid operators to reliably use energy storage capacity procured by the customer
- ✔ Improve air quality, lower GHG emissions
- ✔ Develop a grid-integrated V2G aggregation control system for CA

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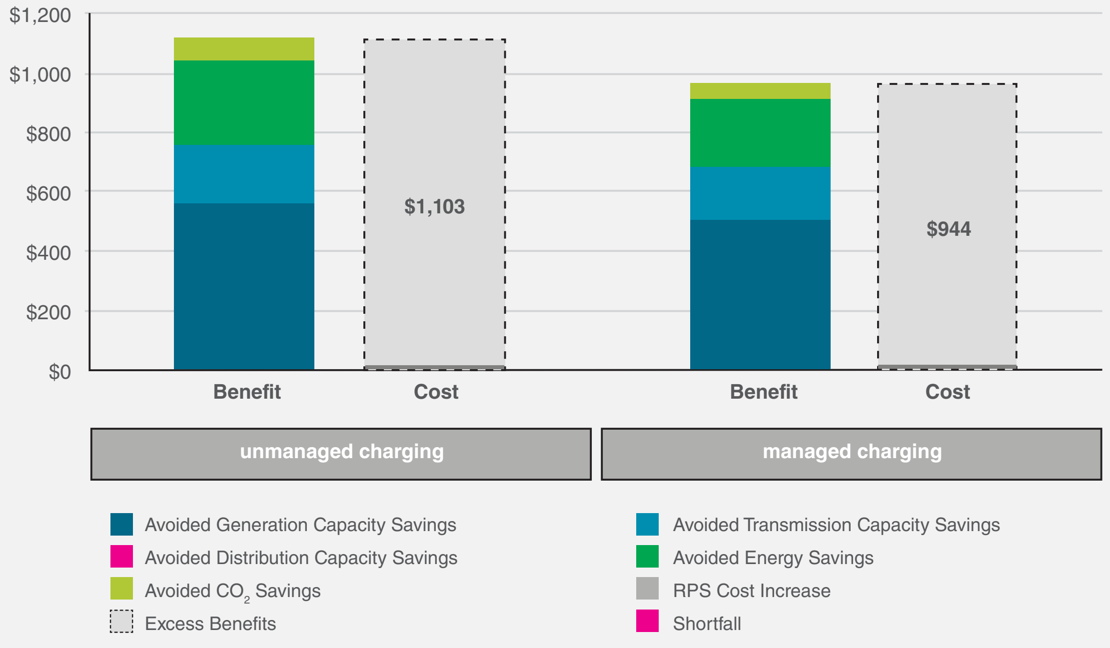
PHASE 4:

Technology Dissemination and Transfer Activities

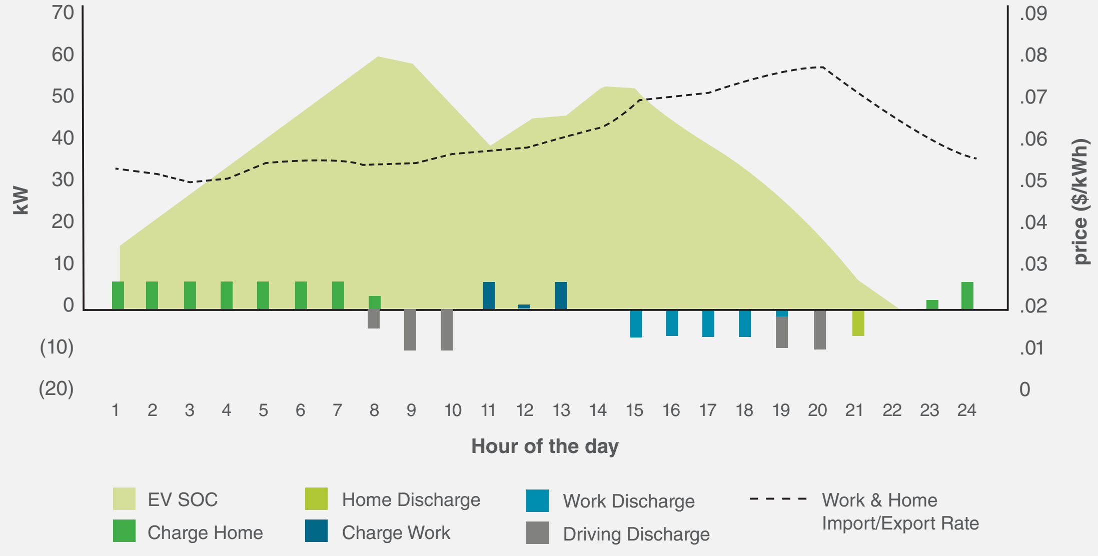
As a part of all EPC projects, the team performed numerous technology transfer activities to introduce the technology to a broad range of stakeholders through EPRI utility membership engagements, regional and national conferences, participation in standards development organization work groups, and application sharing of this technology into other Energy Commission and federally-funded PEV smart grid integration research and development programs. The full report is available at https://www.energy.ca.gov/2019publications/CEC-500-2019-027/CEC-500-2019-027.pdf

