Recovery – Strategy to Accelerate U.S. Transition to Electric Vehicles

DE-EE0002628

Final Technical Report

General Motors LLC (GM)

March 29, 2010 – April 30, 2014

This material is based upon work supported by the Department of Energy
under Award Number DE-EE0002628

TABLE OF CONTENTS

PROJECT CONTACTS

General Motors

Richard Leach
Manager, Government Contracts
GM Global Research & Development
30500 Mound Rd, Warren, MI 48090

Joseph LoGrasso
Principal Investigator
Global Electrification Engineering
30001 Van Dyke Ave, Warren, MI 48090

Sandra Monterosso
Program Manager
Global Electrification Engineering
777 Joslyn Ave, Pontiac, MI 48340

DOE Project Officer:
Jason Conley
National Energy Technology Laboratory
3610 Collins Ferry Road
Morgantown, WV. 26507

Project Start Date: *3/29/10*

Project End Date: *4/30/14*

EXECUTIVE SUMMARY

The objective of this project was to develop Extended Range Electric Vehicle (EREV) advanced propulsion technology and demonstrate a fleet of 146 Volt EREVs to gather data on vehicle performance and infrastructure to understand the impacts on commercialization while also creating or retaining a significant number of jobs in the United States. This objective was achieved by developing and demonstrating EREVs in real world conditions with customers in several diverse locations across the United States and installing, demonstration and testing charging infrastructure while also continuing development on second generation EREV technology.

The project completed the development of the Chevrolet Volt and placed the vehicle in the hands of consumers in diverse locations across the United States. This demonstration leveraged the unique telematics platform of OnStar, standard on all Chevrolet Volts, to capture the operating experience that lead to better understanding of customer usage. The project team included utility partners that installed, demonstrated and tested charging infrastructure located in home, workplace and public locations to understand installation issues, customer usage and interaction with the electric grid. Development and demonstration of advanced technologies such as smart charging, fast charging and battery to grid interface were completed. The recipient collected, analyzed and reported the data generated by the demonstration. The recipient also continued to advance the technology of the Chevrolet Volt technology by developing energy storage system enhancements for the next-generation vehicle. Information gathered from the first generation vehicle will be utilized to refine the technology to reduce cost and mass while also increasing energy storage capacity to enhance adoption of the second generation technology into the marketplace.

The launch of the first generation Chevrolet Volt will provide additional opportunities to further enhance the RESS (Rechargeable Energy Storage System) with each additional generation. Lessons learned from the launch of the first generation RESS will be demonstrated in the second generation to enhance adoption into the marketplace.

Scope of Work

The recipient shall complete development and validation of the Chevrolet Volt EREV advanced propulsion technology and demonstrate a fleet of EREVs to gather data on vehicle performance and operability with the charging infrastructure to understand impacts on commercialization.

The recipient shall develop, analyze, and test the Chevrolet Volt with the Voltec propulsion system. The recipient shall develop components and subsystems required for an EREV and fully integrate them in a production vehicle. Advanced technologies shall be developed in the areas of charging and secondary use of automotive batteries. GM, the Electric Power Research Institute (EPRI) and the utilities shall install significant electric charging stations covering home, workplace, and public locations to support the vehicle demonstration broadly across utility service territories.

One of the objectives is to demonstrate EREVs in real world conditions. The recipient shall initially demonstrate the EREVs by assigning them to employees from within the company to be driven. The vehicles shall then transition to partners such as EPRI and various utilities, which shall operate EREVs within their fleet and make them available to local stakeholders in several geographic areas covering the

Eastern seaboard, Midwest, South Central and the West Coast. The durability and performance of these vehicles shall be put to the test based on diverse climates, terrain, and duty cycles. Test data on vehicle usage and interaction with the power grid shall be reported to DOE. During this phase advanced technologies shall be demonstrated providing key data on opportunities for new charging technologies and secondary use of automotive batteries.

The recipient shall continue development of the next generation technology to improve the energy storage system and utilize information learned from the first generation vehicles. The engineering development shall focus on reducing cost and mass while also increasing energy storage capacity. GM uses a structured process for meeting the requirements of new technologies by selecting, modifying, and optimizing through analyses, demonstrations, inspections, and/or tests.

Project Details

Demonstration Charging Infrastructure

The recipient shall install infrastructure at the workplace and homes of vehicle drivers and evaluate charge cord and station components. The recipient's utility partners shall install electrical infrastructure to address the charging needs for their deployment of Chevrolet Volts, laying the groundwork for the demonstration and expanding the number of installations over time to accommodate the broader utility service territories and identify any region-to-region variation that would hinder market introduction of charging infrastructure and ultimately electric vehicle acceptance in their regions. Significant charging stations at home, workplace, and public locations shall be installed under this demonstration to understand installation issues, seed early electric vehicle deployment and enable future needs as electric drive vehicles become commonplace.

Installation plans were as follows:

- Install 240V circuits and chargers and ensure adequacy of existing 120V circuitry for EREV charging at drivers' residences
- Install 240V or equivalent circuits and chargers at GM locations in Warren, Pontiac, Milford and Detroit Michigan and the Desert Proving Ground in Arizona to evaluate daytime charging and implications of multiple charges per day
- Installation of electrical infrastructure shall occur in the geographic locations where the utilities provide service in homes, workplace, and/or public locations
    - Establish charging infrastructure plan of suitable and visible locations based on vehicle deployment plans under this proposal and for future vehicle roll-outs
    - Ensure installations meet local jurisdiction building and electrical code and regulations and are in place on a timely basis for this demonstration
    - Ensure training of vehicle operators on use of charging stations

	Charging Stations						
	Home		Business		Public		
DOE Utilities	Plan	Installed	Plan	Installed	Plan	Installed	% Complete
Cost Sharing Utilities							
DTE	10	11	1	1	13	14	108%
Duke	15	15	15	15	5	5	100%
EPRI			51	51			100%
Progress	0	0	42	42	0	0	100%
SMUD			22	22			100%
Non Cost Sharing Utilities							
Austin	0	0	2	2	0	0	100%
Dominion	2	2	2	2	0	0	100%
Pepco	2	2	3	8	3	1	138%
PGE	0	0	20	52	0	0	260%
SCE	0	0	5	8	5	25	330%
	29	**30**	163	**203**	26	**45**	

Table 1 - Utility Charging Stations

Data Analysis and Reporting

General Motors worked in conjunction with EPRI and a number of utilities to promote a strategy to accelerate the transition to electric vehicles in the United States. The primary focus of the project is the deployment and demonstration of the Chevrolet Volt Extended Range Electric Vehicle (EREV), and the installation and maintenance of the supporting charging infrastructure. The key initiatives of the project are the demonstration of the Chevrolet Volt EREVs in real world conditions with real customers. Each utility administered and monitored the use and performance of the Chevrolet Volts and installed fleet charging infrastructure. The utilities that assisted General Motors with this task are:

- Electric Power Research Institute (EPRI)
- Austin Energy
- DTE Energy
- Dominion
- Duke Energy
- Pacific Gas and Electric Company (PG&E)

- Potomac Electric Power Company (Pepco)
- Progress Energy
- Southern California Edison (SCE)
- Sacramento Municipal Utility District (SMUD)

The above mentioned utilities are located across the United States. Their locations are depicted on the following map in Figure 1:

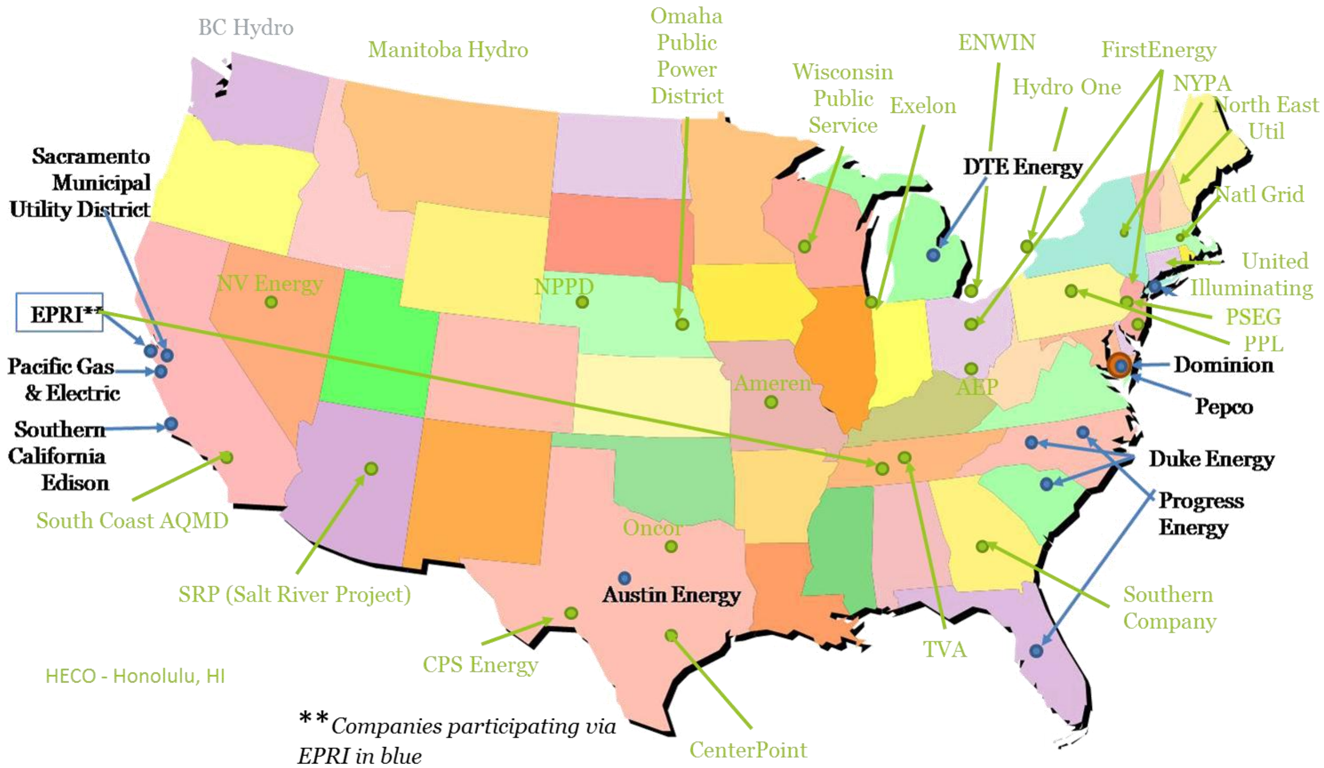


Figure 1 - Utility Locations within the United States

The demonstration vehicles were monitored to capture key project data. The majority of this data was captured using OnStar for remote logging of performance data from onboard vehicle controllers. This data was used to generate reports to support learning for current and future generation designs, and customer preferences. (These reports are discussed later in this report.) The data was collected quarterly by Idaho National Lab (INL) and was reviewed and provided to the DOE. The types of data collected and included in the reports are:

- Fuel economy in charge depletion and charge sustaining modes as well as overall fuel economy
- Demonstration fleet statistics including number of trips, distance traveled, and types of driving
- Charging events including charging duration, charge energy and charging times

To ensure vehicle data transmission was ongoing, GM maintained communication on a regular basis with OnStar and each of the utilities. We reported the data transmission status to the DOE during our monthly status calls. Table 2 below is a sample of the summary that was presented to the DOE on a monthly basis.

			August	September	October	November	December	January
DOE Utilities	Location	# Volts	Vehicles Reporting	Vehicles Reporting	Vehicles Reporting	Vehicles Reporting	Vehicles Reporting	Vehicles Reporting
Austin	TX	2	2	2	2	2	2	2
Dominion	WDC	2	2	2	2	2	2	2
DTE	MI	10	10	10	10	10	10	10
Duke	NC	15	15	15	15	15	15	15
EPRI	CA	68	65	65	64	67	64	68
Pepco	WDC	9	9	9	9	9	9	9
PGE	CA	10	10	10	9	9	9	10
Progress	NC	12	11	12	12	11	12	12
SCE	CA	6	6	6	6	6	6	6
SMUD	CA	12	12	11	12	12	12	12
		146	**142**	**142**	**141**	**143**	**141**	**146**

Table 2 - OnStar Data Transmission per Utility

Sacramento Municipal Utility District (SMUD)

Project Activities and Results

Vehicle Demonstration

Vehicles

Ten Chevrolet Volts from the 2011 model year were received by SMUD on August 2, 2011. The City of Sacramento purchased their two vehicles on their own as part of the overall demonstration program. Four Chevrolet Volts were assigned to project partners - Sacramento State (2), UC Davis (1), and Los Rios Community College District (1). Four Chevrolet Volts were assigned to SMUD departments and two Chevrolet Volts were assigned to SMUD's general pool fleet.

The Chevrolet Volt is an Extended Range Electric Vehicle, which is an electric vehicle that provides for extended range through an on board gasoline engine with generator. The Chevrolet Volt charges with the SAE J1772™ charging standard connector to provide an electric range of approximately 35 miles. The extended range gasoline engine allows for an additional 300 miles of range after the battery is discharged to a sustained minimum state of charge.

Vehicle Management

Accessibility

Project partners (Sacramento State, UC Davis, and LRCCD) had assigned drivers for the vehicles, who managed sharing and access to the vehicles as needed. Usage of vehicles assigned to SMUD Departments was managed through locally designed systems such as by Outlook calendar or hand-written calendar. Vehicles in SMUD's general pool fleet were administered through a web-based pool vehicle management system called Fleet Commander.

Training

SMUD developed laminated graphical cards tethered inside vehicles that explained how to use the Chevrolet Volt for vehicles at SMUD. SMUD also offered 1-hour training classes on how to use the Volt that were available to all of SMUD and were announced through the company wide email. SMUD also prepared a 4-minute video on how to use a Chevrolet Volt that was posted on Fleet Commander. Drivers at partner sites were personally trained as needed.

Maintenance

Most vehicle maintenance was routine and related to oil, tires, and brakes. A unique maintenance item that affected all vehicles was an update to the vehicle structure and battery coolant system. This update was offered as a voluntary customer satisfaction update by General Motors in response to an NHTSA Chevy Volt Investigation which concluded that the Chevrolet Volts were no less safe than conventional vehicles.

Other unique maintenance items were not consistent across the vehicles. The only moderate repair items that occurred were replacement of the drive motor relay on one vehicle. Aside from that, some minor repairs were done for cracks in the shifter lever, wear on the front air dam, and tight operation of charger cover door. There were also 3 minor vehicle accidents with no injuries which required minor body work for repair.

Vehicle Data Collection

Energy consumption and usage data was collected from the OnStar telematics system and SMUD smart meters beginning with Q4-2011. A summary of this data is shown in Figure 2.

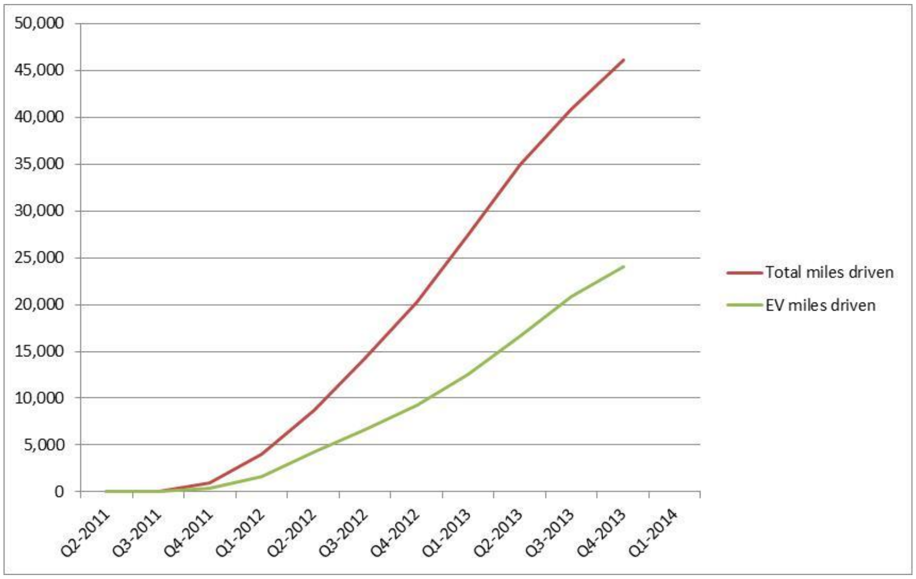


Figure 2 - Chevrolet Volt Miles Driven

Of 46,000 total miles driven from the electrified fleet of Chevrolet Volts, 24,000 miles were driven in a pure electric mode. This equates to approximately 52% reduction in tailpipe emissions. The observed fuel economy was 359 Wh/mi in electric mode and 29.7 mpg in extended range hybrid mode. For 24,000 miles driven in electric mode, approximately 808 gallons of gasoline consumption was avoided in exchange for 8,961 kWh. Considering SMUD's low carbon generation mix of 30% hydro, 24% renewable, and 46% high efficiency natural gas combustion, this much electrical energy yields approximately 1/3 of the carbon emission associated with the displaced gasoline consumption.

Driver Data Collection

On December 24, 2013 a contract was approved with the UC Davis Institute of Transportation Studies to survey and interview participating drivers regarding their vehicle and charging infrastructure experiences for the task final report. Over 50 drivers were estimated to have used the Chevrolet Volts during the course of this project. Of these drivers, 27 drivers were surveyed and 12 were interviewed.

The fleet drivers found the Chevrolet Volt adequate for 82% of their fleet needs, while at other times there was a need for passenger or cargo space of SUVs/trucks. About 71% of the driving was perceived to be electric, which exceeded the 52% measured amount of electric driving according to data collected through OnStar. About a quarter of the

drivers used the Volt daily, another quarter of the drivers used the Volt weekly, and half of the drivers used the Volt

monthly as shown in

Figure 3. **Error! Reference source not found.**4 shows that about half of the trips were less than 40 miles, which can typically be covered with in all electric.

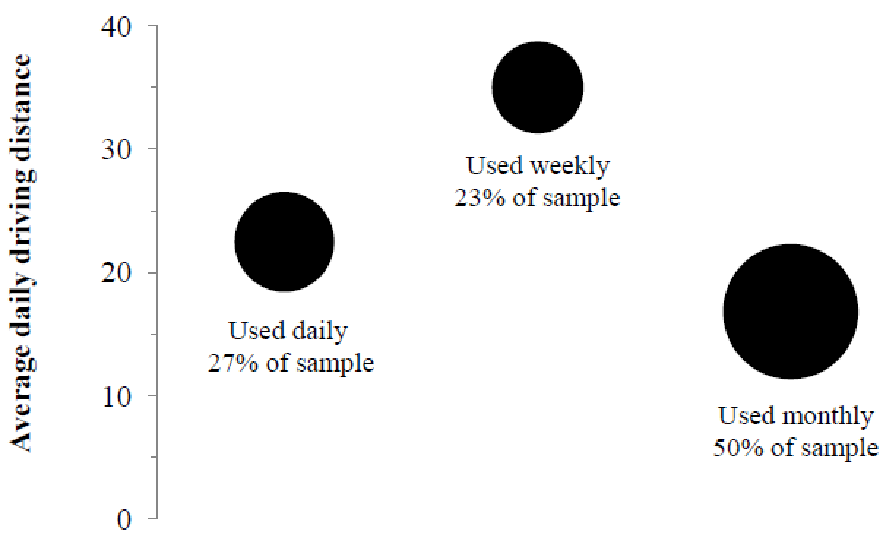


Figure 3 - Chevrolet Volt Regularity of Use (Davies & Nesbitt, 2014)

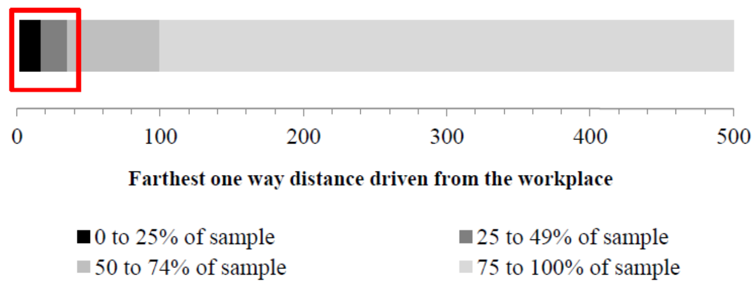


Figure 4 - Chevrolet Volt Regularity of Use (Davies & Nesbitt, 2014)

The 50 drivers talked with an estimated 850 individuals about the Volt. Of these conversations, about 70% were favorable. Of the drivers with favorable perceptions, 37% recommended a Volt purchase to somebody else. Three drivers purchased PEVs partly as a result of Volt experience. Of the drivers with an unfavorable perception, 17% of drivers discouraged a Volt purchase to someone else.

The most positive attributes used by drivers to describe the vehicle were: environment, commuting, appearance, acceleration, comfort, and reliable. The most negative attributes used by drivers to describe the vehicle were: limited seating & cargo capacity, EV range, and visibility.

Infrastructure

Hardware

Charging equipment was procured after competitive bid in July 2011. Charging equipment was required to be in compliance with the SAE J1772™ standard and Level 2 with a 240V/20A or greater branch breaker. The AeroVironment EVSE-RS unit was selected as primary EVSE and subsequently the ClipperCreek CS40 units were approved as a second option. The ClipperCreek units with a higher water resistance rating (NEMA 4) were used in landscaped areas that could be exposed to watering sprinklers. The Aerovironment units with a lower water resistance rating (NEMA 3R) were used in all other areas.

Installation Locations

A total of 29 Level 2 EVSE installations were made to support twelve Chevrolet Volts that were part of vehicle fleets spread among multiple buildings and locations. Installations were made in compliance with NEC Article 625. The installation sites included facilities for SMUD; City of Sacramento; Sacramento State University; American River College, Los Rios Community College District; and the University of California, Davis. During the process of Level 2 installations, vehicles were supported by Level 1 charging with the portable cord sets included with each vehicle until relevant Level 2 charging was in place. Table 3 summarizes the installation sites.

# EVSE	Date Complete	Location	Brand
1	9/22/2011	SMUD Headquarter Mezzanine Parking Deck 6201 S St Sacramento, CA 95817	AeroVironment
2	10/19/2011	SMUD Main Campus Warehouse 1708 59th St Sacramento, CA 95819	AeroVironment

7	2/17/2012	SMUD Fitness Center 6301 S St Sacramento, CA 95817	ClipperCreek
2	6/27/2013	SMUD East Campus Office Building 9750 Kiefer Blvd Sacramento, CA 95827	ClipperCreek
1	8/15/2013	SMUD East Campus Fleet Garage 9750 Kiefer Blvd Sacramento, CA 95827	AeroVironment
4	12/18/2013	SMUD Solar Port Parking Lot 6077 S St Sacramento, CA 95817	AeroVironment
2	5/15/2012	City of Sacramento, Corporate Yard 5730 24th St, Building 20 Sacramento, CA 95822	AeroVironment
2	11/27/2012	City of Sacramento, Public Safety Building 5770 Freeport Blvd Sacramento, CA 95822	AeroVironment
2	1/15/2013	City of Sacramento, City Hall Fleet Parking Garage 915 I St Sacramento, CA 95814	AeroVironment
2	3/22/2013	City of Sacramento, Richards Police Facility 300 Richards Blvd Sacramento, CA	AeroVironment
1	7/13/2012	American River College Automotive Technology Building 4700 College Oak Drive Sacramento, CA 95841	AeroVironment
1	8/24/2012	Sacramento State University, Sacramento Hall 6000 J St Sacramento, CA 95819	ClipperCreek
1	8/21/2012	Sacramento State University, Parking Structure 1 6000 J St Sacramento, CA 95819	ClipperCreek
1	12/12/2012	U.C. Davis, Institute of Transportation Studies PH&EV Center 1605 Tilia Street, Suite #100 Davis, CA 95616	ClipperCreek

Table 3: Summary of Installation Sites (Aswani & Hatfield, 2014)

Installation Process

Figure 5 details the process that SMUD followed in conjunction with site stakeholders, engineering contractors, installation contractors, and inspection authorities to install the 29 EVSE for this project.