V2G with Real Time Pricing Results

Annual Net Benefits (2017$) for Total Resource Cost Relative to Unmanaged and Managed Charging



Sample Dispatch for EV 4, Tuesday 7th June



Phases for EV-Grid Solution Project

The project was conducted in four phases; each phase is described below in greater detail.

1

PHASE 1

Requirements, Design, and Technology Development

2

PHASE 2

Technology Integration, Deployment, and Testing

3

PHASE 3

Value and Planning Pathways Assessment

4

PHASE 4

Technology Dissemination and Transfer Activities

1

PHASE 1:

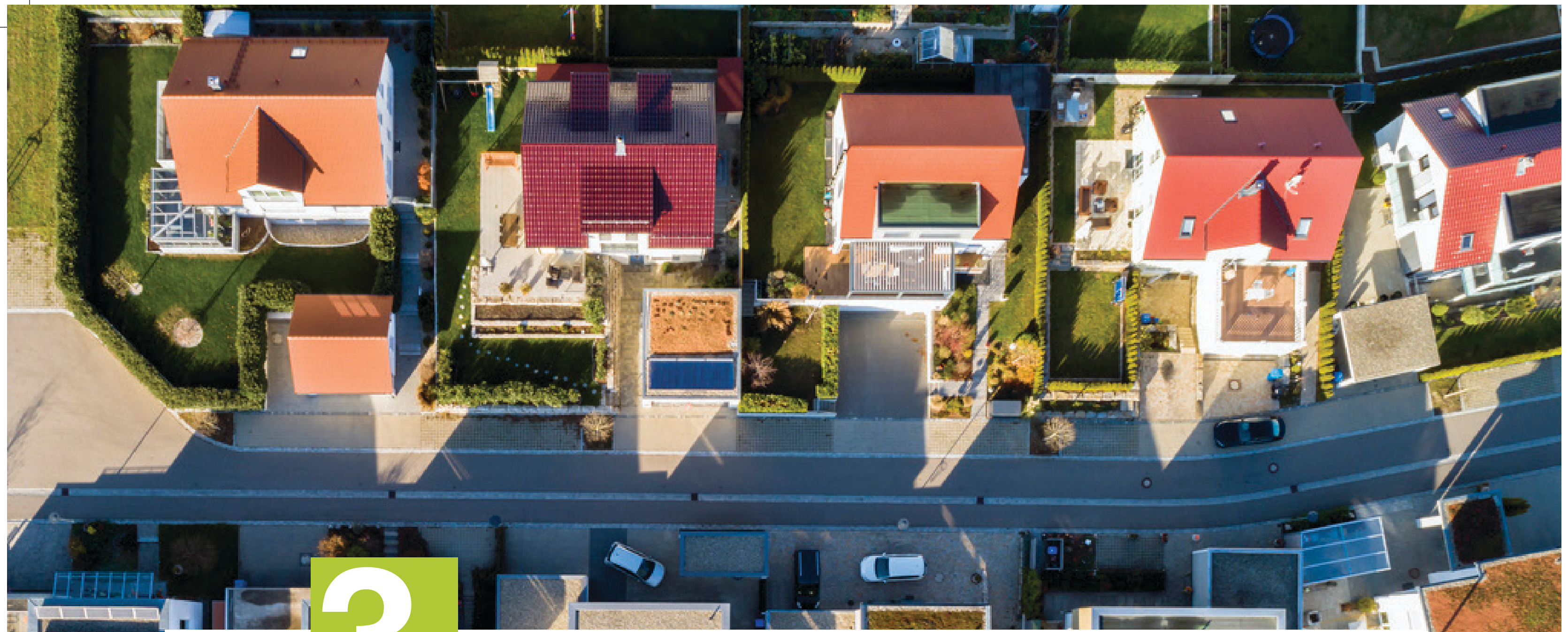
Requirements, Design, and Technology Development