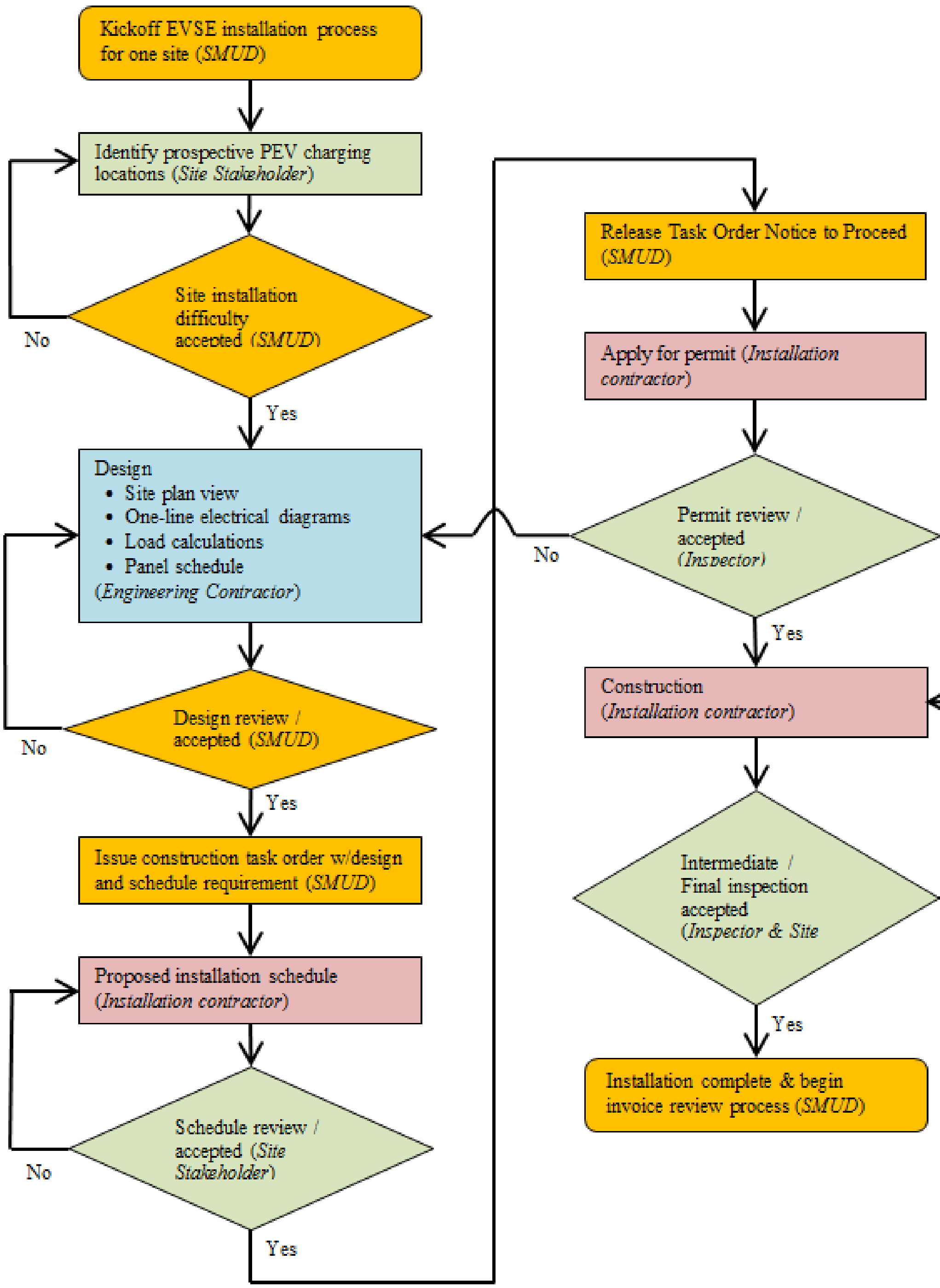


Figure 5 -Installation Process Flow Chart (Aswani & Hatfield, 2014)

Costs

The costs per EVSE installation site are detailed below in Table 4, categorized by engineering; EVSE hardware; materials, tools, & other; permit; construction labor; and independent inspection labor.

	Location	# EVSE	Engineering	EVSE Hardware	Materials, Tools, & Other	Permit	Construction Labor	Inspection Labor
SMUD	Headquarter Parking Deck	1	$4,689	$1,172	$1,440	x	$2,453	$742
	Main Campus Warehouse	2	$8,185	$2,344	$717	x	$2,910	$881
	Fitness Center	7	$20,927	$18,190	$10,869	x	$26,002	$7,872
	East Campus Office Building	2	ǂ	$5,898	ǂ	x	$3,248	x
	East Campus Fleet Garage	1	ǂ	$1,172	ǂ	x	$537	x
	Solar Port Parking Lot	4	$2,143 ǂ	$10,936	$11,471	$758	$16,417 ǂ	$4,970
City of	Corporate Yard	2	ǂ	$2,344	ǂ	ǂ	ǂ	x
	Public Safety Building	2	$9,063	$5,468	$8,493	$494	$17,583	$5,323
	City Hall Garage	2	$16,278	$2,344	$8,157	$493	$12,412	$3,758
	Richards Police Facility	2	$11,444	$5,468	$1,552	$596	$7,433	$2,250
ARC	Automotive Tech Building	1	$3,524	$1,172	$2,264	x	$5,573	$1,687
CSUS	Sacramento Hall	1	$3,524	$2,243	$1,643	x	$6,551	$1,983
	Parking Structure 1	1	$3,524	$2,243	$2,003	x	$9,116	$2,760
UC Davis	ITS PH&EV Center	1	$0	$2,243	*	*	$5,000	x

* indicates the cost is not available in disaggregated form
ǂ indicates that a portion or all of the cost was covered by a third party
x indicates a cost that is not applicable

Table 4: Summary of Installation Costs (Aswani & Hatfield, 2014)

From the detailed cost data, the following cost model in Table 5 is proposed for workplace fleet installations.

Cost Category	Per Site	Additional Per EVSE	Additional Per Pedestal
Engineering	$5,900		
Inspection & coordination	$2,300		
Permitting	$600		
Construction	$4,100	$1,000	$1,000
Trenching	+$200/ft.		
EVSE hardware		$1,500	$700
Installation hardware & other		$1,600	

Table 5: Level 2 EVSE Cost Model (Aswani & Hatfield, 2014)

Utility Readiness

Market Readiness

In support of market readiness, SMUD created a customer program around an existing PEV electricity billing rate called the Residential Time of use Electric Vehicle rate (RTEV) rate. This rate provides incentives to customers to charge off peak, prevents customers from going into a higher costlier tier rate due to vehicle charging, and protects infrastructure. This rate is provided through sub-metering, where a secondary meter that is downstream of the whole house meter is dedicated to a PEV charging circuit. SMUD provides the second meter with installation if the customer has an intermediate meter socket installed. This option is depicted in Figure 66.

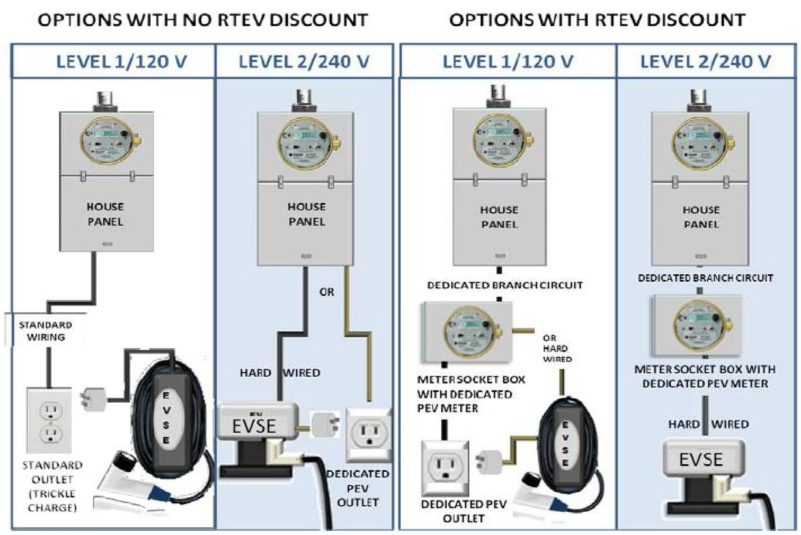


Figure 6 - SMUD PEV Metering and Billing Options (Gehringer & Vargas, 2011)

The specific details of the RTEV rate are depicted in Figure 7.

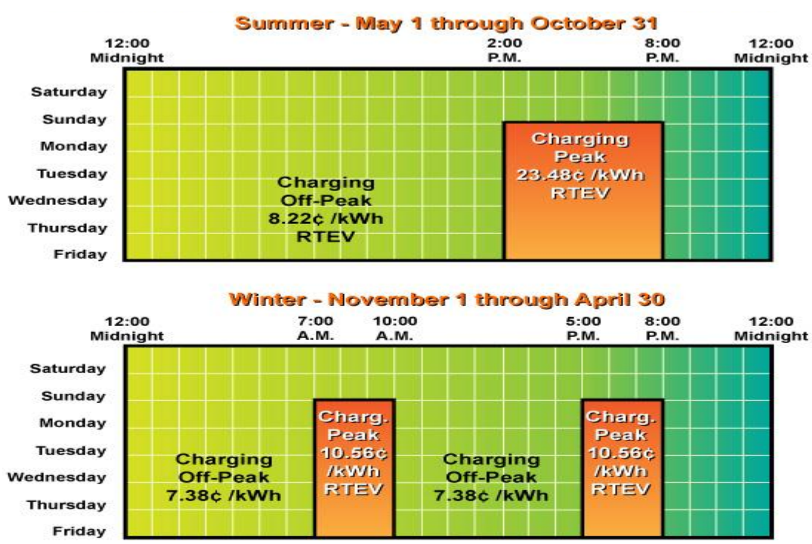


Figure 7 - SMUD RTEV Time of Use Rate (Gehringer & Vargas, 2011)

In 2010, SMUD launched its PEV customer support program. The program is ongoing and SMUD is supporting customers by phone, including an Integrated Voice Response System, (IVR), e-mail and via the website (www.smud.org/pev). SMUD's IVR System routes PEV calls to our contact center where a

Customer Service Representative (CSR) answers basic questions, and creates Contact Logs and Service Notifications for any of three SMUD-recommended charging installation methods. If the CSR is unable to answer the customer's questions, an Energy Specialist will contact them within two business days. If the customer needs immediate assistance, the phone call is routed directly to a program specialist, who has over 10 years of electric vehicle experience. All pertinent customer residence information is logged and Distribution Services is notified to ensure that the customer has adequate electrical service, to assess transformer loads, and to provide additional customer service. The customer coordinates purchase, installation, and inspection of Electric Vehicle Supply Equipment (EVSE) commonly known as charging stations. If the customer has decided to take advantage of SMUD's EV off-peak discount Rate (RTEV), SMUD will install a PEV dedicated meter. All customers on the RTEV rate receive an integrated SMUD bill specifically for PEV charging electrical use. SMUD's Billing group has automated 'subtractive-billing' in order to separate the home electrical use from the PEV charging station/EVSE electrical use. Figure 8 depicts this customer service process flow.

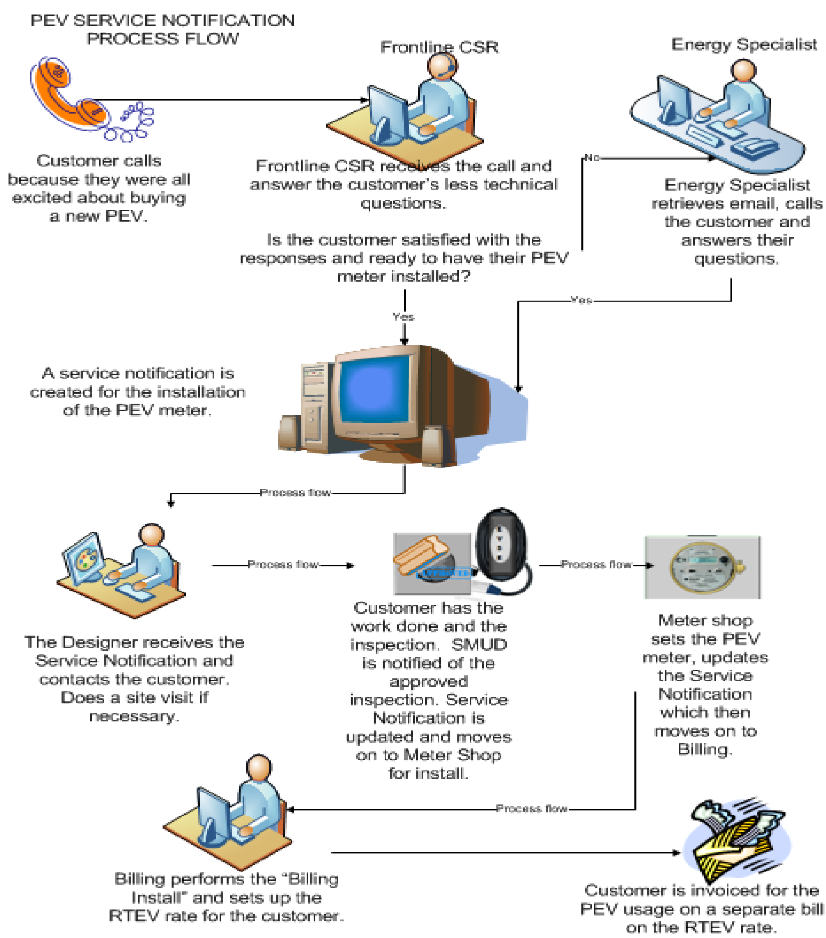


Figure 8 - SMUD PEV Service Notification Process (Gehringer & Vargas, 2011)

Currently SMUD's program has grown into a cross functional team with additional support from the Electric Transportation Research and Development group. SMUD monitors customer contacts to help improve staff's knowledge and improve the ability to support customers on this topic as the program progresses. SMUD's PEV website (smud.org/PEV) is a significant tool for internal customer support as well as for direct contact with the customer. SMUD's website is continually updated to support the increased PEV manufacturing for the 2012 model year. SMUD has also provided brochures to the local auto dealerships explaining the PEV market. SMUD has developed detailed training for the CSRs, Energy Specialists, and Contractors. SMUD has created an independent customer support process for preparing customer's homes for PEV charging and also created standards for how the electrical sub meters should be installed for the RTEV rate.

Multi-family Considerations

Property owners and managers of 30 apartment and condominium complexes were surveyed to get perspectives on different configurations for installation, ownership and maintenance of multi-family residence chargers. Different neighborhoods in Sacramento County were selected for the survey to provide a diverse sampling of demographics and multi-unit building characteristics. All the rent statistics included in this report are from the 2000 U.S Census.

The site survey looked at each location's existing capacity to install chargers and the opportunities to upgrade the existing infrastructure, including the following questions:

1. Is there a need for charging infrastructure among tenants?
2. Who will manage the decision, installation, and permitting process for each EVSE installation?
3. Who will own and maintain the equipment?
4. How will the installation be financed and the cost recovered?
5. Will the equipment be shared or assigned/dedicated?

The survey results are summarized in Table 6,

Table 7, and Figure 9.

Have any tenants asked about EV charging?	5%
If tenants pay for EV chargers, can they remove them if they move?	10%
Are there any tenants currently charging EVs?	0%
Do you plan to install EV chargers within the next two years?	3%

Table 6: Charging Infrastructure Interest Survey Results (Vargas, Durkin, Tang, Oto, & Aswani, 2013)

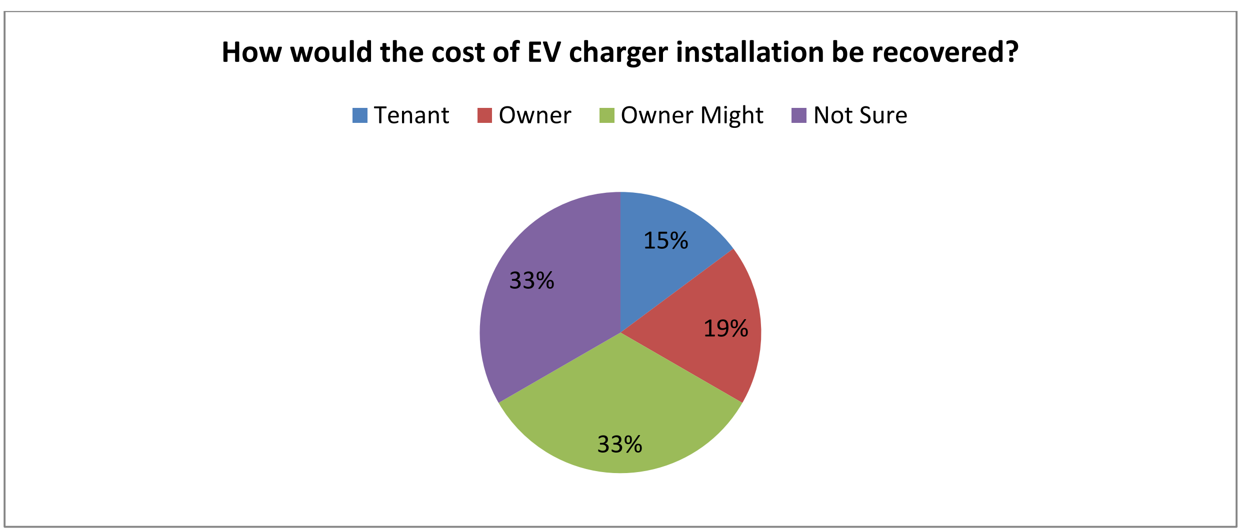


Figure 9 - Proposed Sources for MUD Infrastructure Capital (Vargas, Durkin, Tang, Oto, & Aswani, 2013)

	Average Overall	Folsom	Pocket	Watt/ Howe	Down-town & Midtown
Average number of units for rent	202	202	213	226	149
Average number of tenant parking spaces	226	226	219	232	131
Average number of visitor spaces	86	86	57	89	14
Average number of total parking spaces	311	312	272	321	145
Common electricity allocated to tenants?	13%	10%	28%	0%	14%
Tenants have assigned parking?	86%	80%	72%	100%	71%
Tenants have garages?	59%	80%	58%	20%	86%
CC&Rs exist that impact the installation of EV chargers?	14%	10%	42%	0%	0%

Table 7: Multi-family Dwelling Parameters in the Region (Vargas, Durkin, Tang, Oto, & Aswani, 2013)

Grid Infrastructure

Grid infrastructure may be impacted by the unique and sustained loading of PEVs, especially at the Level 2 rate of 3.3 – 19.2 kW. Power generation and transmission form the backbone of the electric utility infrastructure and are scaled to handle an expansion or reduction in both load and distribution infrastructure. However, the distribution side of the system is significantly impacted by the increased sustained loading of PEVs. At the residential end of the distribution infrastructure, capacity is sized on a per home basis. The residential transformer and associated secondary side and service conductor is usually the bottleneck for residential distribution, as the primary side conductor is often sized for quite high capacity. Sometimes the secondary side conductor and / or the service line between the transformer and the house meter, requires being upgraded to a higher rated conductor depending on the age of the home and secondary side distribution system. Figure 10 -10 is an example of typical capacity ratings for a single residential transformer.

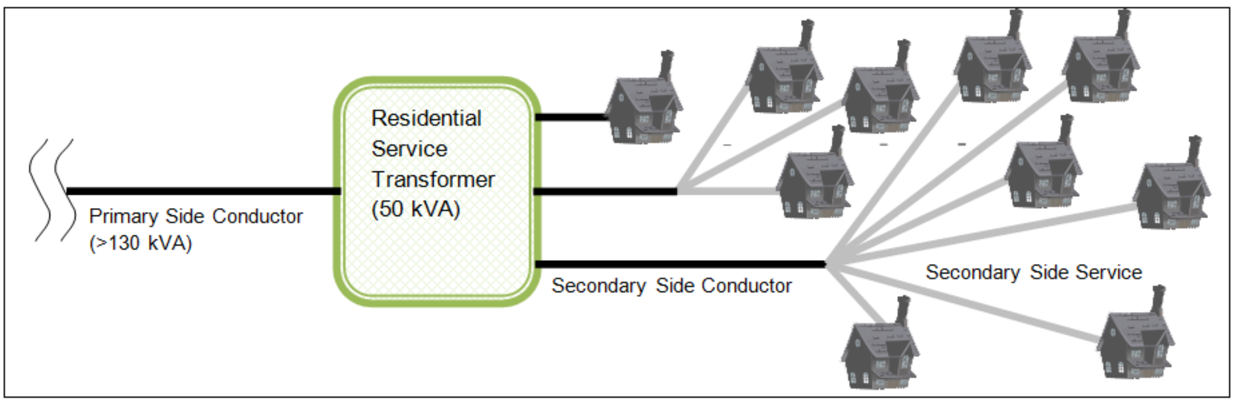


Figure 10 - Typical Residential Service Transformer Network (Berkheimer, Tang, Boyce, & Aswani, 2013)

A residential distribution infrastructure model of SMUD's service region was developed and used to project the impact of PEV market growth in terms of system upgrade costs. Figure1 shows that the charge start time has a significant effect on the cost of infrastructure upgrade costs. Beginning to charge a PEV at 8 PM has almost twice the marginal infrastructure cost as beginning to charge after midnight.

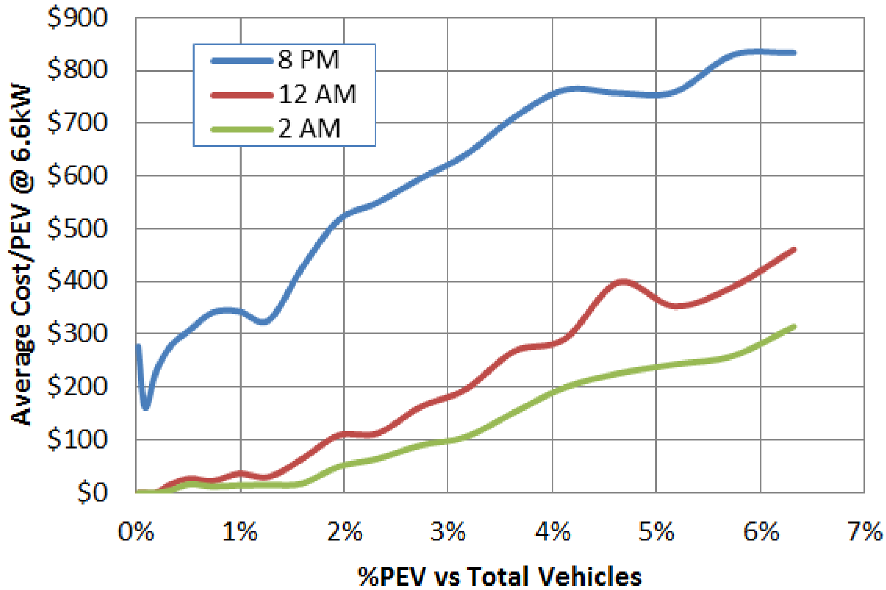


Figure 11 - Infrastructure Cost Impact of Charge Start Time (Berkheimer, Tang, Boyce, & Aswani, 2013)

Also the rate of charge has a significant impact on the marginal cost of infrastructure upgrade per vehicle. Figure 2 shows that charging at 19.2 kW can cost about $1900 in incremental distribution infrastructure upgrades versus about $200 at 3.3 kW charging rate.

In the cost modeling effort, simultaneous geographic, temporal, and charging rate diversity were considered for a nominal flat rate case (replicating Tennessee load profile), 12 AM off-peak incentive (PG&E San Francisco load profile), and a smart charging optimized charging start time. Figure 3 shows that order of magnitude of cost per vehicle for a diversified case is at a magnitude close to $150.

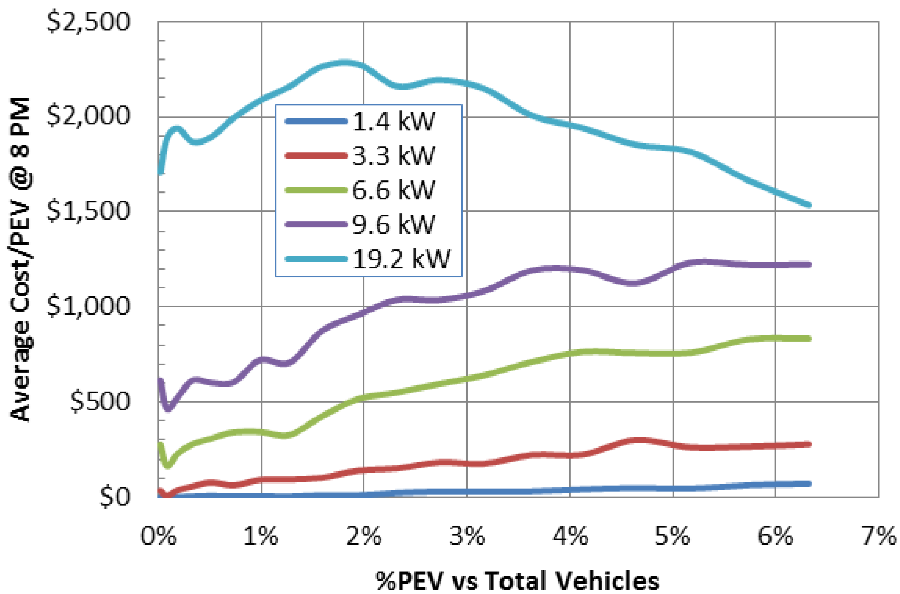


Figure 12 - Infrastructure Cost Impact of Charge Rate (Berkheimer, Tang, Boyce, & Aswani, 2013)

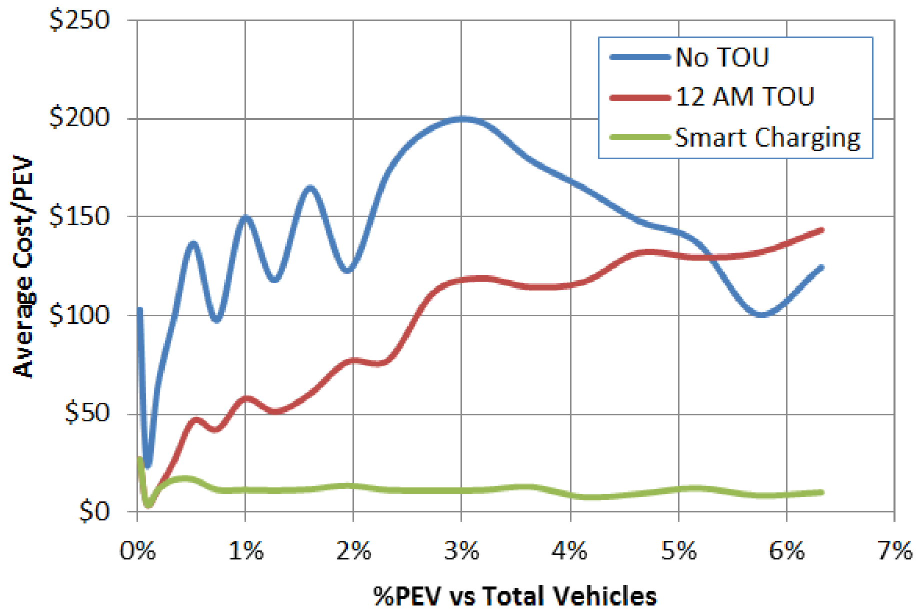


Figure 13 - Infrastructure Cost for Diversified Time and Rates (Berkheimer, Tang, Boyce, & Aswani, 2013)

Regional Readiness

Local Coordinating Council

In order to promote regional readiness efforts, SMUD helped form the Capital Area Plug-in Electric Vehicle Coordinating Council (CAPEVCC), recently rebranded as TakeChargeSAC. The council has been meeting on a bi-monthly basis since September 2011. To form the council, SMUD had several meetings with the other founding members: SACOG, Sacramento Clean Cities, Sacramento Metropolitan Air Quality Management District, and a nonprofit Valley Vision. SMUD also facilitated infrastructure coordination by building awareness between local jurisdictions interested in participating in grant-supported publicly accessible EVSE charging stations and grant recipients such as ClipperCreek and Coulomb Technologies.

Permitting and Ordinances

SACOG provided regional stakeholders with draft planning guidelines on best practices and models for planning, building codes, and permitting processes. This was accomplished by disseminating PEV Planning Guidelines to all Regional Stakeholders in electronic and paper copies. SACOG also conducted workshops to promote discussion for final best practice guidelines for consideration of adoption by local jurisdictions.

SACOG also provided staff from local government agencies within the SACOG service area with detailed information on draft Regional Planning Guidelines and background on best practices in PEV planning, building construction codes, permitting processes, and public infrastructure planning. This included one-on-one meetings which had been identified as one of the key best practices by the successful readiness teams to date.

Infrastructure Planning

With the help of U.C. Davis, SACOG studied the most favorable types of public charging locations in our region. U.C. Davis Institute of Transportation Studies was identified as a strategic partner given its role in PEV market research and participation in the California PEV Collaborative. Specific sites evaluated for public EVSE infrastructure included Interstate 80, Interstate 5, Highway 99 and Highway 50 corridors in Sacramento County. SACOG developed region-specific guidelines for PEV infrastructure deployment for multi-unit dwellings, workplaces and fleets including surveys, education and outreach. Figure 4 highlights some of the recommended charging infrastructure clusters for Sacramento County. SACOG also conducted workshops in Sacramento county for building and property owners to educate them on PEV infrastructure and highlight aspects of the plan that could be implemented in the county, as a special session at the 2013 SARTA CleanStart showcase.

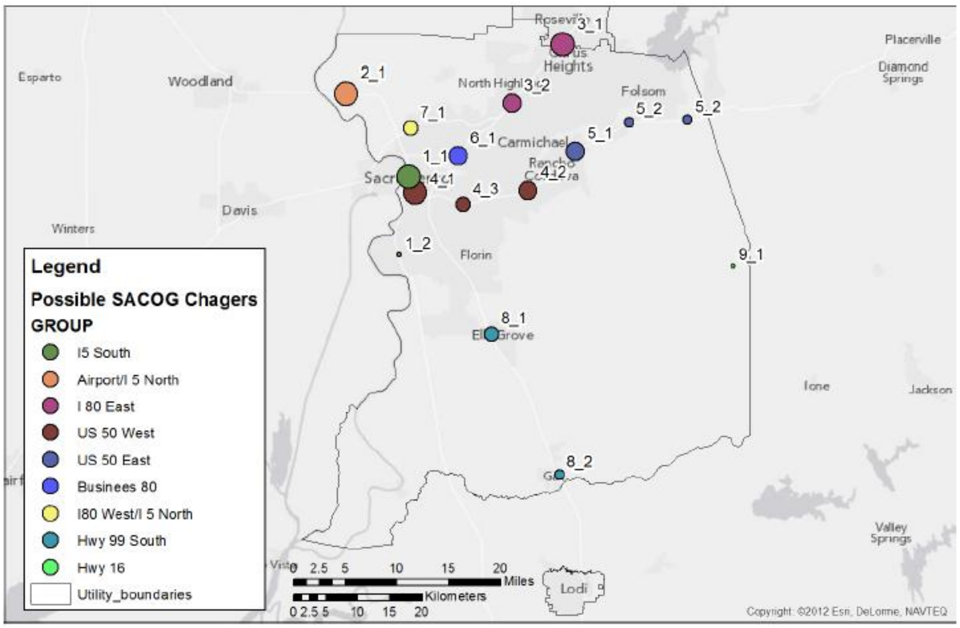


Figure 14 - Recommended Charging Infrastructure Clusters (SACOG, 2014)

Readiness Plan

SACOG drafted a Regional Readiness Plan, as a public document and resource. The intention of this document was to provide a public view of regional coordination activities conducted, resources available, and challenges faced by the region. This readiness plan was also presented by SACOG to the SMUD Board of Directors and to local elected officials.

Future Technologies

With the focus on V2G services through unidirectional power flow, two cases were evaluated. The first case was coordinated unidirectional power flow, which in aggregated form is analogous to Automated Demand Response (AutoDR or ADR). Gaps between power supply and demand can be accommodated by regulating the charging load up or down from some intermediate level.

In spring of 2013, SMUD and OnStar demonstrated this capability with the Chevrolet Volt on a single vehicle. Figure 15 depicts the control mechanism for this ADR demonstration. A web demonstration interface or utility server communicates through the cloud with the OnStar back office server, which then uses the OnStar cellular network to communicate with individual vehicles. The server to server communication implemented by OnStar is a Simple Object Access Protocol (SOAP) based Web Service Definition Language (WSDL).

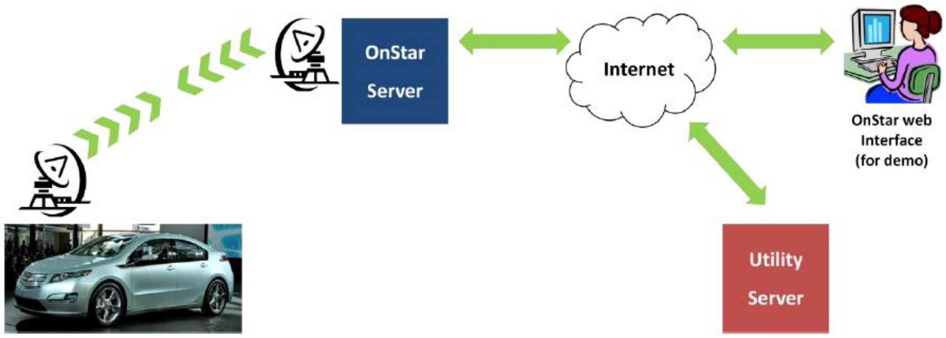


Figure 15 - OnStar Demand Response Network Communication Diagram (Aswani, 2013)

Figure 26 shows the results from a Demand Response demonstration test with a Chevrolet Volt. This plot also compares the smart meter measurements with the calculated cumulative energy resulting from the command, reset at the meter sampling interval. The smart meter measurements are close to what is expected based on the command, demonstrating successful Demand Response according to the command.

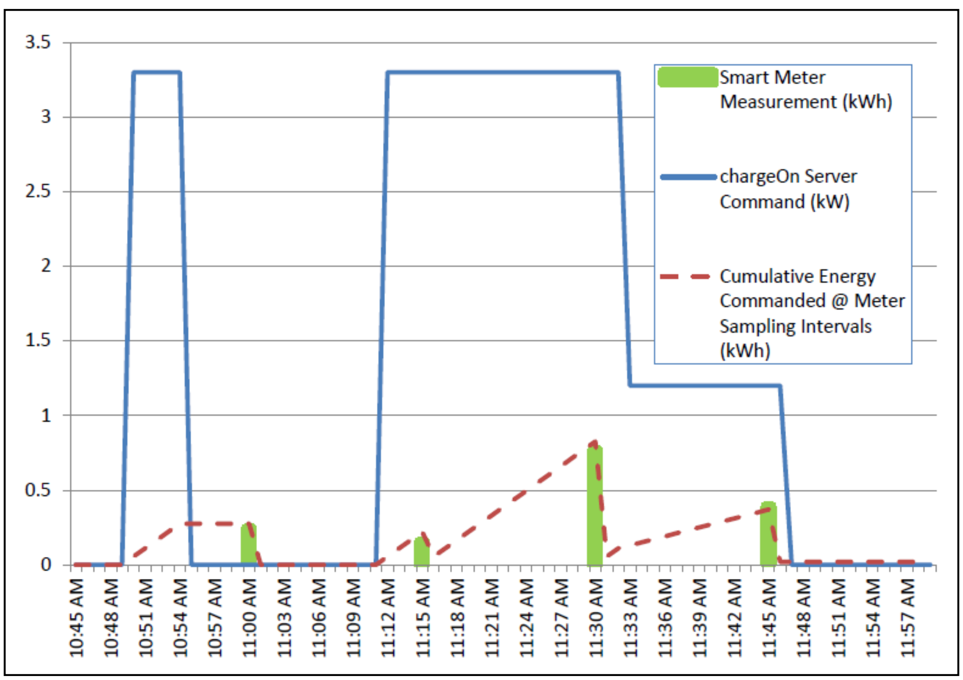


Figure 2Data Recorded from OnStar Demand Response Demonstration Test (Aswani, 2013)

In fall of 2013, SMUD demonstrated a prototype EVSE by Aerovironment that provides (autonomous) primary frequency control V2G services. This type of V2G service works toward meeting WECC requirements for spinning reserve capacity, as required according to generation dispatch and load. This service benefits short term immediate power supply and demand gaps on an overall synchronous grid. This is different from the regulation services (regulation up or regulation down) that are necessary to fill gaps in power supply and demand within a balancing area. However, autonomous frequency control is a simpler alternative to aggregated ADR which requires network connectivity with each vehicle. Figure 37 shows how the charging rate varies with grid frequency.

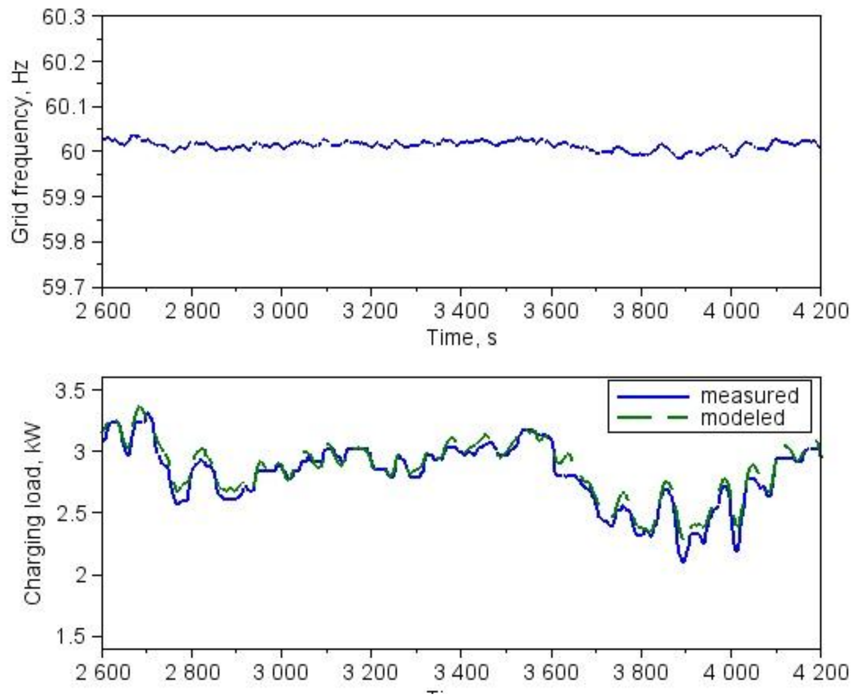


Figure 37 - Frequency Responsive EVSE Recorded Data (Aswani & Boyce, 2014)

For the overall market, the increased supply of spinning reserves leads to an overall avoided cost benefit for ratepayers due to reduced cost to procure spinning reserves as shown in Figure 48.

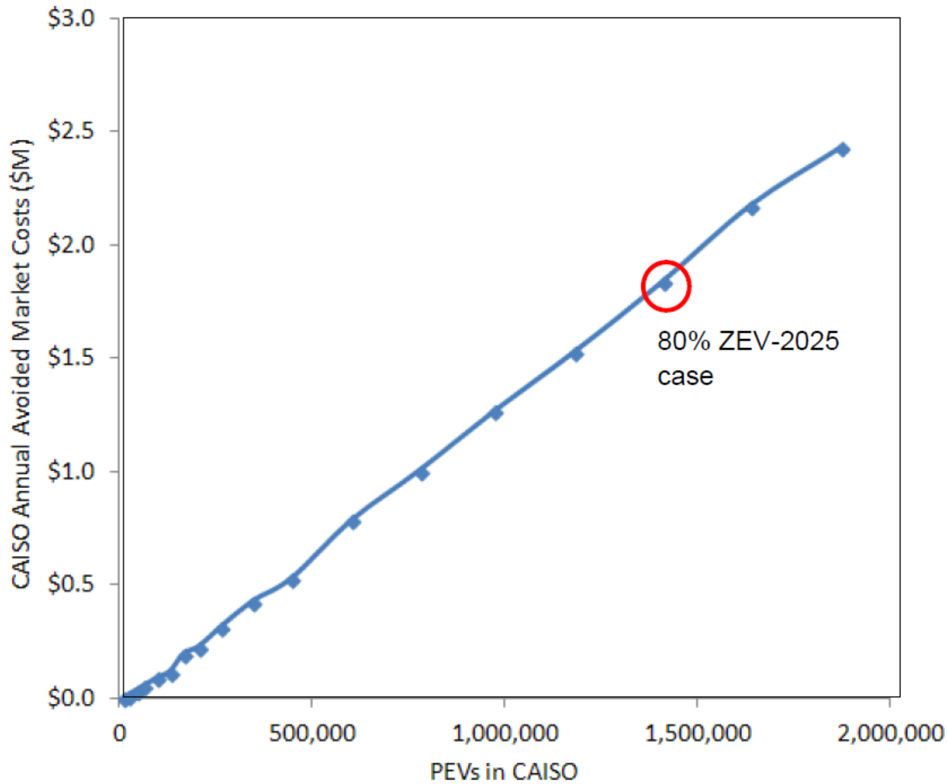


Figure 4CAISO Market Avoided Cost Benefit of Spinning Reserves Procured from PEV at No Cost (Aswani & Boyce, 2014)

Advancements and Conclusion

Vehicle Demonstration

This study helped identify PEV awareness as an area of need to benefit PEV adoption. Understanding PEVs from a consumer perspective and a commercial perspective (fleet) is essential to recognize the value and benefits these new vehicles provide. Fleet experiences can shape residential vehicle purchase decisions, as seen in this project. The majority of drivers had a positive experience which led to positive purchase recommendations and 3 recorded personal purchases. Some drivers had a negative experience, of which some drivers discouraged others from purchasing PEVs. Electrified fleets should be accompanied with awareness activities such as lunch and learn events, ride and drive events, and providing workplace charging for employee personal vehicles.

Infrastructure

Through the 29 Level 2 EVSE installations across fourteen sites, SMUD gained valuable experience in the installation of fleet-oriented charging infrastructure. All Level 2 EVSE installations were intended to support Chevrolet Volts that were registered with this DOE sponsored grant where remote data collection was enabled via OnStar. The average cost per fleet EVSE installation was higher than expected and estimated to be $11,800. Some recommendations to manage installation cost are:

- Ensure that contractors have the appropriate experience.
- Sharing installation cost with site stakeholders to help set cost controls and accountability.
- Use engineer support only when necessary.
- Avoid installation at sites that require trenching or significant equipment upgrades such as transformer additions. If unavoidable, budget additional time and money for uncertainty.
- Select a parking layout where a single EVSE can serve multiple spots so a conventional vehicle occupying one spot does not eliminate access to the EVSE.

In addition to gaining installation experience, SMUD gained experience in the operation and maintenance for fleet-oriented charging applications. Some recommendations to improve the operation and maintenance of fleet-oriented EVSE are:

- Select EVSE quantity and type (Level 1, Level 2, or a mix) with sharing in mind to maximize utilization and minimize capital costs.
- Have policies and etiquette that supports EVSE sharing (disable any charger disconnect alarms)

Incorporate some form of cord management to avoid tripping hazards and cord disorder.

Utility Readiness

SMUD has implemented special rates to encourage PEV adoption and has customer service representatives trained to support PEV customers, in relation to questions about vehicles, charging infrastructure, and special PEV rates offered by SMUD. Although this program support has been received positively by customers, it needs to be continually updated and adjusted as technology evolves and the market needs changes due to maturity.

The challenges to PEV growth for multi-unit dwellings are complex. This seems to be one of the gaps in the electrified transportation industry. In order to address these unique needs, a series of pilot evaluations may help establish several models to provide a mechanism for infrastructure accessibility for multi-unit dwelling residents that may be interested in purchasing PEVs.

SMUD has estimated the order of magnitude of grid integration costs per PEV to be $100-200 per vehicle on average. Better understanding the marginal costs of PEVs can help better define the next generation of PEV energy products for customers. These products could be a combination of programs or rates specialized for customers.

Regional Readiness

The progress of regional readiness activities for the Sacramento area was apparent in SACOG's regional readiness presentation to local elected officials in March 2014. The infrastructure planning efforts supported through this project directly benefited the AB32-funded fast charger location planning by SMUD. Furthermore, many local elected officials and building officials seem to be well versed on the challenges facing electric vehicles such as infrastructure needs, workplace charging, and multi-dwelling unit support. The interest from SACOG and local jurisdictions is helping continue the momentum and activity of TakeChargeSAC. Supplementary funding is currently being sought to further charging infrastructure development projects as well as continue the regional coordination and harmonization efforts.

Future Technologies

The successful demonstration tests provide encouragement for V2G technology. It should be noted that primary frequency control is not a competing service to secondary frequency control. They are complementary functions. In fact, primary frequency control by EVSE can serve as a stepping stone to secondary frequency control by EVSE, if the latter reaches technology maturity for a sustainable business model. With both primary and secondary frequency control, PEV V2G services would more closely represent traditional frequency regulating generation resources.
Several questions remain in two main categories before V2G services may be adopted in a large scale implementation:

a) Technology Maturity
In the case of the OnStar demonstration, considerable software customization was required in the vehicle as well as manual over-ride of services. This suggests that the Smart Charging services are not production-ready with the 2011 MY Chevrolet Volt and further product development may be required. Another requirement for scalability is demonstration of how to aggregate many vehicles under the constraints of utility load requirements and customer expectations for energy delivered by the time of morning departure. Also testing with the Aerovironment prototype EVSE was not exhaustive, and thereby may not have considered all test conditions for a mainstream product.

b) Market Feasibility
The market feasibility for a V2G service requires consideration. Two elements of market feasibility are customer acceptance of V2G services such as demand response and whether the value added can be split in a way that all parties can recover the initial cost of implementation and ongoing services. Also V2G services need to be proven and accepted by RTOs, ISOs, and balancing authorities in order to be recognized as legitimate services.

SMUD Source Reports

This report summarizes the following task oriented reports prepared with support from awards CEC ARV-10-034 and US DOE DE-EE-0002628.

Aswani, D. (2013). *OnStar Smart Charging Demonstration.* Sacramento: Sacramento Municipal Utilty District.

Aswani, D., & Boyce, B. (2014). *Autonomous Grid Services through Plug-in Electric Vehicle Charging.* Sacramento: Sacramento Municipal Utility District.