This phase involved developing technical requirements that support functional specifications, interfaces, architecture, and system test plans. Individual team members designed, tested, and implemented hardware and software components to prepare for the demonstration. The research team developed and used emulators wherever possible to simulate the system surrounding the component to accelerate system integration and create baselines for the on-site demonstration.

Case Summary (annual results)

	Case Description			TRC (real levelized)		Battery Use	
Case Code	Utility or Customer Dispatch	Price Signal	Other Features	Relative to Unmanaged	Relative to Managed	Battery Cycles	Equivalent Miles*
High Value V2G Case	Utility	Energy System Capacity Distribution Capacity	High Capacity Value	**$2,316**	**$1,905**	388	89,320
Base V2G Case	Utility	Energy System Capacity		**$1,103**	**$944**	388	89,140
Base V2G with Limited Dispatch	Utility	Energy System Capacity	Discharge Revenue Threshold	**$763**	**$604**	97	22,238
Base V2G for Bill Reduction	Customer	Retail TOU Rate		**$407**	**$477**	286	65,821

*Mileage estimate based on each full battery cycle = 238 miles of driving



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PHASE 3:

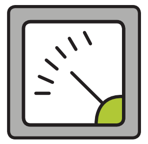
Value and Planning Pathways Assessment

The EPRI and E3 teams studied the project's value for grid services using a cost/benefit framework and simulation tools to analyze the value potential possible from V2G-capable PEVs in a variety of scenarios that were demonstrated at the test site.

Researchers performed the planning pathways assessment by studying the ongoing planning activity managed by the CPUC, California ISO, and Energy Commission to identify what type of operational, scenario planning, and modeling assumptions would need to be created for this new class of flexible loads and resources to create procurement requirements for transmission and distribution system planners.

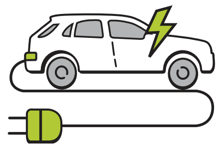
Transformer Management System (TMS) Design

The premise for the system configuration implementation is the development of the TMS, consisting of the Transformer Power Measurement Unit (TPMU) and the Transformer Controller (TC). The TPMU measures the voltage, current, and phase of the secondary output of the local distribution transformer and sends the data to the Transformer Controller. The TC then acts as an IEEE2030.5 server for communication to the electric vehicle supply equipment (EVSE) and PEV at each customer premise. It incorporates the algorithm and control application software, for determining the load balancing criteria across multiple PEVs, based on distribution system (i.e. renewables generation, peak demand, transformer capacity, voltage/frequency excursions, etc.) and PEV customer constraints (i.e. preferences for time charge and minimum State of Charge (SOC)).



Transformer Power Measurement Unit (TPMU)

- Measures voltage, currents and phase
- RS485 Communications Interface to the TC



Transformer Controller (TC)

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

Secure Neighborhood Area Network through HomePLug AV (IEEE1901)

- Ethernet connected to the TC
- Secure IPv6 to all Gateways via the premise drop

Electric Vehicle Supply Equipment (EVSE) System

The EVSE incorporates the IEEE2010.5 client/server function sets for providing the communications bridge between the TMS and the PEV. The EVSE incorporates the J3072 on vehicle grid-tied inverter authentication protocol, the J1772-compliant charge coupling control pilot, and proximity detection safety requirements. The EVSE also incorporates the J2931/4 GreenPHY power line communications (PLC) link to the PEV providing the IEEE2030.5 bridge from the TMS to the PEV. Communications between the EVSE and the TMS can be PLC, WiFi, cellular, or a combination depending on the distribution system, premise locale, and wide area networks (WAN).