Aswani, D., & Hatfield, D. (2014). *Electric Vehicle Supply Equipment Infrastructure.* Sacramento: Sacramento Municipal Utility District.

Berkheimer, J., Tang, J., Boyce, B., & Aswani, D. (2013). *Electric Grid Integration Costs for Plug-In Electric Vehicles.* Sacramento: Sacramento Municipal Utility District.

Davies, J., & Nesbitt, K. A. (2014). *Results and lessons learned from a Plug-in Electric Vehicle (PEV) demonstration project.* Davis: University of California Davis.

Gehringer, D., & Vargas, T. (2011). *Plug-in Electric Vehicle Market Readiness.* Sacramento: Sacramento Municipal Utility District.

SACOG. (2014). *Sacramento Area Regional Coordination for EV Readiness.* Sacramento: Sacramento Area Council of Governments.

Vargas, T., Durkin, M., Tang, J., Oto, S., & Aswani, D. (2013). *EVSE Considerations for Multi-Family Dwellings in Sacramento California.* Sacramento: Sacramento Municipal Utility District.

Idaho National Laboratory (INL) – Data Analysis and Reporting of 150 Chevrolet Volt ARRA Demonstration Fleet

Idaho National Laboratory (INL) received data from OnStar for 150 Chevrolet Volts that was collected from May 2011 through March 2014 as part of the ARRA Vehicle Demonstration. INL analyzed the data and published quarterly reports to http://avt.inel.gov/gmvehicledemo.shtml detailing the vehicle operational characteristics, fuel economy, electrical energy consumption, driving and charging utilization, driving style efficiency, and ambient temperature profiles.

From March 2011 through March 2014, the fleet of 150 Chevrolet Volts accumulated a total distance of 3.84 million miles over a total of 66,572 days of driving. Over the entire data collection period, the fleet average fuel economy is 67.5 mpg and overall AC electrical energy consumption is 167 AC Wh/mi. The Chevrolet Volt has two modes of operation, Electric Vehicle mode (EV) and Extended Range Mode (ERM). Over the entire data collection period the AC electrical energy consumption when operating in EV mode is 358 AC Wh/mi, and the fuel economy when operating in ERM mode is 36.1 mpg. These fleet summary metrics are shown in graphical form in Figure 19.

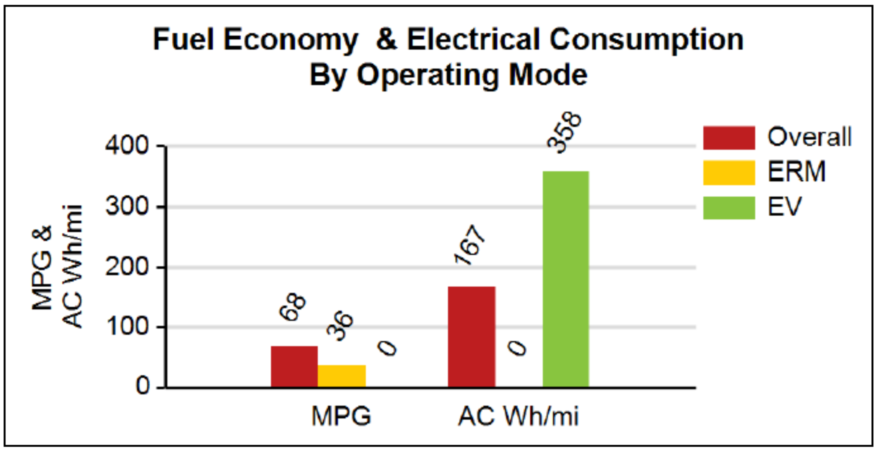


Figure 19 – Overall fleet fuel economy and electrical energy consumption over the duration of the study

In order to better understand how the fleet of vehicles were operated given the two operating modes (EV and ERM modes), a histogram was created to help visualize the distribution of distance traveled in each operating mode for a given total trip distance. Figure 20 shows the percent of total distance traveled for both EV and ERM modes of operation across various bins of trip distance for the entire fleet of 150 Chevrolet Volts over the data collection period. The majority of miles driven in EV mode are primarily in trip distances of less than 50 miles with the largest percentage of total distance traveled during trips of 10 to 20 miles in length. Miles driven in ERM mode are more even distributed across all trip distances. The largest percentage of total distance traveled in ERM mode occurred for trip distances greater than or equal to 100 miles.

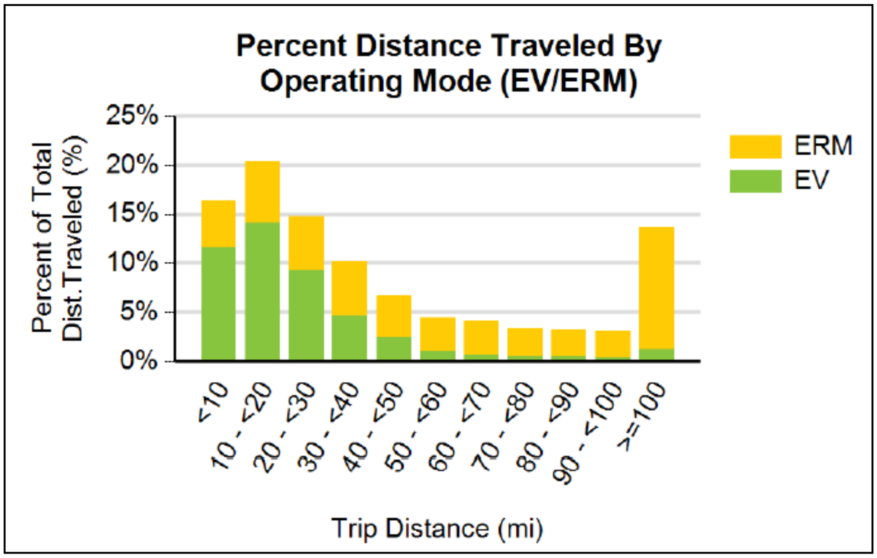


Figure 20 – Percent distance traveled in each operating mode over the duration of the study

During the real world, on-road operation of the 150 Chevrolet Volts, the vehicles were utilized for a wide variety of purposes across a wide range of driving routes. These routes were characterized into two categories, city routes and highway routes, in order to better understand and visualize the vehicle utilization. Predominately the city driving routes are lower average vehicle speed with multiple stops per mile whereas the highway driving routes have a higher average speed with minimal stops per mile. Figure 21 shows the percent of total distance traveled for both city driving routes and highway driving routes for the entire fleet of 150 Chevrolet Volts for the entire data collection period. The majority of city route trip distances are less than 30 miles. In contrast, the highway trips are more evenly distributed across trip distances of greater than 20 miles except for trip distances greater than 100 miles which is significantly the largest percentage of total distance traveled for highway driving routes.

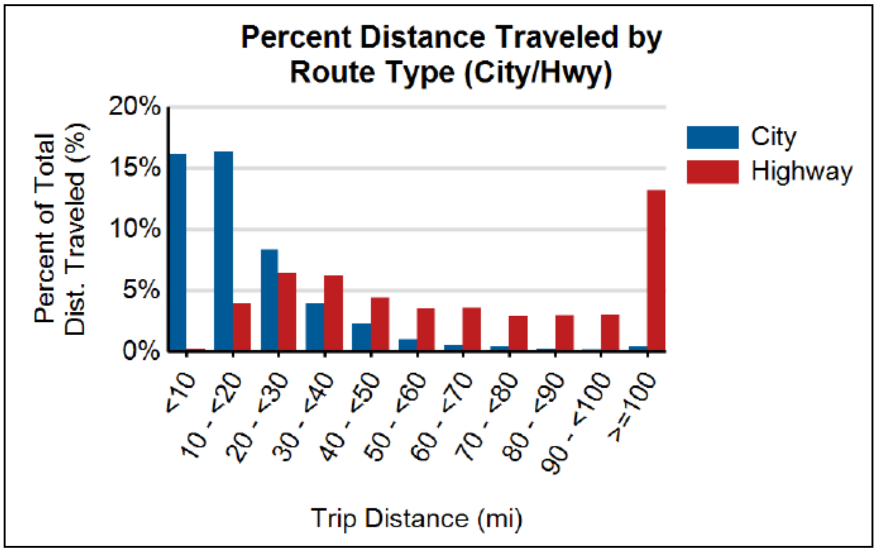


Figure 21 – Percent distance traveled for city or highway route type over the duration of the study

During driving, the Chevrolet Volt calculates a driving style efficiency based on many parameters such as acceleration, vehicle speed, accessory utilization, and many more factors. This driving style efficiency impacts the electrical energy consumption and fuel economy of the vehicle. The higher the driving style efficiency, the better the fuel economy and electrical energy consumption. In order to understand and characterize the fleets driving style efficiency in both the EV mode and ERM mode a histogram was created. Figure 22 shows the percent of total distance traveled versus driving style efficiency for both the EV mode and ERM mode for the entire fleet of 150 Chevrolet Volts for the entire data collection period. The average driving style efficiency for the EV and ERM modes are 78% and 77% respectively. The distribution for the EV mode operation has a slightly wider spread than for the ERM. Also the Mode (most frequent occurrence) for the EV mode operation occurs between 90% and 100% driving style efficiency whereas the Mode for the ERM mode operation occurs between 80% and 90% driving style efficiency.

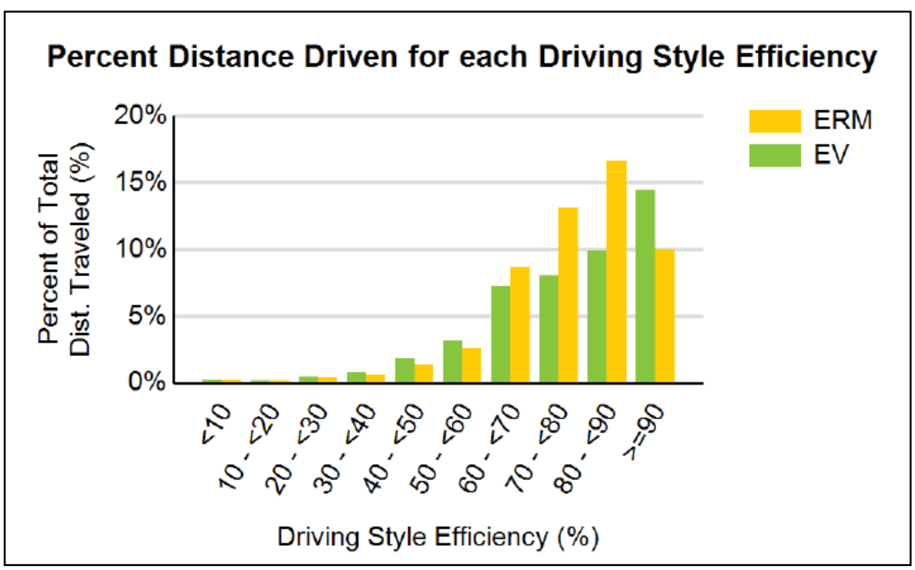


Figure 22 – Percent distance traveled for each driving style efficiency over the duration of the study

For grid connected vehicles, it is important to understand the driving patterns as well as the charging patterns. For the fleet of 150 Chevrolet Volts, the time of day when driving and charging was analyzed and shown in Figure 23 and Figure 24 respectively. Driving primarily occurred during the daytime with a moderate increase between 6:00 AM and 8:00 AM local time as well as 3:00 PM and 5:00 PM local time. The time of day when charging appears to correlate well to charging after the completion of driving. This can be seen by the increase in charge energy between 7:00 AM and 9:00 AM local time as well as 6:00 PM and 7:00 PM local time.

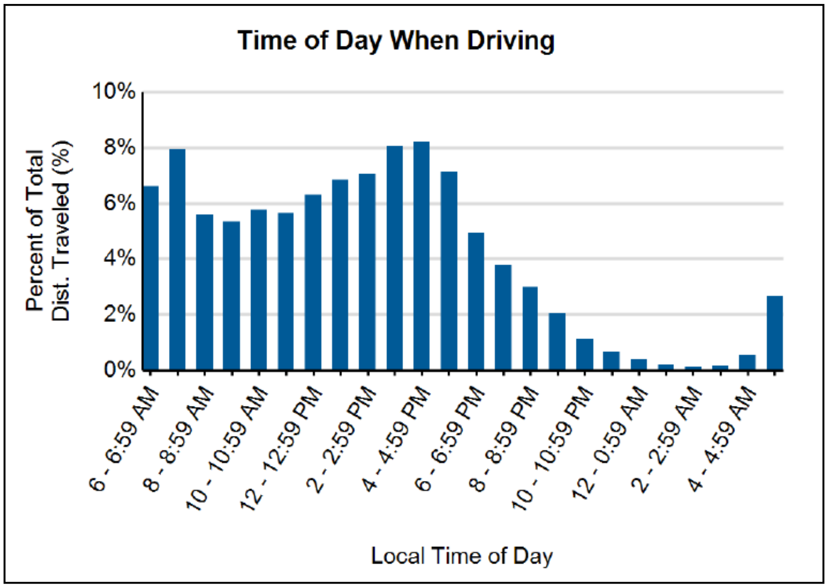


Figure 23 – Percent distance traveled versus time of day when driving over the duration of the study

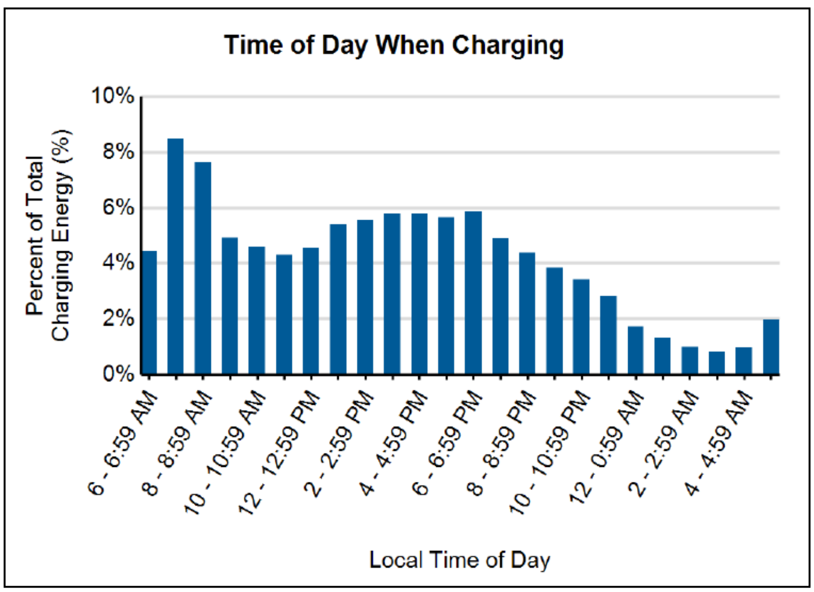


Figure 24 – Percent of electrical energy delivered versus time of day when charging over the duration of the study

From the previously analyzed fleet operational characteristics of driving and charging as well as the EV and ERM mode utilization, additional analysis was conducted on the battery pack state of charge (SOC) with respect to the end of driving prior to plugging in as well as unplugging prior to driving. Figure 25 shows the SOC of the battery pack at the end of driving prior to plugging in. Nearly half of these drive events end with the battery SOC at less than 10% which indicates there is little to no energy remaining on the battery pack. Figure 26 shows the SOC of the battery pack at the end of charging prior to driving. Over 80% of these charge events end with a full battery pack (≥ 90% SOC) which indicates the vehicle will have the opportunity to maximize the EV driving miles since the energy stored in the battery pack is maximized.

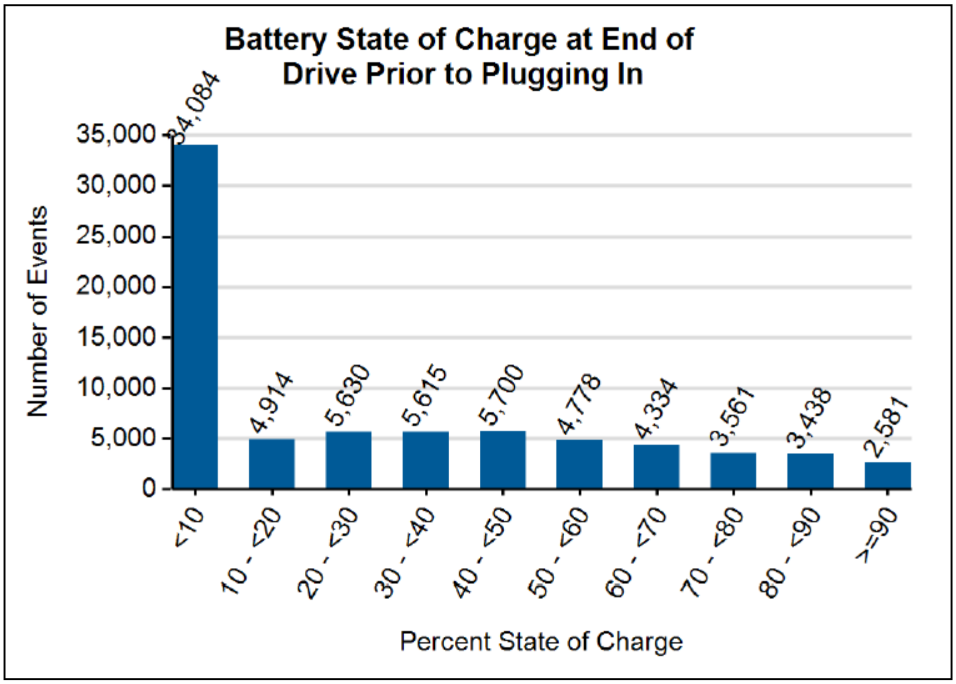


Figure 25 – Distribution of battery state of charge at the end of driving prior to plugging in over the duration of the study

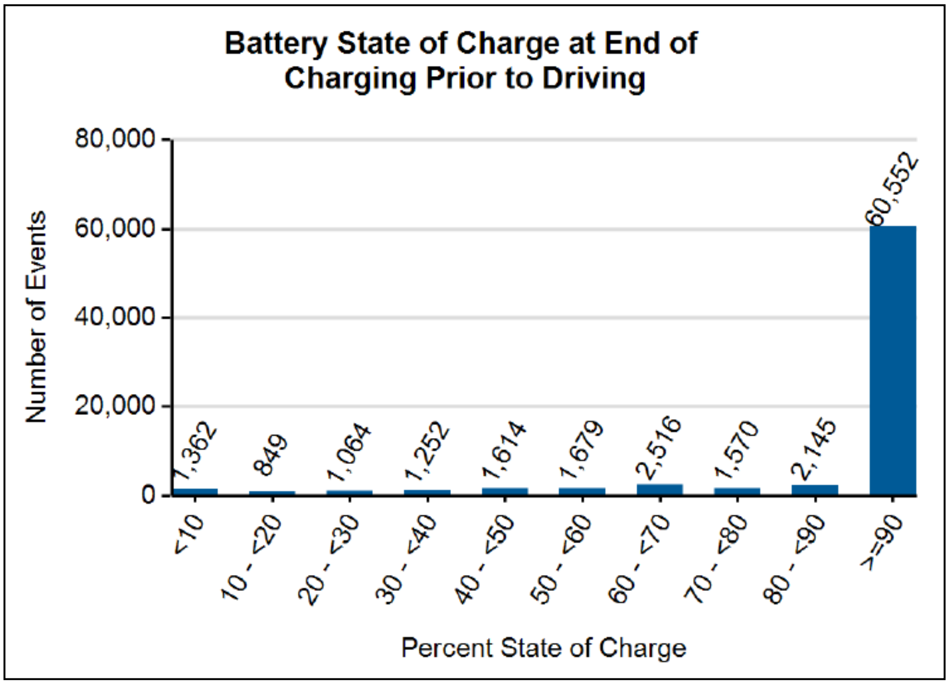


Figure 26 – Distribution of battery state of charge at the end of charging prior to driving over the duration of the study

Throughout the data collection period, additional analysis was conducted to determine other metrics such as percent of total driving distance in EV mode and ERM mode as well as fleet average driving distance between charge events. Figure 27 shows the correlation between fleet average driving distance between charge events and percent of total distance traveled in EV mode over the duration of the data collection period. Near the beginning of the data collection period for the 150 Chevrolet Volts, the fleet average driving distance between charge events was less than 40 miles and the percent of total distance traveled in EV mode was greater than 50%. As the demonstration progressed, the driving and charging utilization of the vehicle changed slightly. By the end of the data collection period, the fleet average driving distance between charge events was greater than 50 miles and the percent of total distance traveled in EV mode was less than 40%. This shows a correlation between the percent of total distance traveled in EV mode and the driving distance between charge events. Decreasing the fleet average driving distance between charge events can increase the percent of total distance traveled in EV mode which inherently improves the fleet petroleum displacement by driving more electric miles.

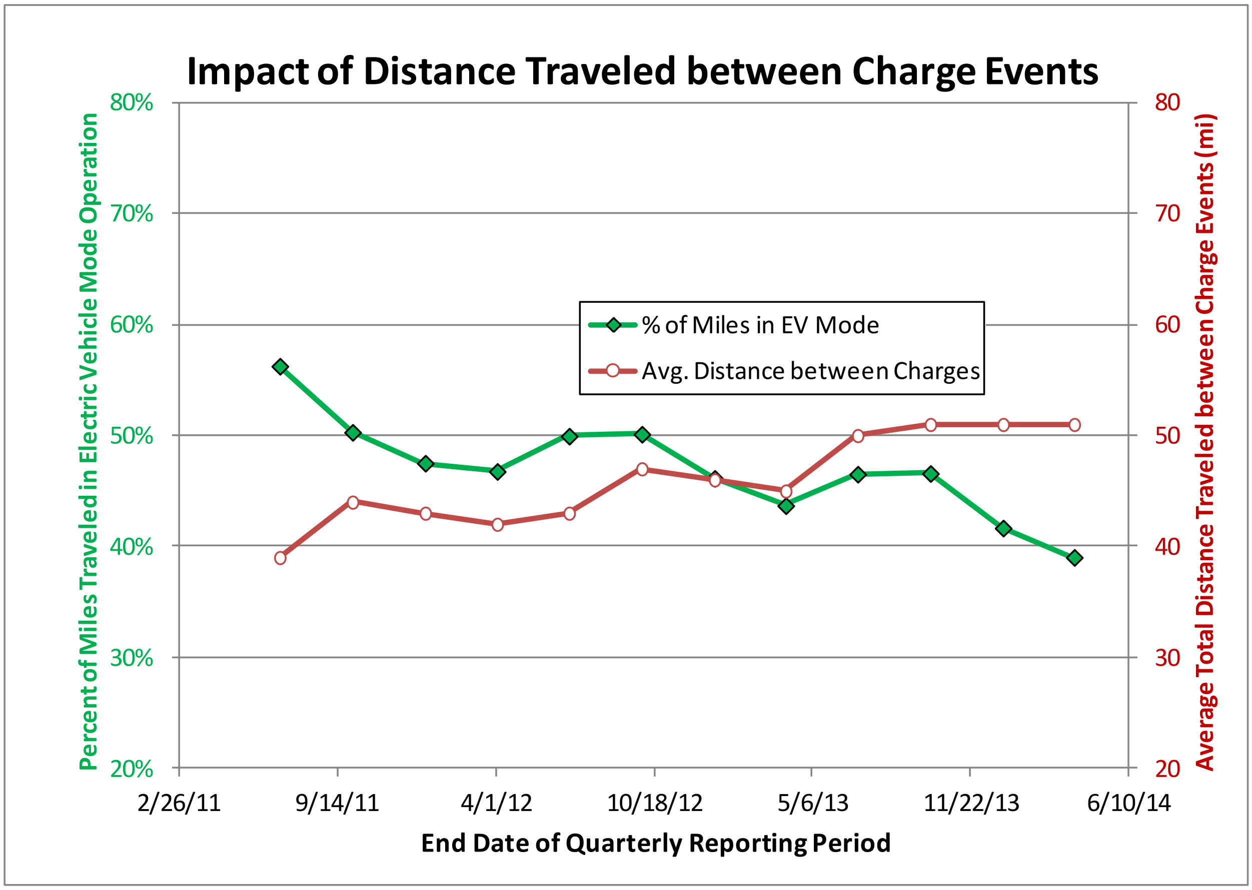


Figure 27 – Impact of average distance driven between charge events on percent of total miles driven in electric vehicle mode

The data collection period for the fleet of 150 Chevrolet Volts nearly covers two calendar years. This enables analysis of seasonal ambient temperature variation impact on vehicle fuel economy and electrical energy consumption. Figure 28 shows the quarterly averaged ambient temperature impact, as averaged on a per vehicle basis, on electrical energy consumption (AC Wh/mi) when driving in EV mode and fuel economy (mpg) when driving in ERM mode. At colder temperatures, fleet averages ambient temperatures (less than 60 degrees F) there is a measurable trend that shows an increase in electrical energy consumption while driving in EV mode as well as a decrease in fuel economy when driving in ERM mode. For moderate temperatures, between 60 and 80 degrees F, there appears to be little to no impact of ambient temperature change on fuel economy or electrical energy consumption.

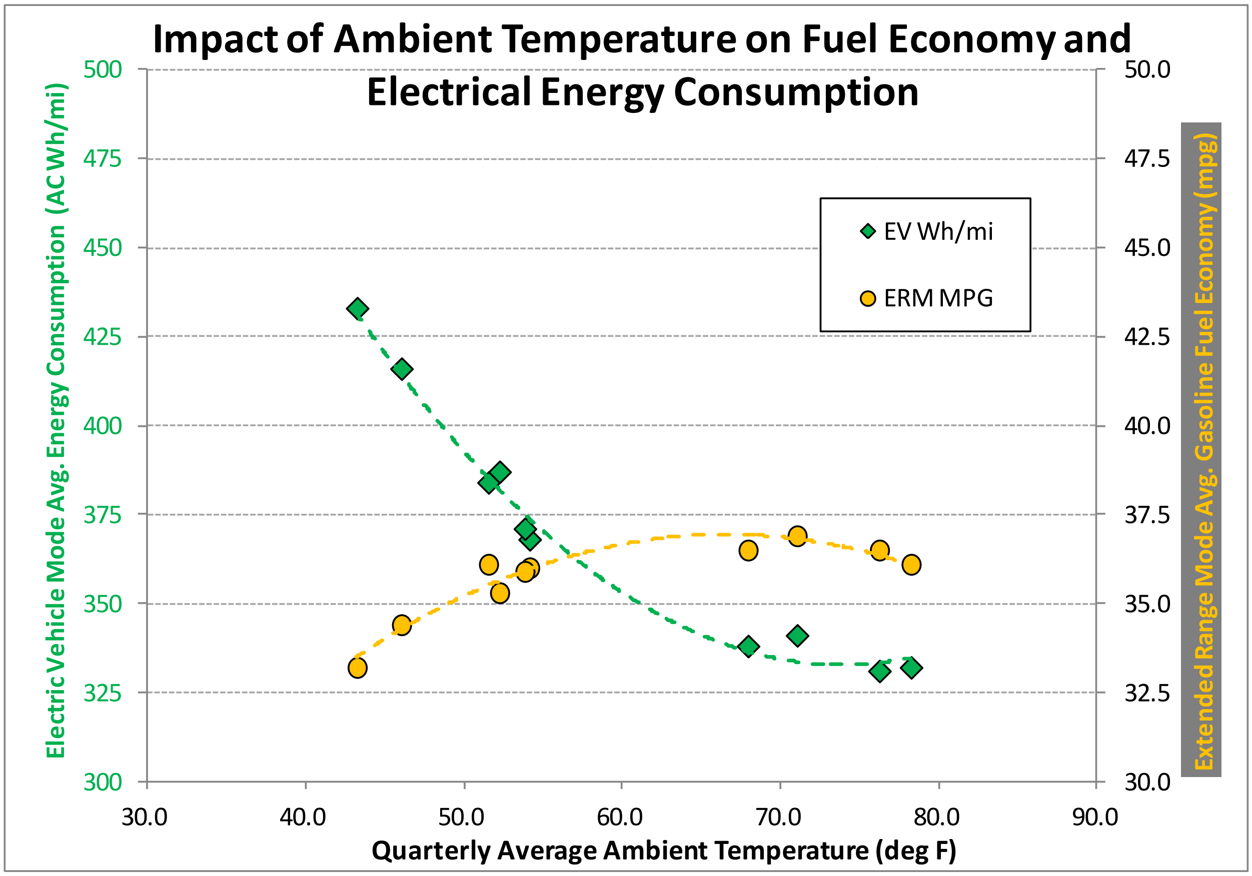


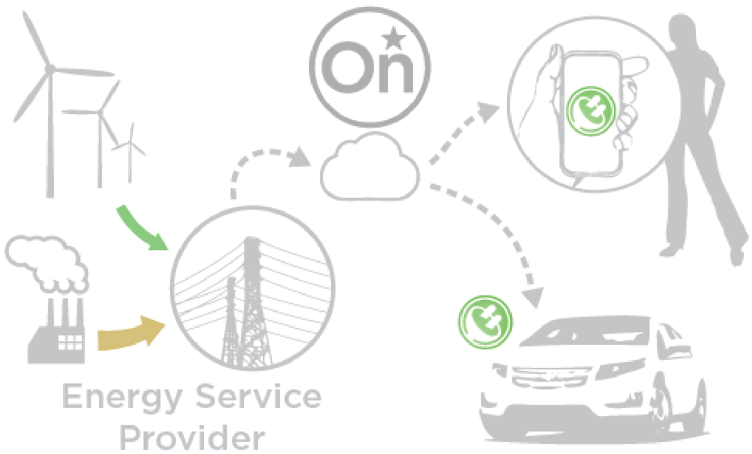
Figure 28 – Impact of quarterly average ambient temperature on fuel economy in extended range mode and electrical energy consumption in electric vehicle mode

Idaho National Laboratory (INL) analyzed data from 150 Chevrolet Volts that was collected from May 2011 through March 2014 as part of the ARRA Vehicle Demonstration. Quarterly reports were published to http://avt.inel.gov/gmvehicledemo.shtml detailing the vehicle operational characteristics, fuel economy, electrical energy consumption, driving and charging utilization, driving style efficiency, and ambient temperature profiles. Over the period of data collection, the fleet of 150 Chevrolet Volts accumulated a total distance of 3.84 million miles over a total of 66,572 days of driving. Over the entire data collection period, the fleet average fuel economy is 67.5 mpg and overall AC electrical energy consumption is 167 AC Wh/mi. Additional metrics were analyzed to characterize and visualize their impact on fuel economy and electrical energy consumption. These additional metrics include ambient temperature, driving style efficiency, EV and ERM mode operation, battery pack state of charge utilization, route type, and distance driven between charge events.

Other Development and Demonstration Activities

Plans include projects that advance interoperability of the vehicle with the electric grid through advanced technology development. These projects include:

Smart Charging OnStar



Smart Grid Stimulus Initiative was an engineering initiative (part of OnStar – Advanced Systems Development (ASD) group) partially funded by U.S. Department of Energy (DOE) to characterize customer usage of electric vehicles. A smarter grid is defined as one where utilities are able to control power devices at customer's locations and end customers are able to make intelligent choices on their power usage based on time and other usage rates. The smart grid team developed services and products that contributed to identifying opportunities that could move the smart grid forward in innovative concepts that can assist in moving the concept of the smart grid further and deeper into its capabilities.

The Smart Grid provides those services based on remote monitoring and control of EV charging through our telematics environment and architecture. The OnStar architecture enables the collection of electric vehicle and smart grid based data including energy consumption, fuel consumption and carbon emissions to name a few of the data points. As the data is collected it is uploaded to a centralized database and stored for future analysis. This process facilitated the data collection and integration of the Volt vehicle into the smart grid through demonstration via telematics.

This format allows the smart grid team to establish processes and procedures that support the vision of the partnership with the DOE:

- Intellectual and Technology Leadership
- Environmental Leadership
- Powerfully simple customer services
- Innovative alternative business model(s)

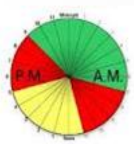
Building Blocks

Since the inception of the program it has been the vision of the smart grid team to create services that could support demonstrations, pilots and projects that confirm the viability of the electric vehicle and highlight the ecological benefits that it provides. We built an initial structure based on the following core services:

Demand Response

Energy Service Providers make informed maintenance and operational choices to control and automate energy usage control

Time of Use



Utility administration can update and sync enrolled consumer TOU rates in the vehicle with changes that occur in the market based on supply and demand

Data/Information

Providing timely information that keeps the consumer aware of the status of their vehicle to faciltate appropriate Electric Vehicle Charge management

Aggregated Services

Generation of the ability to manage and address Grid Load Management from the perspective of the Energy Service Provider for an identified Region

As we developed these core services we identified additional opportunities that would drive our solutions to a deeper and more pragmatic level of conceptualizing the capabilities of the smart grid and the role of the electric vehicle in that environment. The complimentary services that the OnStar team built are as follows:

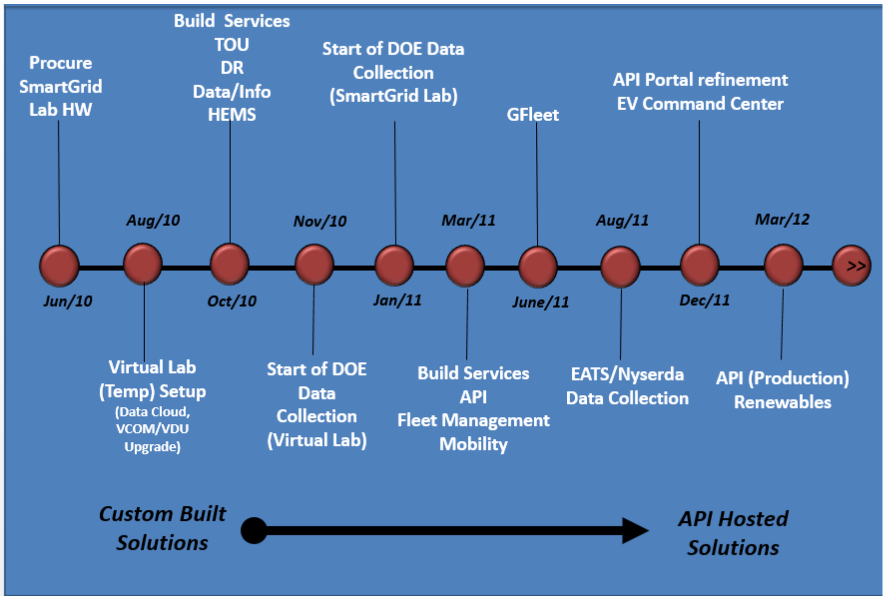
Our development efforts also uncovered the opportunity to partner with other smart grid participants and the team developed an API based environment so that we could have a medium to exchange data, services and innovative capability. The method relied heavily upon an API based structure.

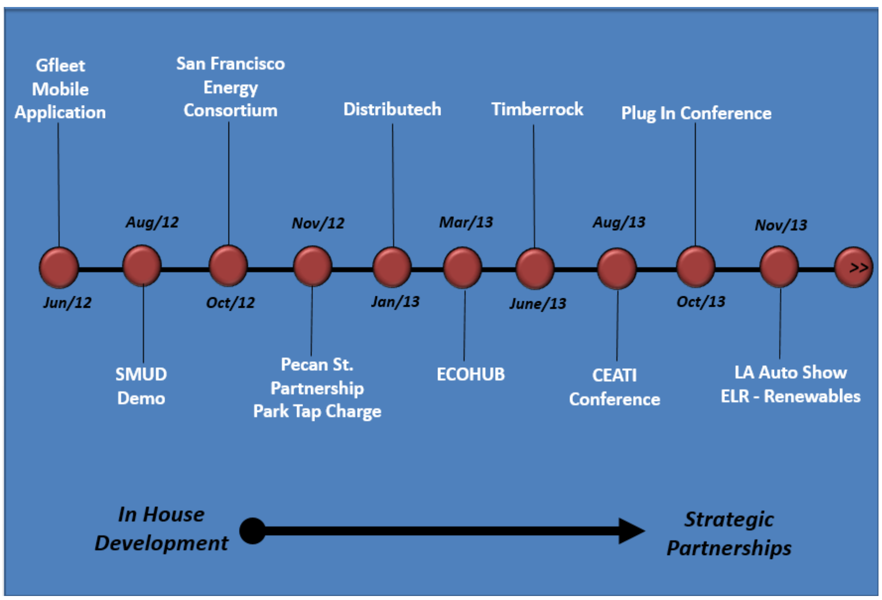
Smart Grid APIs, allow developers and application engineers to programmatically interact with the electric vehicle through the OnStar back office. These APIs integrate the electric vehicle to the grid system bi-directionally and enable an efficient and effective messaging process and procedure.
Using the listed API set, developers shall be able to develop applications targeted for different channels like web, mobile, head unit etc. The benefit of this approach is that the market could drive the development of applications faster and relevant that will service OnStar customers:

The development of our services combined with API capabilities allowed our team to extend strategic partnerships and facilitate pilots and conference demonstrations that enabled our smart grid team to highlight the capabilities of the electric vehicle within the smart grid environment.

Timeline

Over the life of the project the GM smart grid team has embraced every opportunity to promote the smart grid and highlight the role of the electric vehicle and how the vehicle can be leveraged to promote a more green society with significant ecological benefits. A high level view of the timeline for how we developed the solution and displayed its capabilities is depicted on the next page:



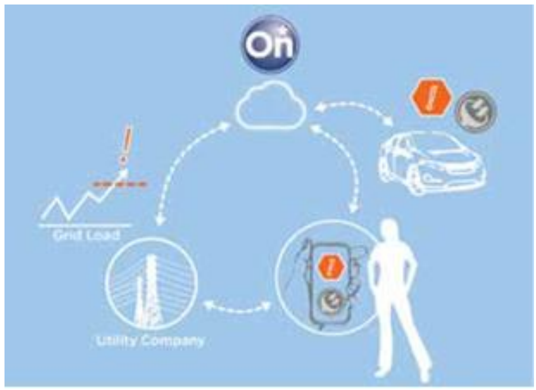


Initially we developed our customized solutions to build one off approaches to demand response and time of use. As the team matured we moved to a more holistic API hosted model which eventually morphed into the development of key strategic partnerships with organizations such as General Electric, DTE, Duke and Pecan Street.

Services

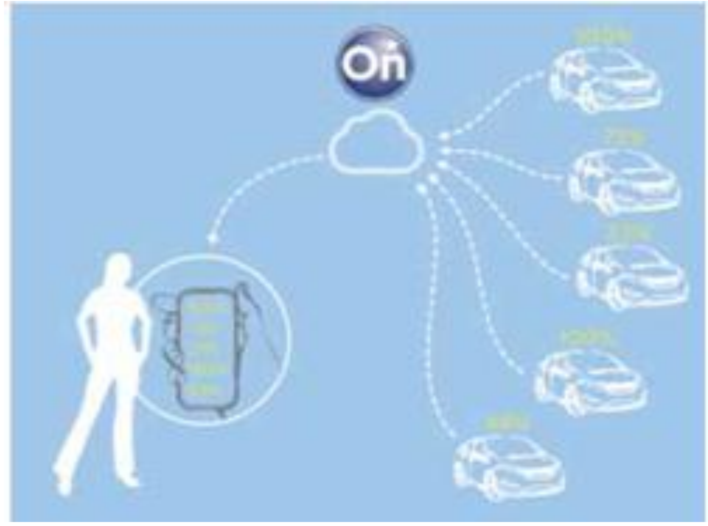
The development environment that supported our smart grid agenda allowed our team to enable a very flexible and innovative approach. Through brainstorming and pushing the envelope the smart grid team developed very unique and realistic services:

DEMAND RESPONSE
The team developed the demand response service to enable Energy Service Provider (ESP) to make informed maintenance and operational choices to control and automate energy usage. Providing consumers with the ability to receive incentives and participate in programs that facilitate grid load management. Developed method to send signal notifying the ESP of peak demand and enabling the opportunity to take electric vehicles off of the grid.



TIME OF USE
The team developed the Time of Use (TOU) service to provide consumers with viable options for energy savings. Utility administration can update and sync their TOU rates with changes that occur in the energy market based on supply and demand. Our services provides the mechanism to deploy those updates to the end users' cell phone or vehicle.

FLEET MANAGEMENT
The team developed a single mobile app or web application that provides a snapshot of the current energy state of each vehicle that is a member of an organizations designated fleet of electric vehicles. This feature enables proper management of electric vehicles that exist within the fleet of the organization.



RENEWABLES
Renewable Energy Service Providers can partner with Onstar as the first telematics provider that has developed a renewable energy management solution for fleets and the individual consumer.

The smart grid core services enabled the development of several innovative products that were showcased in a multitude of demonstrations and conferences across the United States.

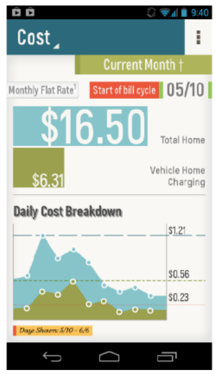
Products

The services that were developed to drive our innovative processes led to the development of unique and powerfully simple solutions and products that addressed the needs of the smart grid:

ECOHUB

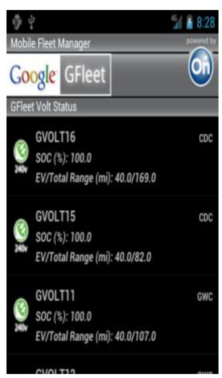
Develop a solution that enhances the experience of GM EV ownership:

- ✓ Know how much it costs to charge EV
- ✓ Know how EV impacts home's energy signature
- ✓ Learn optimal charge times and behaviors to boost cost efficiency and decrease ecological footprint



GFLEET

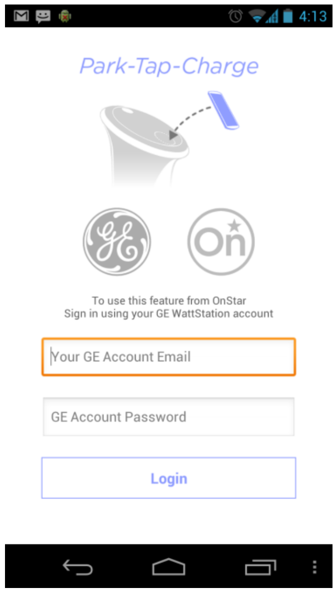
OnStar fleet app allows users to scroll through a list of available Volts and look up a Volt's: driving range, location, charge status, and charge completion time.



GOOGLE GLASS

Google Glass was developed to show real-time stats like speed, gear, engine RPM, and g-force that it picks up via a GM vehicles <u>LTE</u> connection.

PARK TAP CHARGE
OnStar Park Tap Charge application enables the ability to use a mobile device to pay for an electric vehicle charge session at a public charger. The application provides the time required to receive a full charge, the price that you are currently charging and notification that the charge has completed and the vehicle is fully charged.



Data Collection

Since the inception of the project the SmartGrid team has been collecting data that captures the charging behaviors of the electric vehicles that have been included in the project. This data provides insight on a plethora of activities that enlighten the public about the use of electric vehicles and the charging behavior of their owners. This information provides guidance to assist in preparing smart grid infrastructure decisions and planning for future smart grid activities.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy | VEHICLE TECHNOLOGIES PROGRAM

Chevrolet Volt Vehicle Demonstration

Fleet Summary Report — Reporting period: Nov. 2010 - Dec. 2010

Number of vehicles: 145 — Number of vehicle days driven: 2,783

All operation

Overall gasoline fuel economy (mpg)	53.6
Overall AC electrical energy consumption (AC Wh/mi)	209
Total number of trips	15,027
Total distance traveled (mi)	169,626
Average Ambient Temperature (deg F)	29.5

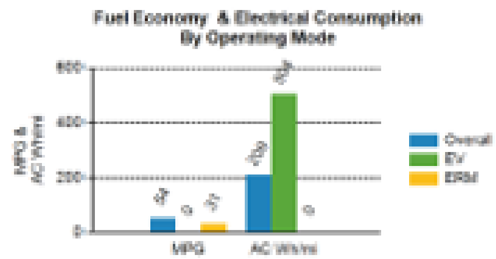
Electric Vehicle mode operation (EV)

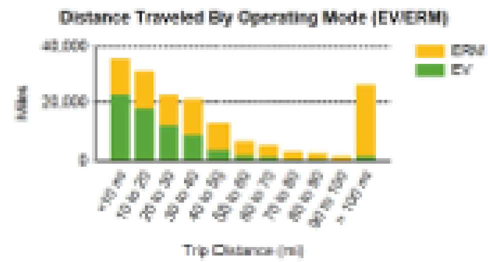
Gasoline fuel economy (mpg)	No Fuel Used
AC electrical energy consumption (AC Wh/mi)	504
Distance traveled (mi)	70,329
Percent of total distance traveled	41.5%
Average driving style efficiency (distance weighted)[1]	59%

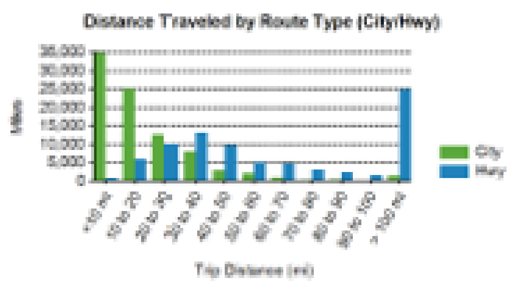
Extended Range mode operation (ERM)

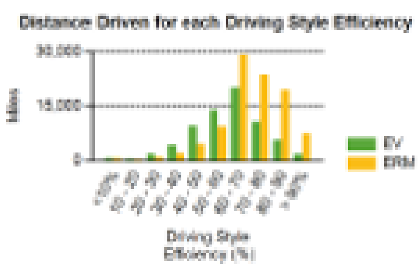
Gasoline fuel economy (mpg)	31.4
AC electrical energy consumption (AC Wh/mi)	No Elec. Used
Distance traveled (mi)	99,297
Percent of total distance traveled	58.5%
Average driving style efficiency (distance weighted)[1]	69%

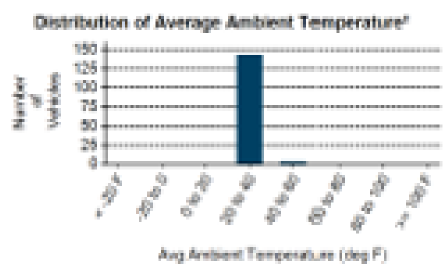
	City Driving[3]	Highway Driving[3]
Percent of miles in EV operation (%)	71.0%	29.0%
Number of trips	13,134	1,893
Total distance traveled (mi)	88,474	81,152
Average trip distance (mi)	6.7	42.9
Average driveng style efficiency (distance weighted)[1]	60%	71%











1 The energy efficiency over the drive cycle is based on driving style. Driving in a more efficient manner results in a higher percentage for driving style.