The EVSE module incorporates the IEEE2030.5 server function sets that control clients in the PEV. The client function sets are controlled by the respective function set servers in the TMS module.

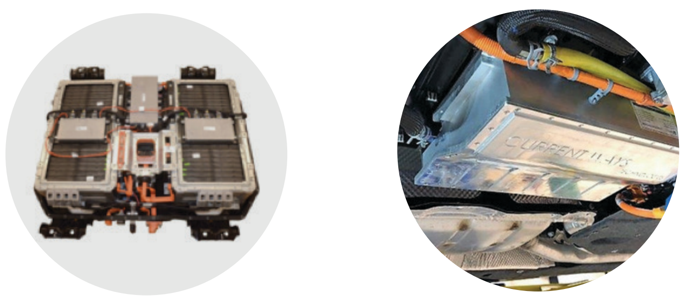
UCSD Site Vehicle Integration

EPRI and FCA completed a comprehensive end-to-end test with the Pacifica Van PHEV at the Chrysler campus in Auburn Hills prior to shipment to University of California San Diego (UCSD) for the field site demonstration. This was primarily to iron out any issues with the vehicle more expeditiously due to the proximity of vehicle software engineers at the Chrysler campus. This entire setup was replicated at a UCSD microgrid site for field integration and testing.

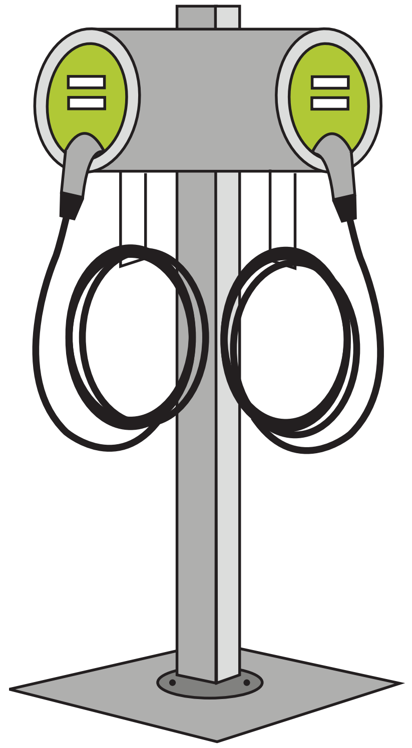
- ✔ 3 FCA Pacifica PHEVs
- ✔ 1 Honda Accord PHEV
- ✔ Assigned parking spaces (2 each side)
- ✔ Crew on-site 9 May 2018 – EPRI, FCA, Kitu, and UofDel representatives
- ✔ Verification of communications / power / meter data / TMS data transfer / interoperability PHEVs / EVSEs

FCA Pacifica Van PHEV - V2G Integration

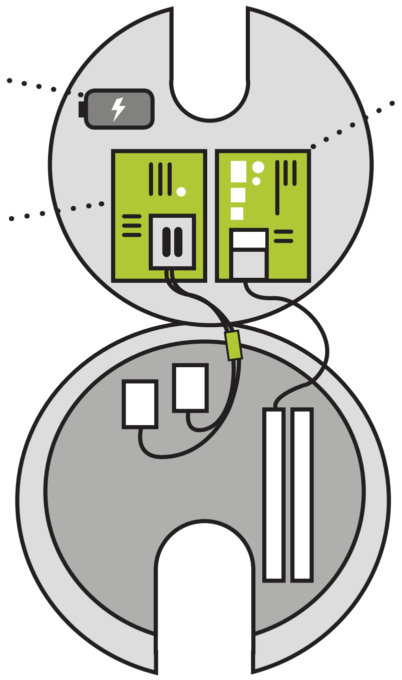
- On-board charging module is mounted under the vehicle
- Battery pack has total capacity of 16.4 kWh; 11.8 kWh is usable