2 Plot shows average ambient temperature during all driving in the reporting period for each vehicle

3 City / Highway defined per SAE J2841

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Partnerships

As the smart grid team built the core services and developed scalable and message friendly APIs, we created the ability to partner with a multitude of organizations to demonstrate and validate the role of the electric vehicle within the smart grid. A brief description of our main endeavors is provided in the following section:

The OnStar partnership with PJM has leveraged the ability to process a signal that is sent from PJM that identifies the available wind to provide for renewable energy that can be leveraged to charge an electric Vehicle – demonstrated functionality internally.

OnStar and GE worked together to develop a charge station solution that allows a user to initiate a charge Session by tapping their cell phone on a GE Wattstation -- demonstrated functionality at the SF Energy Consortium and Distributech.

OnStar and Google worked together to create an application that would provide charging data to the users of Volt vehicles that are parked at the campus lot. The mobile and web versions of the application provides the charge status of the vehicle(s) so that the user can make the best vehicle selection to support their trip – demonstrated functionality at Distributech and internally, live application running at the Google Campus.

OnStar and Duke developed a demonstration that executed the Demand Response Service to a Volt vehicle through an application that called the DR API from the service that was built by the Smart Grid team – Demonstrated at the Duke Envision Center and at Distributech.

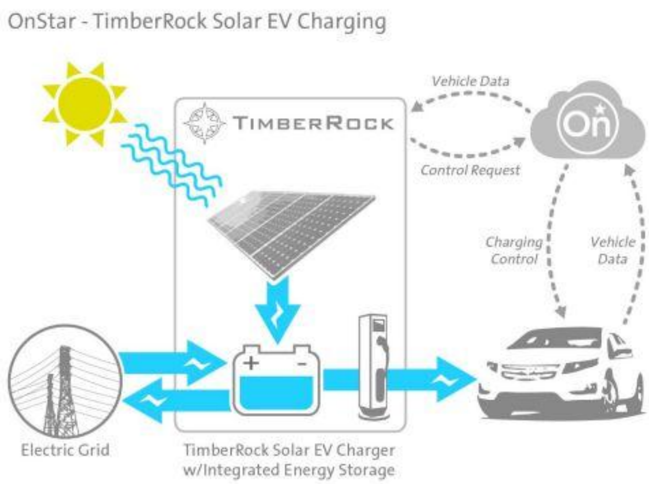
OnStar has formed a partnership with Pecan Street to demonstrate the capabilities of the Volt vehicle and identify the services and benefits that can be generated by the inclusion of the Volt vehicle in the ecosystem of the Mueller Community. Demonstrated as a live environment at Pecan Street Mueller Street Community.

DTE Energy

OnStar developed a TOU based solution in partnership with DTE that allowed consumers the ability to take advantage of optimal energy pricing that was predicated by aligning the vehicle to the best TOU rates that were being provided by the market – Demonstrated at DTE headquarters.

TIMBER ROCK

The existing TimberRock/General Motors (GM) project at White Marsh will demonstrate how the integration of solar PV, storage and EV charging can improve the economic performance of EV infrastructure with the goal of accelerating infrastructure deployments. Demonstrated as a live environment with three Production vehicles owned by Timberrock.



Although we only mentioned a handful of opportunities our partnerships extended to many of the key players within the smart grid market:

Technological Stewardship and Innovation - Standards

Our experience from building our solutions and services has led to being included in the development of key standards that drive the evolution of the smart grid and the required communication standards. An overview of the standards that we assisted in developing is documented below:

Standards Development

- **SAE J2931/5 - Telematics Smart Grid Communications Interface**
  - Establish standard API for Telematics Smart Charge Communications and Control
  - Provide a single common applications programming interface for PEV load monitoring and control communications with Utilities, ISO/RTOs, EMS, HAN, Aggregators, and Energy Service Providers
- **SAE J2836/5 Customer communications**
  - Establishes use cases between Plug-In Electric Vehicles (PEV) and their customers.
  - The customer will be able to interact with the PEV as it charges/discharges.

- **OnStar SmartGrid team involvement in other Standards Organizations**

- **NIST PAP11** – Interoperability standards to support plug-in electric vehicles.
- **NIST PAP03** – Common specification for price and product definition.
- **IEEE P2030.1** – Draft guide for Electric-sourced transportation infrastructure.
- **SEP 2.0** – Smart Energy Profile
- **OpenADR** – Automation of Demand Response

Technological Stewardship and Innovation - Patents

Our experience from building our solutions and services has led to identifying multiple opportunities to patent the ideas and concepts that have been created due to the SmartGrid Program. The Smart Grid team has submitted numerous Patent applications that are currently under review or has previously been awarded.

Summarization

- ✓ Increased the demand for electric vehicles through electric vehicle demonstrations, marketing and education
- ✓ Provided numerous marketing and publicity opportunities for the Smart Grid and the viability of the electric vehicle and the benefits it provides to the consumer
- ✓ Identification as an industry leader; developing new and different market offerings that are demonstrated with partners and at multiple conventions and conferences
- ✓ Developed strategic Partnerships that can leveraged for future Innovative solution development
- ✓ Validated and demonstrated the theory that Smart-grid technology can enable EV-charging (grid-to-vehicle, or G2V) load to be shifted to off-peak periods, thereby flattening the daily load curve and significantly reducing both generation and network investment needs.
- ✓ Provided customers and utilities with real-time data and enabling customers to schedule charging in a way that minimizes costs to them and to the utility.
- ✓ Enhanced awareness and education of how the electric vehicle can be integrated with the smart grid to drive innovation and forward thinking concepts for smart management of energy
- ✓ Job creation based on the smart grid program
- ✓ Proved that the technology to integrate the electric vehicle into the smart grid eco system exists and is viable entity as the smart grid continues to evolve

- ✓ Looking into the future technological capabilities of the smart grid and electric vehicle is a great opportunity but there is a need for more support from on public policy and Public Utilities Commission
- ✓ Carried forward the electric vehicle solution to be embraced by more GM electric vehicles (MINI BEV and Cadillac ELR)

Smart Charging Power Line Communications and Home Plug

Project Details

Method II was the development and demonstration of the OnStar Non AMI communications capability with specified enhancements and the development and demonstration of direct vehicle/utility AMI communications using HomePlug Power Line Communications (PLC) technology. Messaging structures/protocols were intended to be Smart Energy 1.0/2.0 and SAE J2847 compliant. The design and integration concept was developed, tested, and verified through two levels of bench top demonstrations and one level of vehicle- level demonstration. OnStar Non AMI and the PLC AMI communication functionality were integrated into a Chevrolet Volt as a vehicle level demonstration.

Three benches were developed with each consisting of unique properties:

Bench 1 was a proof of concept bench. The bench was based on SEP 1.0 messaging as this was the only standard available. Communications and SEP 1.0 messaging was thru a smart meter using ZigBee to PLC communication.

Bench 2 was an operational bench with utility communications to a vehicle simulation computer and included a dash board mockup of Volt radio control software. This bench also used SEP 1.0 messaging.

Bench 3 consists of a SEP 2.0 server simulating utility communications with PLC and CAN commutations connected to a road worthy electric vehicle, GM Volt. Vehicles were intended to demonstrate production implementable Smart Charging functionality and provide evaluation and verification testing of SAE J2847/1 messaging and SEP 2.0 application standards.

Actual Accomplishments

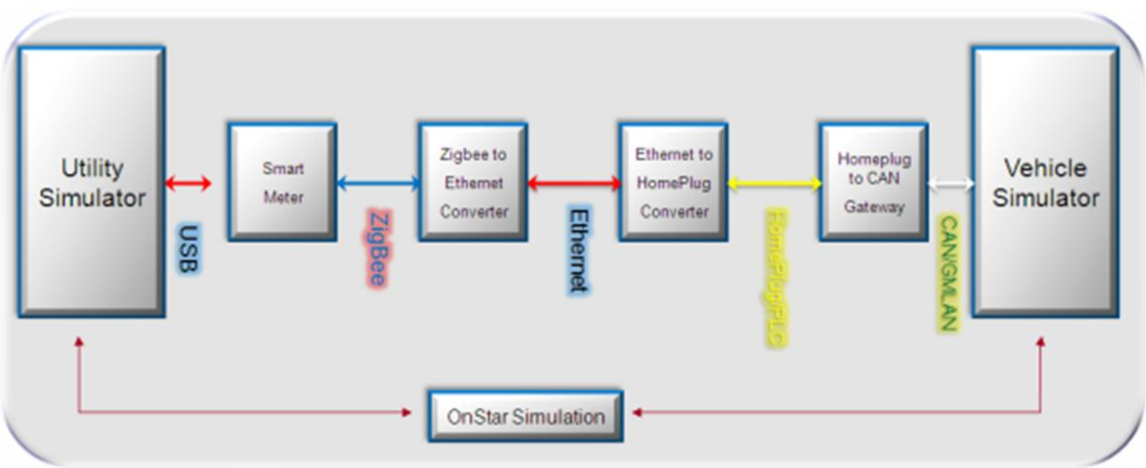
Bench 1

Each Bench was developed using the above requirements. The original plan Bench 1 was to demonstrate a proof of concept using 2 laptop computers but was extended to test various communication strategies and components. This bench used a utility simulator connected to an Itron developmental smart meter with a ZigBee 1.0 communication card to communicate to a Zigbee Alektrona gateway module. HomePlug PLC (Powerline Communication) was used to communicate with a Gen 1 Multiprotocol Router creating a PLC to CAN (Vehicle messaging software) conversion, for communication to the vehicle simulator. 2 displays provided information about the messaging generated by the Utility simulator and the results and communication from the Vehicle simulator. There was also an OnStar simulator provided with the software.

Bench 1

Features of Bench 1 included:

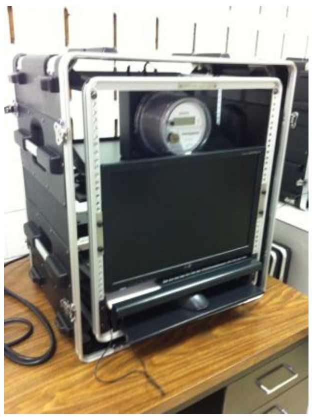
- Simulated Vehicle and Utility ends
- Real time communications link
- Touch-screen computer simulating OnStar (non-AMI) interaction
- An Itron meter with a ZigBee 1.0 communication card
- Zigbee Alektrona gateway using HomePlug PLC to communicate with a Gen 1 Multiprotocol Router.
- CAN messaging to the Vehicle simulator
- Software was developed to provide a basic Utility/Vehicle simulation.
- A graphic user interface (GUI) was to create events for Pricing, Time and Demand Response / Load Control using a touchscreen monitor.



Communication Strategy used in Bench 1

Bench 2

This bench was developed as a 2 piece unit with wireless communication between the two units. Utility software was developed and communicated via computer through an Itron meter using Zigbee communication protocols and connected wirelessly to the Vehicle Simulator module. SEP 1.0 messaging was used as this was the only messaging standard available at the time. Due to program restrictions to not modify the software of the Volt directly a "top hat" configuration was developed where the charging decisions and controls were managed in a separate computer and delivered to a vehicle simulator. Similar to modifying the software in the vehicle but done off board. There was also a remote connection ability provided to the Utility software.



Utility Simulator Vehicle Simulator

The bench had the following unique features:

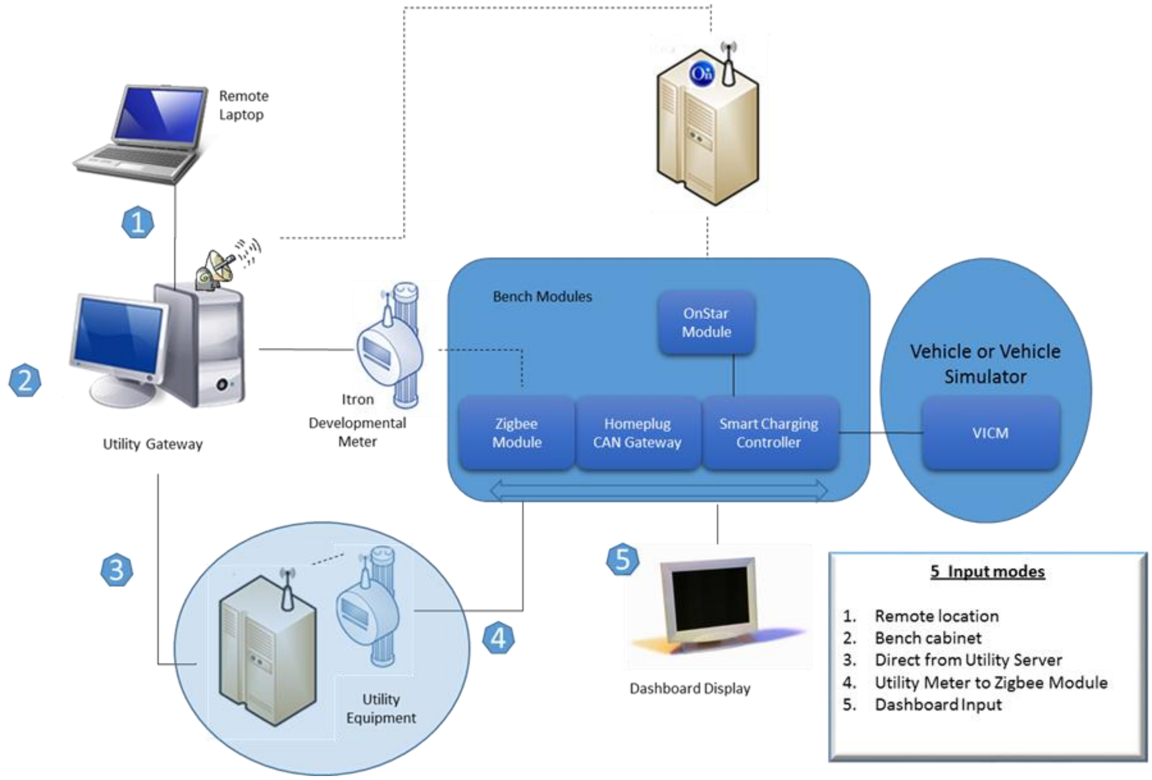
- Three means of connection to the bench for Utility software/meter trials
    - Utility simulation software using Itron developmental meter
    - Connection of Utility meter directly to the Alektrona Module via Zigbee.
    - Software messaging directly to the Utility Gateway using the Utilities software and the Itron meter

- A remote laptop was provided with a wireless connection to the Utility Gateway. This was to allow control of the charging in a remote location from the bench. This was in addition to controls located at the bench.

- A touch screen similar to the Volt Navigation Radio Screen was provided and included additional features which added support and control for Utility messaging and status feedback, not found in the production Volt.

- Non-Ami operation via OnStar Simulation was developed. This was a connection though the Utility Gateway computer using a software simulation of the OnStar communication.

- SEP 1.0 message structure utilization.

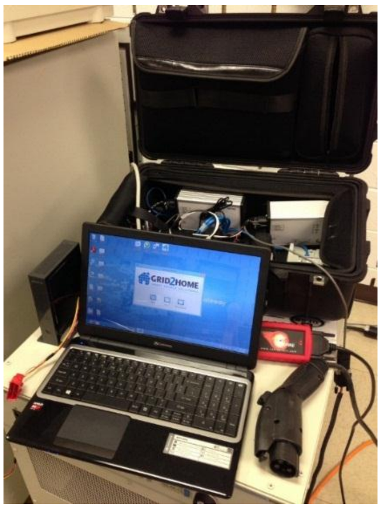


Bench 2 Schematic

Bench 3

The third bench was designed to be an interface from the Utility communication software to the Vehicle and was to provide actual control of the vehicle charging based on the SEP messaging.

Initially the only messaging set available was the SEP 1.0 standard but during the bench design phase the SEP 2.0 standard was released and communication hardware was developed to utilize it.



Bench 3

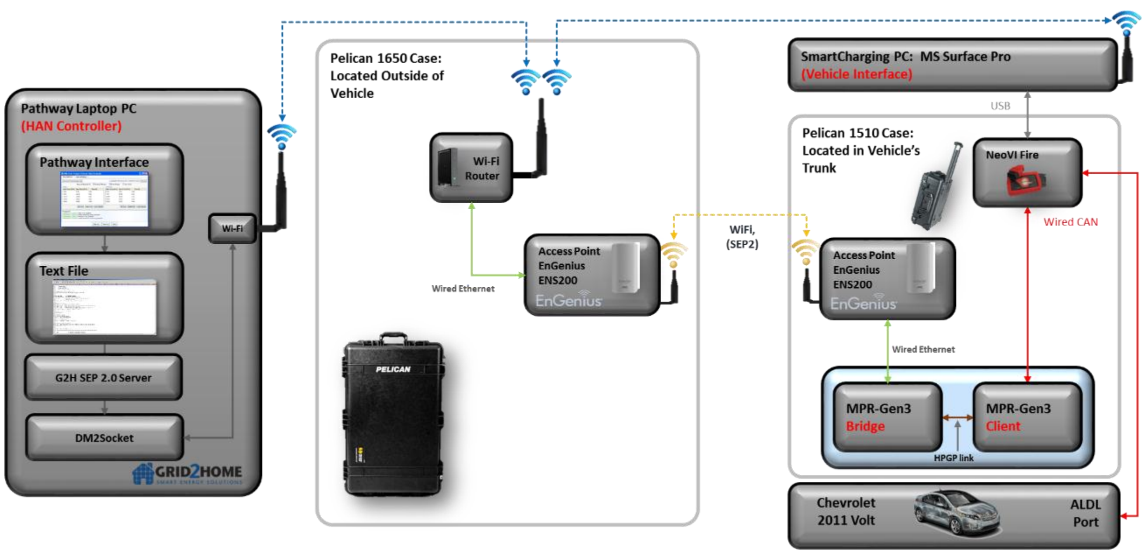
The features of Bench 3 include:

- SEP 2.0 Server Software
- Real communications link
- Multiprotocol routers with PLC communications
- Direct CAN messaging feed to vehicle though ALDL port via NeoVi Fire
- Communication to Microsoft Surface for Vehicle Status via CAN
- GUI is used to create events for Pricing, Time and Demand Response / Load Control
- Compact design for in vehicle portability

Since the software in the vehicle was not to be modified, the actual decision and control of the vehicle is made in the SCC (smart charging controller) computer and connected to the vehicle through the ALDL port. This is similar to the arrangement found in the second bench.

Instead of using the Utility simulator software in the second bench, a SEP 2.0 server was introduced to provide the utility control. This software was developed by Grid2home. The message set from the server is transmitted wirelessly to a Multiprotocol module that converts the signal to PLC which talks another Multiprotocol router that converts the PLC messaging to CAN messaging which is then sent to the vehicle.

There is two way communication between the server and the SCC computer, which acts as part of the vehicle software. In addition all the information transferred is displayed on a tablet computer which also has a representation of the dashboard screen.



Bench 3 Schematic

The following software languages and communication protocols were used in the development of the bench:

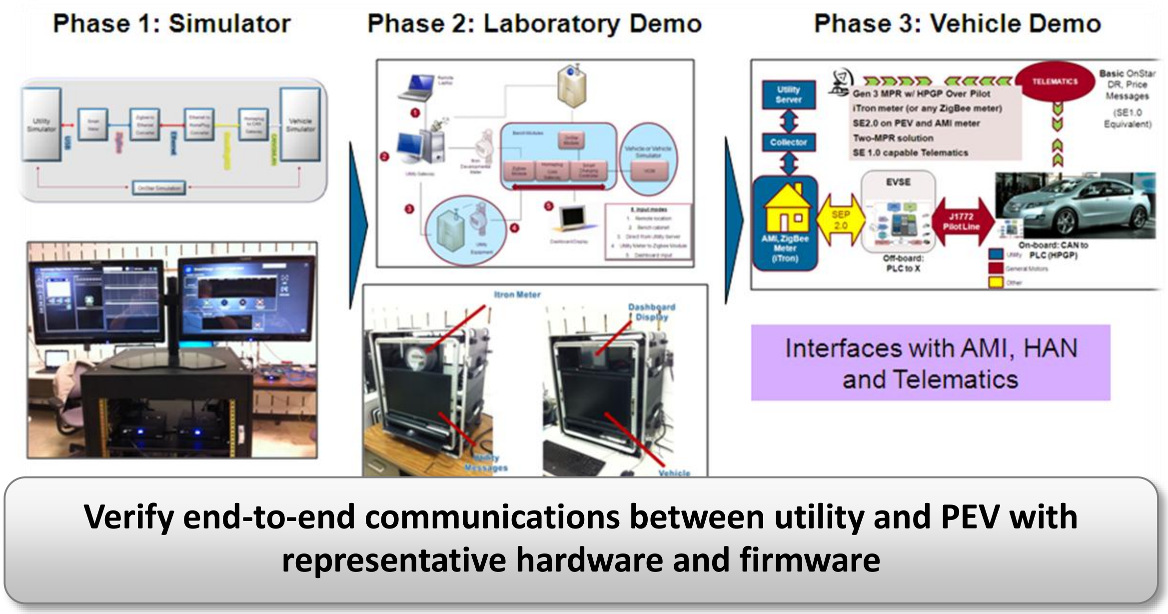
- Object Oriented Programming (OOP) and Classes
- C# Language
- Visual Studio integrated development environment (IDE)
- Simple Object Access Protocol (SOAP)
- Extensible Markup Language (XML)
- Web Services Description Language (WSDL)

- XML Schema Definition (XSD)
- IntrepidCS API (for NeoVI Communications)
- Program Threading
- Event Based Programming
- Hypertext Transfer Protocol (HTTP)
- Controller Area Networks (CAN) communications
- GMLAN Normal Mode and Diagnostic Mode communications (In particular Diagnostic IDs … DIDs)
- Transmission Control Protocol (TCP) and the Internet Protocol (IP) … TCP/IP
- Networking PCs and other devices
- Bench consists of 3 executable programs written in C# (Total Program Source Code size = 305 Megabytes):
- Main Smart Charging Control Program (SCPC_Main_B3.exe = 7.3 Megabytes)
- SmartCharging Graphic User Interface (SC_GUI.exe = 5.7 Megabytes)
- Time Of Day Graphic User Interface (TODC_GUI.exe = 2.7 Megabytes)
- In Bench communication via:
- Wi-Fi (TCPIP)
- USB
- ZigBee
- HomePlug (Power-line communication)
- Ethernet
- Controller Area Network (CAN) – GMLAN HS, GMLAN LS, Custom HS buses
- Custom Set of CAN Normal Mode Messages (used to exchange SEP Data between Vehicle & Utility)
- GMLAN Normal Mode Messages (used to monitor Vehicle Information/Status)
- GMLAN Diagnostic Mode DIDs (used to control Vehicle via User & Utility Override commands)

Problems Encountered

The major problem encountered was with the Itron development meter and software. The unit was not designed to be used in this type of development. The software was limited and developed a critical error. The meters were updated with new software that created compatibility issues with the Zigbee modules. Control files (.dlls) were reverse engineered and rewritten to make the meter perform to the program specification. Also the Zigbee communication protocol was not stable and required special startup procedures for connectivity. In addition, further in the program it was determined for safety purposes that the onboard vehicle software could not be modified. This lead to the development of the off board SCC computer software.

Summary



The final results of the development lead to three unique benches that met all the program requirements. From proof of concept to final control of a vehicle each bench built on the learnings from the previous bench, but each had their unique features. Benefits of each included:

Bench 1

- Simulation of communications and messaging of SEP 1.0 thru a smart meter.
- SEP 1.0 communication using PLC direct to PEV, with vehicle response.

Bench 2

- Learnings on the dashboard simulation will drive content in the vehicle.
- Participation of utilities in dashboard simulation will enable them to request content that will meet utility specific needs.
- Dashboard simulation will provide the connectivity to facilitate transmission of SEP 1.0 communications between the PEV and a Utility.

Bench 3

- Roadworthy demonstration of Bench 2 learning's.
- Provide evaluation and verification testing of SAE J2847/1 messaging and SEP 2.0 application standards.

DC Fast Charging

Project Details

The following information will be a summary reviewing the development and demonstration of DC fast charging. The project scope was originally defined as follows:

- Support development of standard electrical and communication interfaces between the Electric Vehicle (EV) and the charger (EVSE) and increase the understanding of the vehicle and grid impacts of fast charging
- Focus on the development of a standard DC connection interface and communication standard for fast charging along with the design and integration of this into a vehicle
- Install fast charging systems and modify a few vehicles with the fast charging hardware and controls. These vehicles shall be added to the existing demonstration vehicles for demonstration
- During the demonstration period data shall be collected and analyzed to study grid impacts, vehicle impact, thermal management, charging profiles, user ergonomics and efficiency

Several modifications were made to the project scope throughout the life of the project, mostly around the installation and demonstration of DC fast charging. Due to the longer than anticipated development timing DC fast chargers were only installed at GM facilities. With this in mind, all partners were invited to participate in an onsite DC charging demonstration, data collected during that demonstration can be found later in this summary.

A significant portion of the project was to develop the standard to support DC charging between the EV and EVSE. The standard work included both defining hardware as well as communication development. All data gathered during this project was provided to the SAE committee for implementation into the SAEJ1772 standard. All messages in the standard were completed using PLC (Power Line Communication) that were transmitted over control pilot, reference Figure 29 for the final system layout. Request/response messages were defined to properly initialize a DC fast charge. Working with DC fast charge suppliers this DOE project was able to help define and clarify the messaging to ensure interoperability of future EV's and EVSE's.

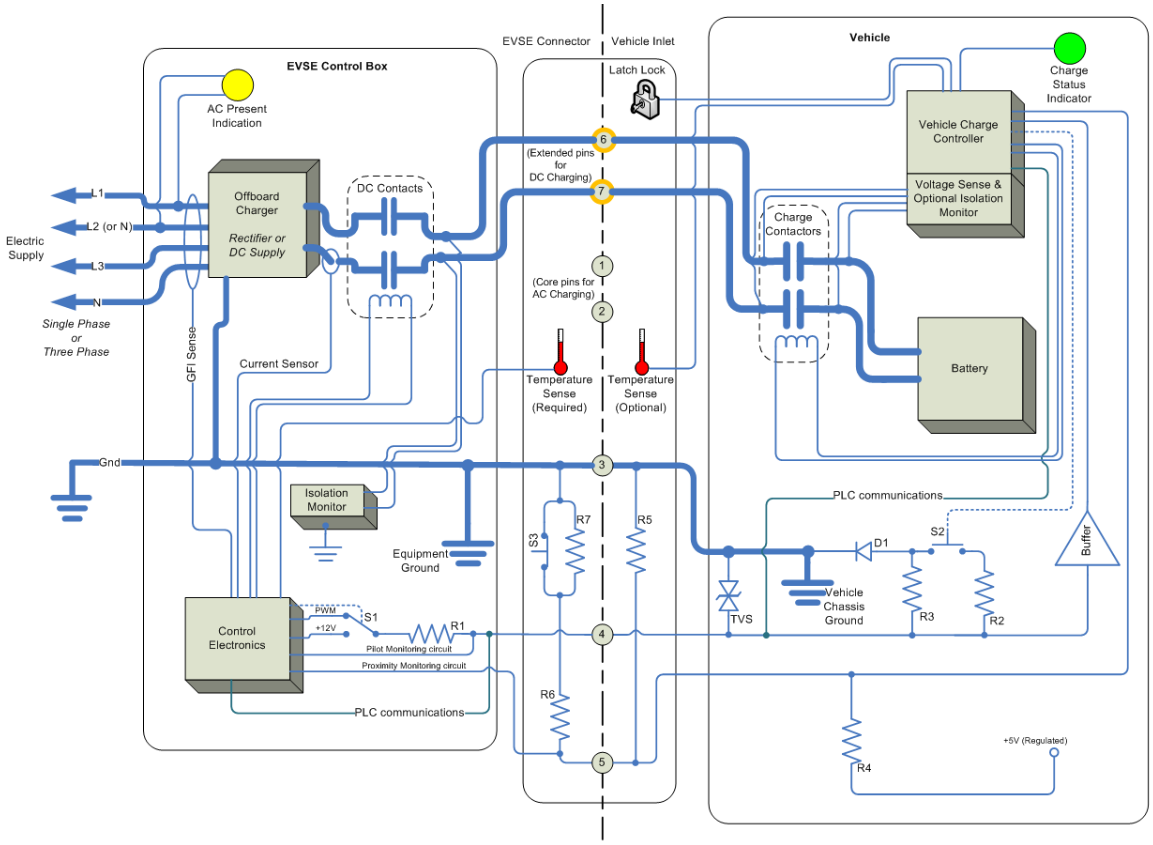


Figure 29 – SAE J1772 Schematic of the DC Fast charge system

Accomplishments

Publication of DC Fast charging standards

- SAE J1772
- SAE J2847
- DIN 70121
    - The DIN communication standard was used to develop the communication for DC charging. This standard will be rolled into the ISO/IEC15118 in the future.

Work was completed throughout the project to ensure the DIN 70121 standard remained harmonized with the SAE standards.

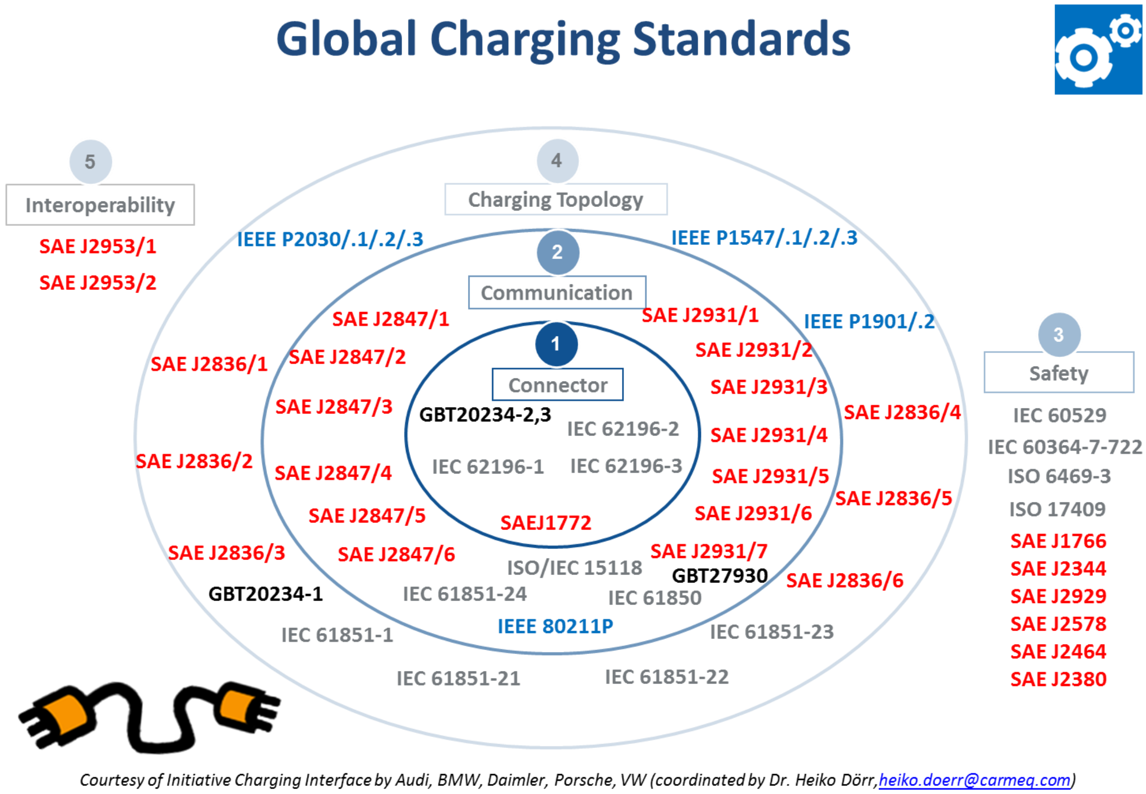


Figure 30 – Global Charging Standards Topology Review

DC System Vehicle Integration

Based on the development work of the SAE standard work was also completed on integrating the hardware and software in the Spark Electric Vehicle (Spark EV).

Additional hardware for the Spark EV consists of two components. The first is the receptacle which contains the additional two pins for DC HV+/-. A locking mechanism required by the J1772 standard is also integrated into the receptacle, the lock is controlled by the EV. The High Power Charge Contactor (HPCC) module is also required to be integrated into the system for DC fast charging. In addition to the HV contactors the HPCC also includes the gateway communication module. This communication module provides the ability for the vehicle to receive PLC messages, decode the messages and communicate with additional modules on the EV.

EVSE Development

EVSE development was key to this project, initially work was completed with Aker Wade for implementation of the EVSE off-board charge station. As the standard was farther developed additional suppliers began EVSE hardware and software development. Throughout this DOE project General Motors worked with all EVSE suppliers on the development of their EVSE to confirm interoperability between OEM's. This work included two separate interoperability events, one held at General Motors and one held at BMW. These events were used to verify customer satisfactions with EVSE suppliers. In total, General Motors has worked with eight EVSE suppliers including Aker Wade, ABB, Eaton, Efacec, IES Synergy, EVtec, BTCPower. Feedback from these customer satisfaction events was given directly to the standards committee for updates/clarifications to the standard.

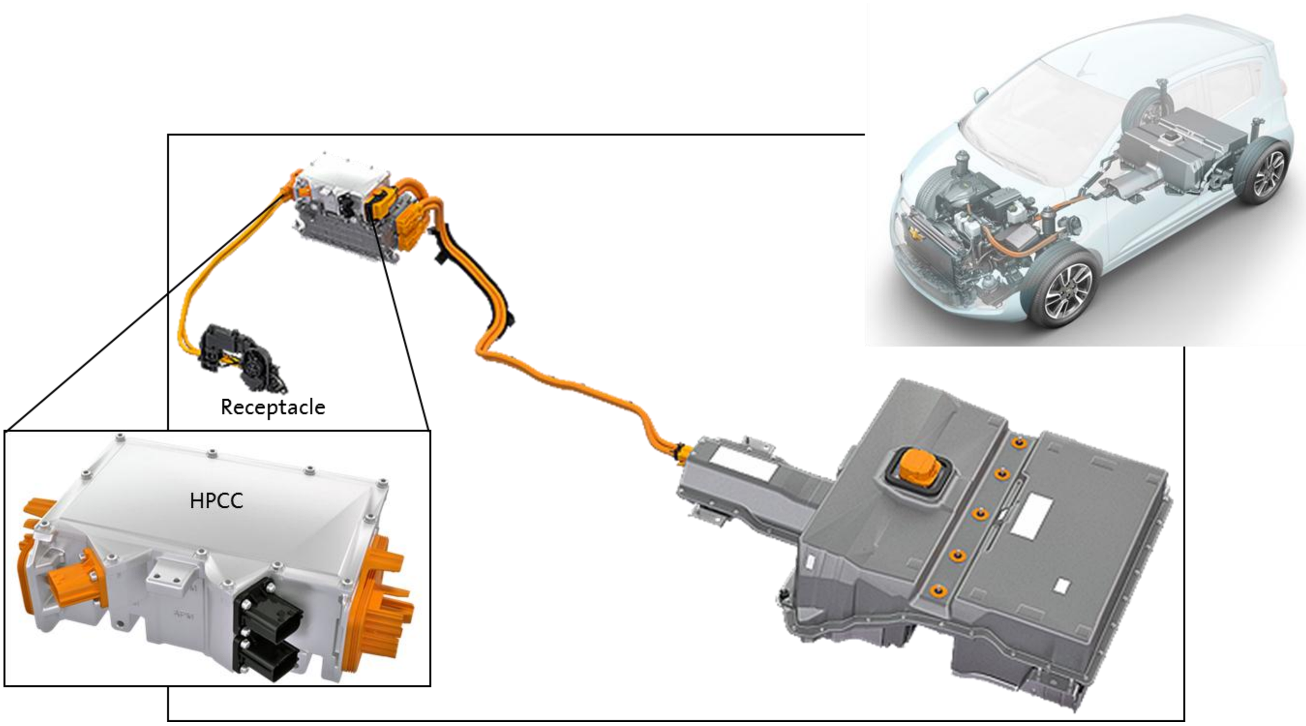


Figure 31 – Integration of DC Fast Charge into the Spark Electric Vehicle

Problems Encountered

Problems were encountered with the development and implementation of the PLC protocol. Overall, the development of the request/response message protocol for the SLAC phase (Signal Level Attenuation Characterization) took significantly longer than expected to ensure interoperability. This portion of the standard was critical as it represented the association/session set up between the EV and EVSE. Initially, the protocol was vague and interpretation of the standard could vary between OEM's and EVSE suppliers. For example, bits/bytes of message content could easily be interpreted incorrectly making messages incompatible. Feedback to the standards community led to revised versions of the standards to clarify these concerns.

The Qualcomm chip intended to be used in the gateway communication module required frequent updates as issues were discovered. Initially, messages could be dropped from the line with no indication of a message was received and/or sent. In addition for a firmware update from Qualcomm all chips were required to be updated to verify the signal strength was within the specification limits. These two updates significantly decreased the occurrence of messages dropping.

DOE Demonstration

Included in the project was a demonstration of DC fast charging with our project partners. This demonstration took place on 12/13/13 at the Milford Proving Grounds. Participants at the demonstration included EPRI and NC State. The purpose was to acquire power and energy measurements of a DC fast charger while connected to a Chevrolet Spark. Power and energy measurements were taken during 6 charge cycles:

1) Vehicle low state of charge (SoC) to full SoC at 50kW
2) Vehicle low SoC to full SoC at 30kW
3) 60-65% initial SoC to full SoC at 50kW
4) 60-65% initial SoC to full SoC at 30kW
5) 30-35% initial SoC to full SoC at 50kW
6) 30-35% initial SoC to full SoC at 30kW

Data collected during this demonstration was given to both NC State and EPRI for analysis. Charging profiles are below for the 30kW and 50kW demonstrations.

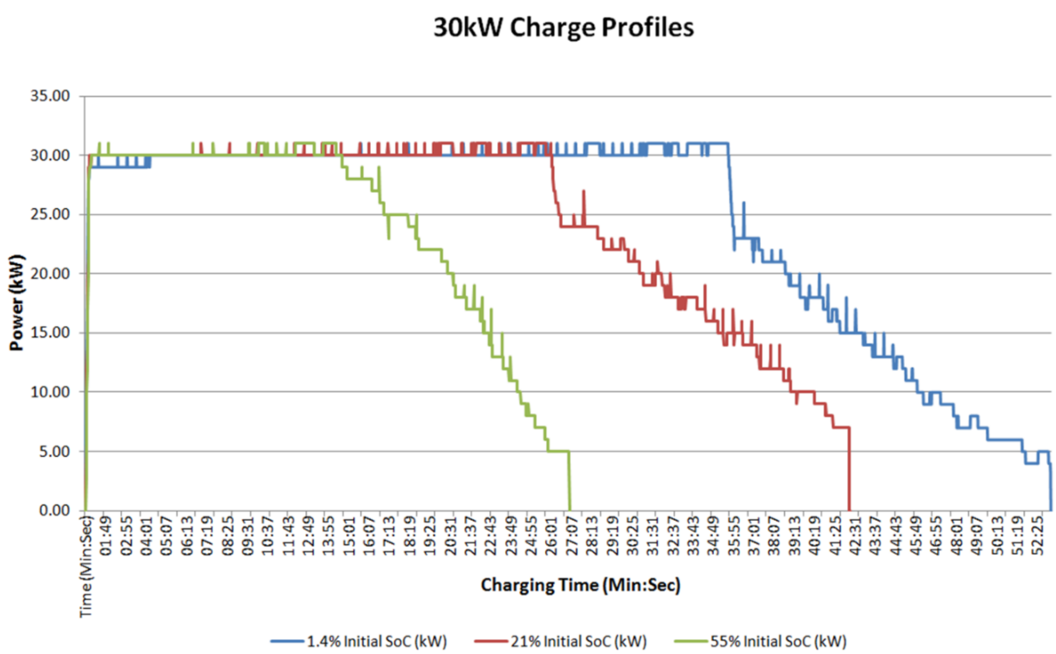


Figure 32 – Charge Profiles – EVSE limited to 30kW Output Power

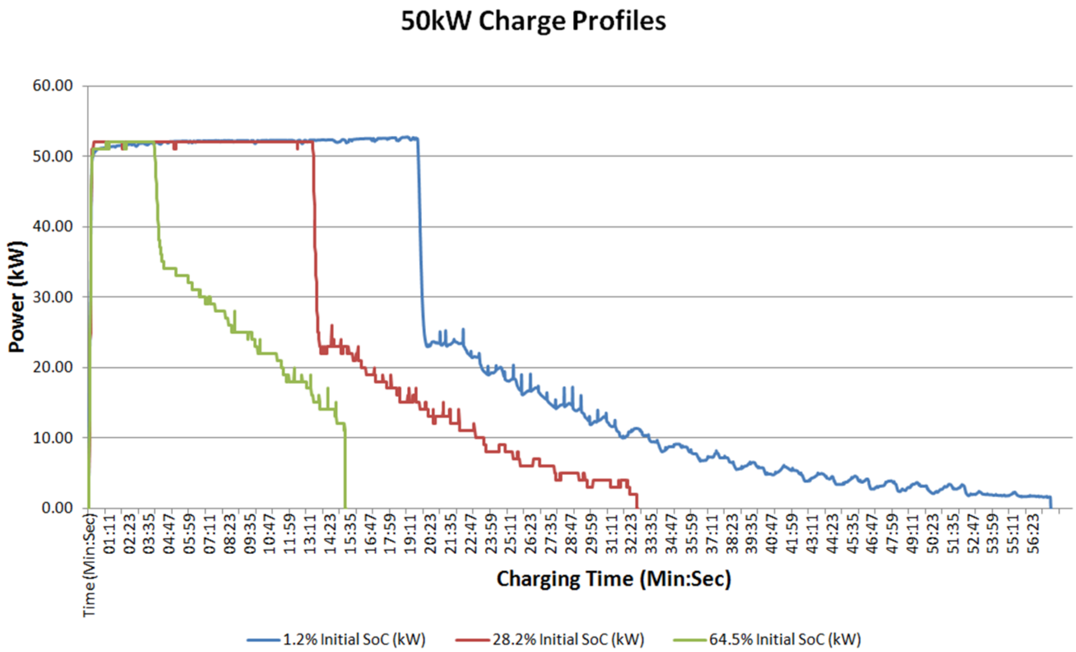


Figure 33 – Charge Profiles – EVSE limited to 50kW Output Power

In addition to voltage and current measurements a Hioki 3198 Power Meter was installed at EVSE power input. Current probes were attached to each phase and were verified prior to the testing. The harmonic data for the testing is shown in figures six and seven.

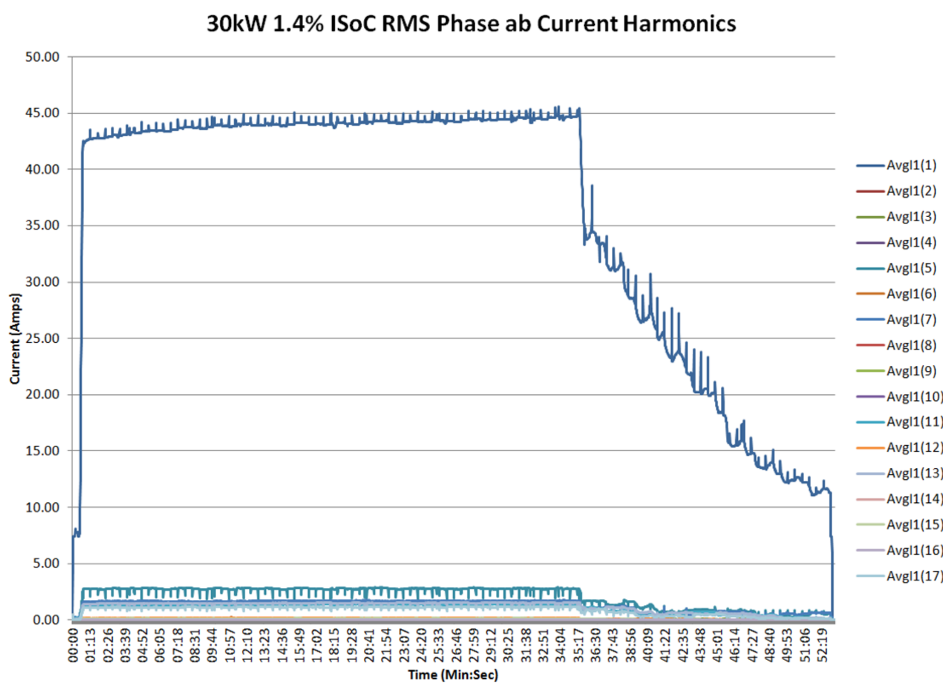


Figure 34 – Harmonic Profile – 30kW EVSE

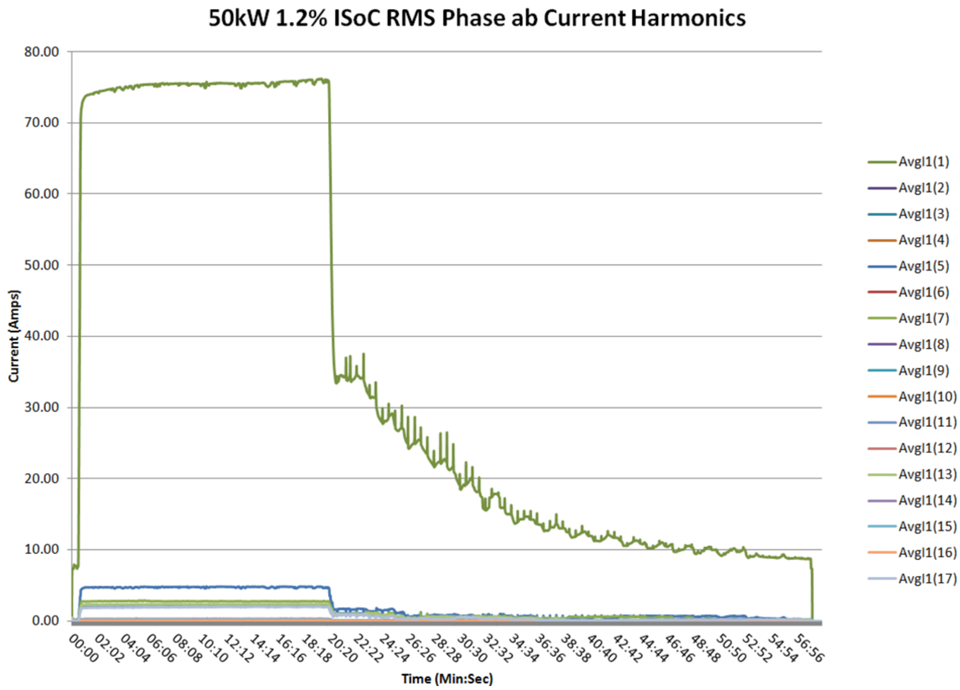


Figure 35 – Harmonic Profile – 50kW EVSE

Summary

In summary, this DOE project supported the development of a standard electrical and communication interfaces between the EV and the charger and greatly increased the understanding of EV and EVSE impacts while using PLC communication. The focus of developing the standard from both an interface and communication standpoint was successfully completed and integrated into the Chevrolet Spark EV. General Motors installed over a dozen DC Fast charge stations and completed a demonstration with all interested partners. The SAE standard is now being used by two OEM's (GM and BMW) on production vehicles. Stations have begun to be installed in California and surrounding regions.