Pacifica PHEV Battery Pack



Dual L2 AV EVSE
UL-Certified



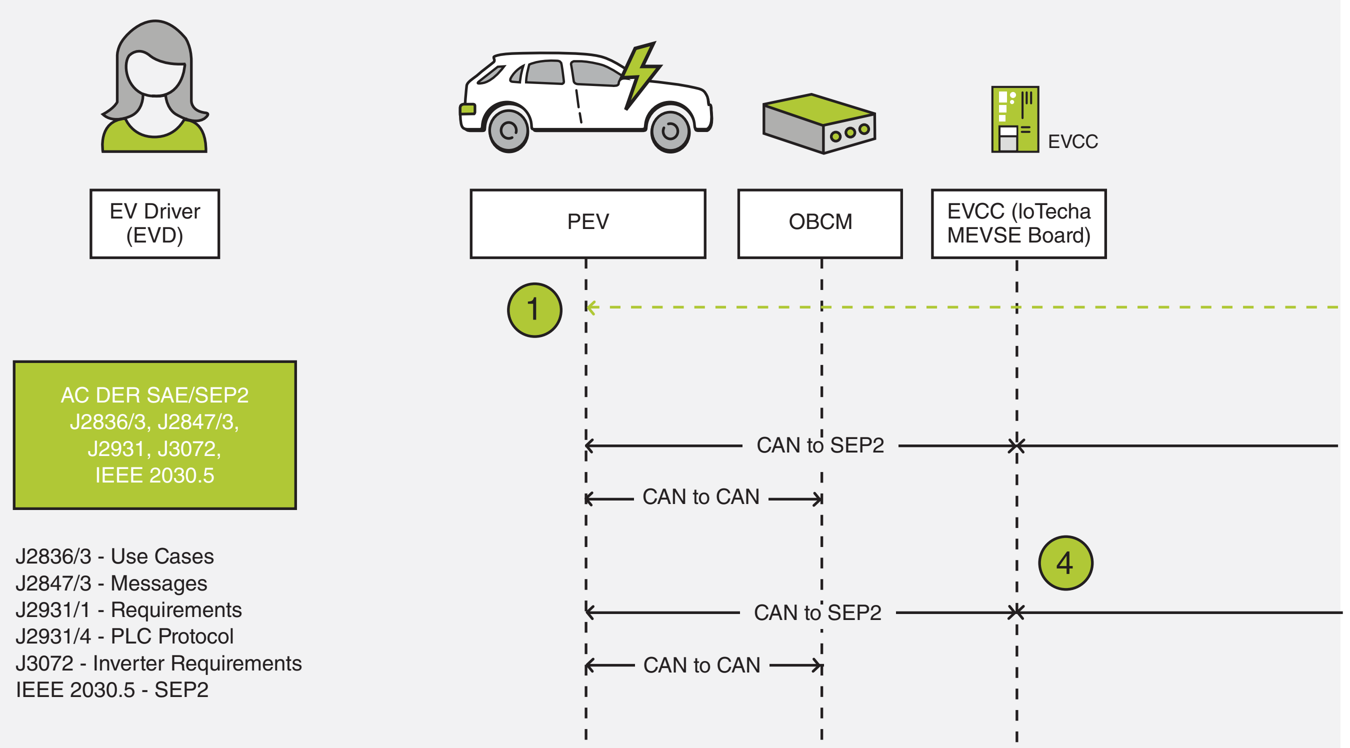
IoTecha Board contains the J3072 and IEEE 2030.5 software and connects to EVSE RS Control Board through UART (serial port). Pilot signal is generated by the EVSE RS Control Board. PLC signal is injected onto the pilot wire on the Expansion Board. The Pilot to the output cable to the EV is connected to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

On-Vehicle Communications Modules

The PEV incorporates a module with the IEEE2030.5 client function and sets for V2G control communications using the PLC link provided through the EVSE to the TMS. The PEV module also incorporates the J3072 protocol for on-vehicle inverter V2G or reverse power flow authentication and authority. Once authentication is established, the PEV initiates communications with the TMS using the IEEE2030.5 protocol.