Battery-To-Grid

Project Details

Automotive battery performance requirements are very stringent. It is anticipated that automotive batteries may have sufficient capacity at the end of vehicle life to satisfy stationary use requirements. The increased demand for stationary energy storage on the electric grid to enable renewable energy sources and reduce infrastructure stress through load management is an opportunity to extend the usage of automotive batteries. This task shall study the technical challenges of automotive battery reuse for grid storage and demonstrate this application.

The first portion of this task shall study stationary energy storage requirements and compare them to battery capabilities following vehicle use. Multiple types of ancillary services from stationary storage such as VAR compensation, voltage regulation and frequency regulation shall be included in this study.

Requirements for applications to support renewable integration to the electric grid for solar and wind generation systems shall also be included.

The second portion of this task shall integrate a grid-tied bidirectional power converter with a battery pack to demonstrate battery to grid functionality. Applicable standards shall be incorporated in this demonstration property. Communication requirements for grid to storage systems shall be developed to provide dispatched power capability.

During the demonstration period data shall be collected and analyzed to study the grid and battery impacts of bidirectional power flow. Use cases shall be developed to incorporate into future standard revisions.

Accomplishments

The bi-directional matrix converter (BMC) power stage architecture is a single galvanic isolated power stage that has the capability of meeting the interface requirements of both the utility grid and the vehicle battery. The BMC system consists of high frequency link, matrix converter, and high frequency filter as shown in **Error! Reference source not found.**36. The high frequency link comprises a high frequency isolation ransformer and a full bridge chopper/rectifier. The BMC has two modes of operation; namely, the Charging mode (grid to battery) and the Battery to Grid or alternatively EPTO mode. The Bidirectional power flow is established by engineering the mesh of matrix switches which electrically couples two input portals with the high frequency link.

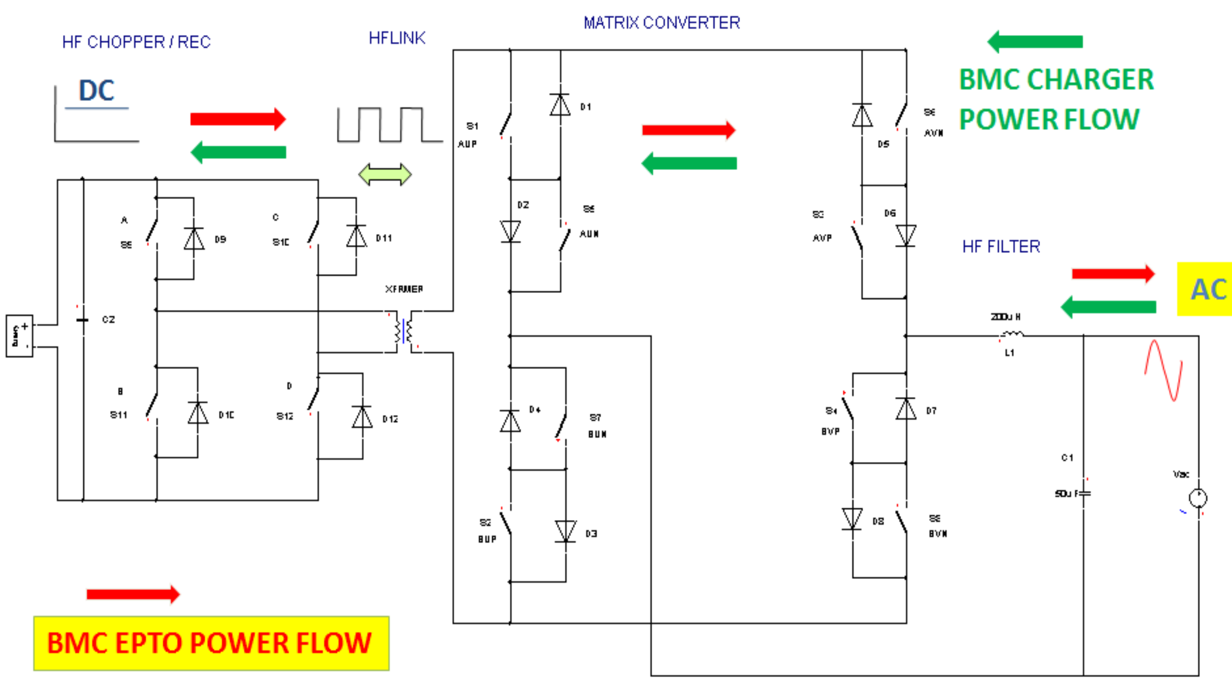


Figure 36 – Bi-Directional Matrix Converter Topology

The BMC was developed under a DOE AIETS project and that work was leveraged to further evaluate the BMC as a potential topology and to generate the performance requirements for the GaN based bi-directional charger. Simulations were created for several grid connect modes using the BMC as the baseline hardware. These modes included Hold voltage and Power @ Premises, Supply Grid with Current as per commanded magnitude and Phase, Supply Grid with VAR or PWR per command, and various building blocks required for these modes to function such as current magnitude ad phase control. The modes were identified as a result of working with EPRI to define the ancillary functions required to support connecting to the grid. As part of the B2G project, a laboratory test set up with the BMC prototype had been built in the lab at the Torrance, CA, ATC location as shown in Figure 37.

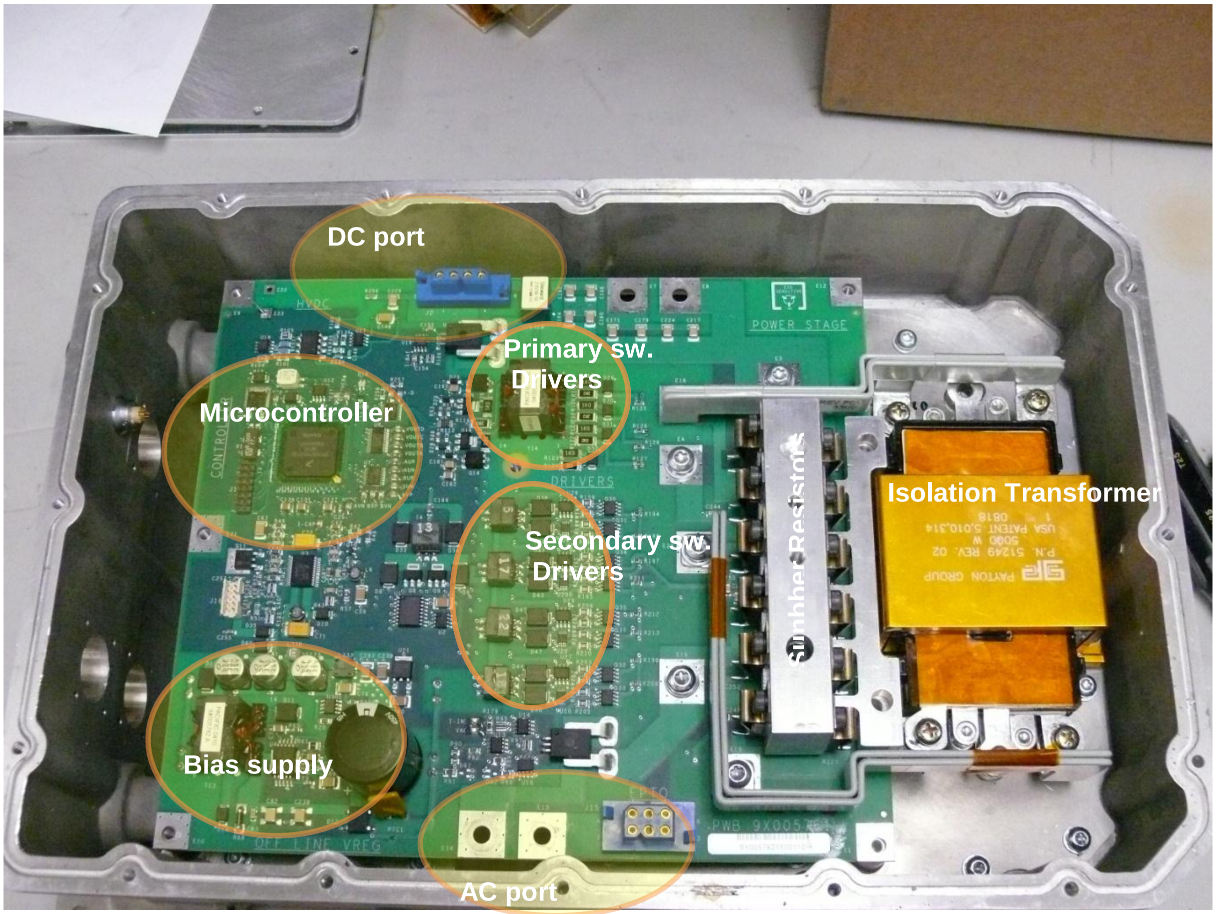


Figure 37 – BMC Unit

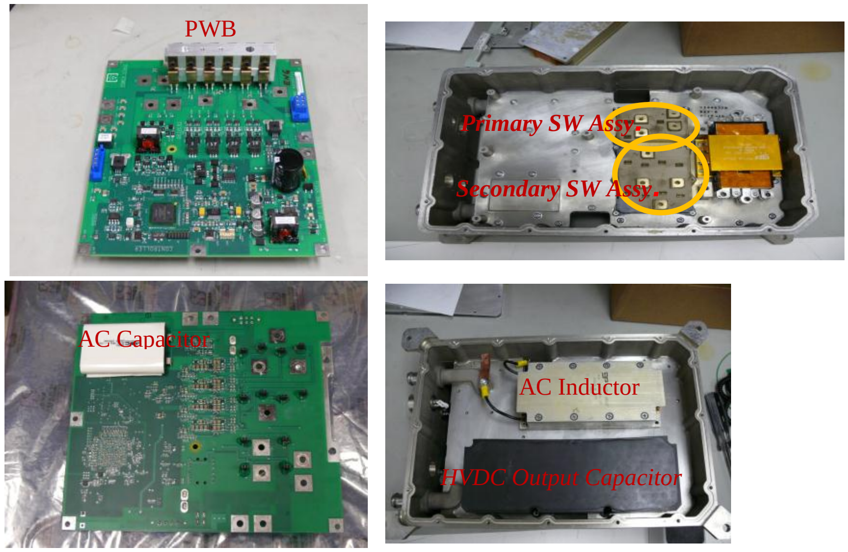


Figure 38 – BMC hardware

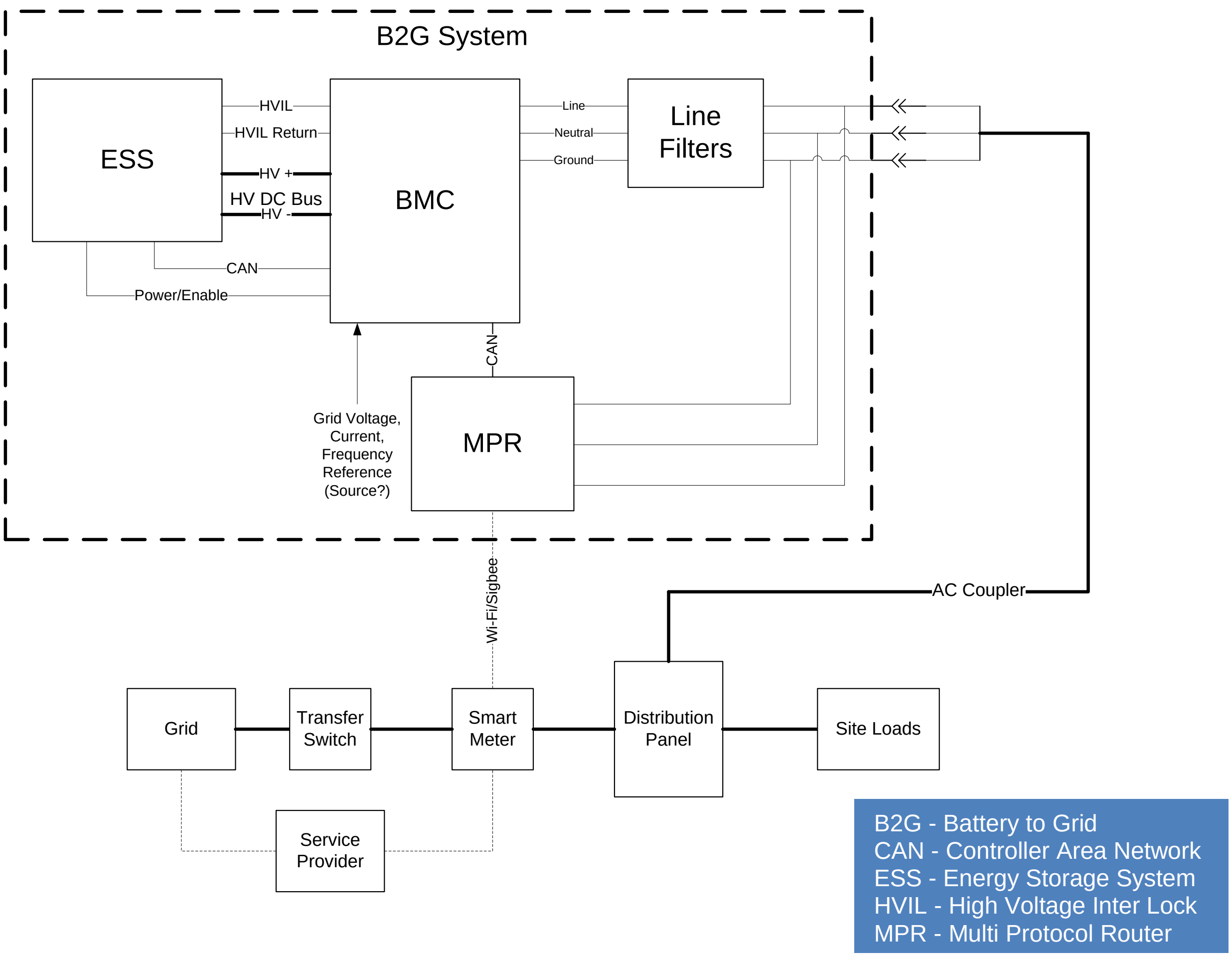


Figure 39 – System Block Diagram

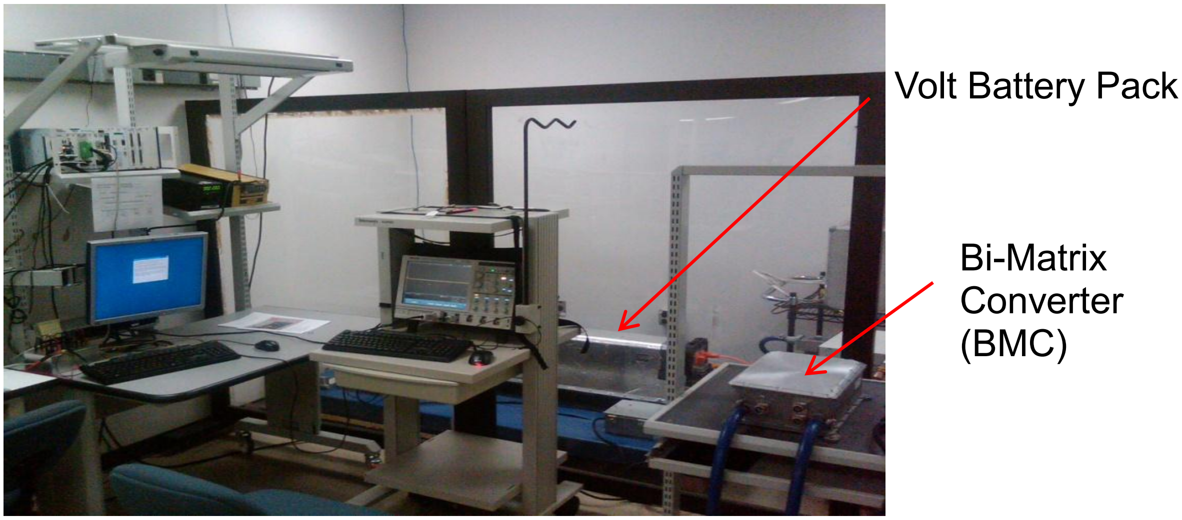


Figure 40 – Picture of Battery to Grid lab set-up

Conclusions

The BMC (Bi-Matrix Converter) demonstrated both charging and inverter mode. Battery operating voltages inputs up to 430V were demonstrated. The concept successfully demonstrated functionality for battery to grid using a single converter. Commercialization of the technology though will greatly be affected by the development of reverse blocking semiconductor switches, e.g. RBIGBT's .

Gen II Rechargeable Energy Storage System Development, Testing and Performance

Project Details

The RESS development shall focus on key battery systems and components. The development shall be completed to established levels of enhanced performance consistent with conventional production RESS requirements, including but not limited to, operating environment, duty cycle, and durability. To effectively demonstrate an improved implementation to the marketplace, measurable targets will be utilized. Specific enhancements include:

- 20% Reduction in Cost
- 10% Increase in Volumetric Density
- 10% Increase in Gravimetric Energy Density

Overview

The focus of the Gen II RESS focused on optimizing the overall value to the customer. The development work concentrated on four areas. These areas were pack performance, pack cost, pack mass, and pack volume. The development cycles for this optimization occurred in 5 events. The improvements were spread over these events based on the maturity of the pack components at the time of each event. The different levels of design maturity for these different events were determined by base design, supplier selection, supplier design development, development/validation results, and manufacturing capability. The development work was conducted on these packs during these design cycles. Development work consisted of pack testing for performance, pack testing for durability, and pack integration into vehicles. Pack testing for performance included sealing capability, electrical performance, safety performance, and energy performance. Pack testing for durability included mechanical fatigue testing, thermal fatigue/shock testing, corrosion testing, and cycle life testing. The testing performed on the packs validates the design to be used in vehicles.

Development

Cycle 1

The first cycle of pack development concentrated in the three core areas of the RESS. The areas were the module system, the housing system, and the electrical system. The first build was the first hardware integration of the three areas in the pack. The first focus area on the build was module. This build validated the basic module design. The module design was optimized for a reduction in complexity while still meeting the pack level requirements. This first build included the initial optimized cell. The cell was optimized for its Power/Energy ratio. This allowed the cell to be designed the lowest cost while meeting the pack level requirements. The second area of concentration for the build was the housing system. The build validated the module to the tray retention system and the sealing system for the enclosure. The final area to be validated during this build was the high voltage component concepts. The battery disconnect unit and manual service disconnect designs were integrated into a pack for the first time.

Cycle 2

The second cycle of the pack development concentrated on two areas of improvement. The pack monitoring electronics were new. The module included updates to the cell joining board and section end plates. The electronics were optimized to reduce complexity over Gen I RESS. This optimization allowed improvements to the cell joining board. The section end plates were further optimized for cost during this build.

Cycle 3

The third cycle of pack development concentrated on the three core areas of the RESS. This included housing updates, module updates, and electrical updates. The housing update included a tray change from cast aluminum to stamped steel. The module update concentrated on changes following the selection of the production supplier for the cell joining board. This selection drove a number of design changes which needed to be integrated into the pack. The electrical updates were driven by changes following the production supplier selection. The wiring had to be updated based on the cell joining board updates and build observations from Cycles 1 and 2. The last area of design change was in the battery disconnect unit. Observations from the design concept used in Cycle 1 and 2 were complete and integrated into the pack for this development cycle.

Cycle 4

The forth development cycle had one area of concentration, the cell. During the third development cycle the cell supplier approached the RESS execution team on an improved cell design. This design further optimized the internal cell design while meeting the power to energy ratio of the cell used in development cycles 1-3. This pack design would be used in the vehicle development fleet while undergoing pack level testing in parallel.

Cycle 5

The fifth development cycle concentrated on two areas. The areas included the pack housing system and electrical system. The housing system optimized the module retention system based on validation testing and field observations on Gen I. The housing system brought production suppliers online for this event. The production changes necessary for manufacturability were included in at this time. The electrical system had the wiring design updated based on supplier manufacturability concerns and GM assembly quality concerns. The electrical system also provided an updated battery disconnect unit based on component and RESS testing.

Improvements

The Gen II RESS development cycles optimized many aspects of the RESS system. Areas of the RESS optimized included performance, cost, mass, and volume. The three core areas supported this improvement. These core areas were the housing system, the module system, and the electrical system. The housing system improved the cost and mass of the components. The cost improvements seen in the system came from Gen 1 studies of pack performance for the pack cover, complexity reduction of the tray based on vehicle structural optimization. The vehicle structural optimization supported the mass reduction of the housing system. Cost improvements in the sealing system supported the overall goal of the RESS. The overall volume of the RESS was determined by the housing system. This overall volume was determined by balancing internal RESS requirements for clearance with the available packaging space within the vehicle.
The module system of the pack optimized the system for cost and mass. The cost improvements in the module system were driven by cell cost optimization and component complexity reduction. The cell internal construction was optimized for its power to energy ratio. The cell footprint was maximized within the available space allowed. This allowed the cell to be optimized for cost while meeting the pack level requirements for power and energy. The optimization of an individual cell allowed the module system to undergo a complexity reduction. By optimizing the thermal characteristics of the module through CAE and demonstrated through the development cycles, the module system reduced part count significantly. The part count reduction directly supported improvements in mass and cost of the RESS.
The electrical system of the pack improved the system for cost and mass. The cost improvements seen in the electrical system focused on the RESS electronic modules and battery disconnect unit. The electronic modules were integrated to reduce complexity. This reduced complexity of the modules but increased the complexity of the pack wiring. This integration at a system level provided an overall system

improvement. The battery disconnect unit was optimized with discrete components. This included the adding components from other areas of the Gen 1 pack into the unit. This supported an overall reduction in cost and mass of the system.

Conclusion

The work completed during the development cycles of the Gen II RESS has concluded with an overall improvement to the system when compared to the Gen I RESS.
Table 9 is a summary of the comparative improvements:

Enhancement (Pack Level)	Target Improvement	Achieved Improvement
Cost ($/kWh)	20%	35%
Volumetric Density (kWh/l)	10%	5%
Gravimetric Density (kWh/kg)	10%	20%

Table 8 – Gen II RESS Performance Improvements

Publications and Collaborations Generated under the Cooperative Agreement

Publications

- Sacramento Municipal Utility District Plug-in Electric Vehicle Market Readiness – December 14, 2011
- Advanced Vehicle Testing Activity – Plug-In Electric Vehicle Demonstration Results (Thus Far) – February 2012
- Industry Standard DC Fast Charging in now a reality thanks to the IES Keywatt DC combined charging system – March 8, 2013 (http://www.ies-synergy.com/en/actualites/page/2)
- INL Website – complete set of project reports – May 2011 through March 2014 (http://avt.inel.gov/gmvehicledemo.shtml)
- Electric Vehicle Supply Equipment Infrastructure (Sacramento Municipal Utility District) – January 16, 2014
- Results and lessons learned from a Plug-in Electric Vehicle (PEV) demonstration project (Sacramento Municipal Utility District) – March 29, 2014
- Autonomous Grid Services through Plug-In Electric Vehicle Charging (Sacramento Municipal Utility District) – March 30, 2014
- Sacramento Area Regional Coordination for EV Readiness (Sacramento Municipal Utility District) – March 31, 2014
- Data Analysis and Reporting of the 150 Chevrolet Volts ARRA Demonstration Fleet – July 2014

Networks/Collaborations

- INL Website - http://avt.inel.gov/gmvehicledemo.shtml