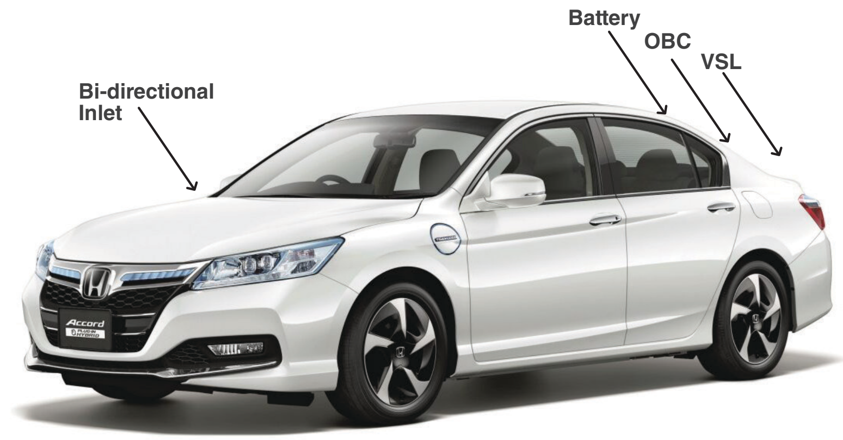
1. **Implements two separate on-vehicle V2G communications modules**
    - UofDel Vehicle Smart Link (Honda)
    - EPRI Electric Vehicle Communications Controller (FCA Pacifica)

End to End Communications Sequence between V2G System



Honda Accord PHEV – V2G Integration

- ✓ Based on 2014 model
- ✓ 6.7kWH battery
- ✓ 2kW prototype bidirectional charger (OBC)
- ✓ Modified VSL to add PLC and SEP2 and includes SW and HW changes



Vehicle Smart Link (VSL) Module (NUVVE / UDel)

Transformer Management System Component

The TMS system component consists of two parts:

1. Transformer Management Engine

- Schedules charging/discharging based on the TMS algorithms
- Reads the monitoring parameters from the energy meter, uploads data to the server for archival storage, and provides input to the TMS algorithms.
- Reads parameters about the vehicles from the SEP 2.0 client and schedules discharge and charge commands in the SEP 2.0 server.

2. SEP 2.0 Server Component

- Provides authentications for the EVSE SEP 2.0 client and Electric Vehicle SEP 2.0 client.
- Retrieves information about the SFDI of the connected vehicle in SEP 2.0 messages from the EVSE.
- Retrieves information about the status of the vehicle (i.e. connected, disconnected, sleeping) connected to the EVSE from the EVSE SEP 2.0 messaging.
- Processes and parses vehicle information received from the SEP 2.0 client in the Electric Vehicle.

Vehicle information is spread over several messages; parameters gathered include the current state of charge, target state of charge, charge rate, discharge rate, and time the vehicle must be ready.

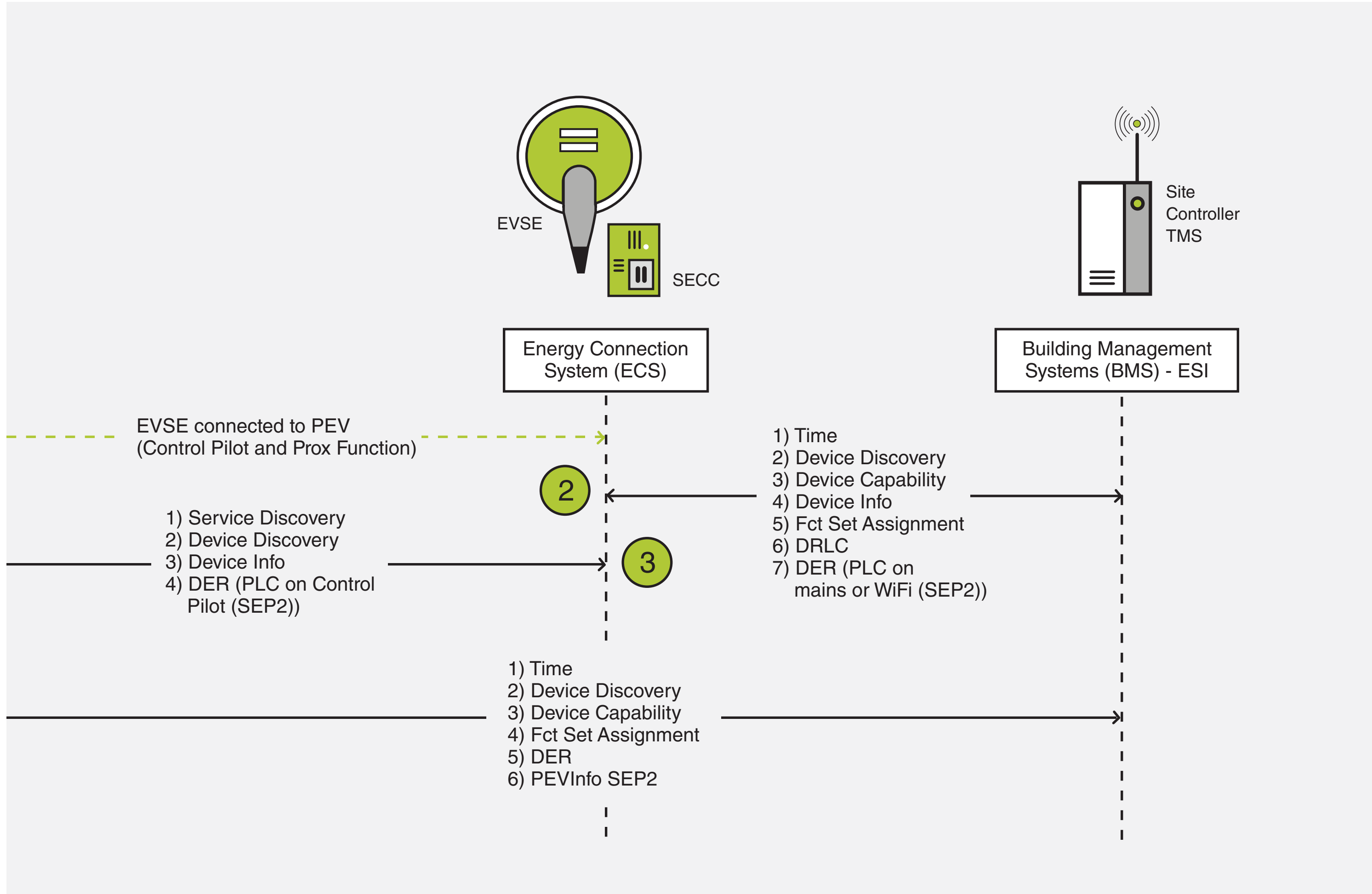
System Deployment and Demonstration

The V2G communications systems were independently developed and tested by Honda and Fiat-Chrysler Automobiles (FCA): the Chrysler Pacifica Van PHEV by FCA in Auburn Hills, MI, and the Honda Accord PHEV at the University of Delaware and Honda Tech Center in Torrance, CA.

2. Incorporates multiple protocols

- J3072 to EVSE authorization protocol
- IEEE2030.5 DER Function Set (Client) per J2847-3 Standard
- IEEE2030.5 to Vehicle CAN interoperability
- PLC communications per J2931-1/J2931-4 (HomePlug AV)
  - Utilize IoTecha MEVSE PLC Board
- Communicates through PLC (EVSE Bridge) to TMS

3. Demonstrates effectiveness of standards through verification of interoperability with common EVSE



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PHASE 2:

Technology Integration, Deployment, and Testing

During Phase 2, AeroVironment and Kitu developed the electric vehicle supply equipment and control software, respectively; the University of Delaware (Honda) and Fiat-Chrysler Automobile developed the on-vehicle software and performed hardware implementation, while IoTecha completed development of the control card interface.

EPRI developed and integrated the transformer management system (TMS.) Then the project team integrated the subsystems (PEV, electric vehicle supply equipment, and TMS) and tested the entire system at Fiat-Chrysler's Auburn Hills facility. Finally, the entire system was integrated at the University of California, San Diego campus test site where test and data collection activities were performed.

System Software

The system consists of a number of software components to support the IEEE2030.5/ SEP 2.0 protocol and the J3072 protocol. The figure below shows the main software components as they pertain to a complete system view.