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FINAL PROJECT REPORT

Demonstrating Plug-in Electric Vehicles Smart Charging and Storage Supporting the Grid

California Energy Commission

Edmund G. Brown Jr., Governor

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PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Demonstrating Plug-in Electric Vehicles Smart Charging and Storage Supporting Grid is the final report for the Demonstration of PEV Smart Charging and Storage Supporting Grid Objectives project (Grant Number EPC-14-056) conducted by UCLA SMERC. The information from this project contributes to Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

This report presents the development and deployment of an electric vehicle (EV) charging system in Santa Monica, California, consisting of smart charging, vehicle-to-grid, vehicle-to-building, demand response and power quality sustainable capabilities to achieve grid resiliency and economic benefit to EV fleet owners. The research team from the University of California, Los Angeles (UCLA) Smart Grid Energy Research Center used its wireless network communication system and bi-directional EV charge infrastructure technologies to demonstrate the grid needs such as peak shaving, load leveling, and renewable source smoothing. The team developed unique algorithms, software, and hardware, and integrated a battery energy storage system EV. As a project result, the UCLA Smart Grid Energy Research Center validated the viability of bi-directional electric vehicle infrastructure, air quality enhancement, and financial benefits from the system.

Keywords: Plug-in Electric Vehicle, Microgrid, Battery Energy Storage System, Photovoltaic, Vehicle-to-Grid, Smart Charging, Demand Response.

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EXECUTIVE SUMMARY

Introduction

There has been significant growth of plug-in electric vehicles (PEVs) in California as a result of societal awareness of their environmental benefits, substantial improvement in battery technology and attractive federal, state, and local government incentives. California's goal is to reduce greenhouse gases to 40 percent below 1990 levels by 2030, and PEVs are expected to substantially contribute to this reduction. Besides helping to reduce pollutants and emissions, PEVs also can be used as a unique and essential method for energy storage.

The American Automobile Association and Federal Highway Administration state that a typical U.S. driver spends less than an hour each day in personal vehicles and drives an average of 37 miles per day, resulting in the vehicle being stationary for more than 23 hours each day. A modern PEV, when plugged into the electricity grid, could therefore serve as a supplemental energy storage device by using the battery to provide electricity for peak demand and congestion. Drawing from the supplemental stored energy of the PEVs would reduce having the grid operator purchase additional energy storage.

Moving towards California's 2050 renewable target of reducing greenhouse gases by 50 percent below 1990 levels has been helped by large amounts of solar photovoltaic (PV) generation into California's electric grid. Excessive generation in the middle of the day from PV is the ideal time to charge the PEVs- a service the PEVs can easily provide especially in larger numbers. Effectively managing the grid with PEVs using sensors, data, modeling, analysis and smart software-based controls, energy pricing, driver preferences, real-time and historical PEV charging information, renewable electricity generation on the grid, and grid capacity information would convert the PEVs into a high value storage asset and help manage inconsistent renewable energy generation. Therefore, the infrastructure for "smart" electric vehicle support equipment is essential to the success in growth of PEVs.

Vehicle-to-grid (V2G) and vehicle-to-building (V2B) technology takes grid impacts into account and may provide additional value to customers, while supporting the grid. For example, V2G and V2B enable a PEV to discharge energy into the grid or to support building loads which helps reduce peak loads and associated energy bills or can provide power to the customer during times of power shortage. While most current PEVs only support unidirectional charging from grid to vehicle, V2G and V2B technology allows power to flow in the reverse direction so a PEV can act as a battery energy storage system. Although a single vehicle may not provide large amounts of power, large numbers of vehicles can be aggregated into a single resource allowing the grid operator to draw significant amount of power.

Grid services help utilities resolve issues of reliability and stability. For example, PEV charging can be used to take excess energy during times of over-generation (such as during peak PV generation) or provide energy back to the grid when demand is high. The challenge with PEVs providing grid services is the ability to aggregate and control multiple PEVs for a coordinated response.

California has been a leader in PEVs nationwide. The market is focused on meeting the basic demands of charging, and the market needs to integrate an electric vehicle support equipment infrastructure with the electric grid. Advanced technologies, such as smart charging, V2G and V2B solutions, are required to be developed and demonstrated to solve electric grid problems and reduce costs of PEVs.

Project Purpose

This project was designed to develop and demonstrate advanced charging infrastructure (software and hardware) for smart charging, V2G and V2B, grid services, and cost recovery validation. Demonstration occurred in a controlled setting at the University of California, Los Angeles (UCLA) and then expanded into public infrastructure in the City of Santa Monica.

This project developed and demonstrated a solution for smart charging, V2G and V2B, and grid services. This solution is helpful for PEV fleet and parking garage owners, because it can help bring down the cost of adding charging infrastructure and the cost of charging large numbers of PEVs through coordinated control.

Project Process

The research team conducted the project in four phases: (1) technology development, (2) infrastructure setup, (3) algorithm implementation, and (4) data collection, analysis, and system refinement. In the first phase, research was conducted on relevant technologies and a system was designed. The project team determined that it was necessary to develop a flexible smart PEV charger, V2G and V2B station, and a communication network to support demonstrations in the second phase. This step was necessary because the PEV manufacturers require different V2B connectors and the architecture of PEV chargers are not commonly standardized. The team collaborated with the UCLA facility management and campus fleet operation on the deployment plan.

The team continually refined the station and the communication network. The project team also identified power ratings from pre-existing PV panels on the demonstration site and designed a battery energy storage system with suitable resource capacity to support the average PEV charging load to supplement the PV during peak charging and support grid services. The PV generation was monitored with a power quality analyzer and used as an influencing factor for smart charging. The battery energy storage system was used to support grid service such as peak load reduction.

In the second phase, prototypical smart charging and energy management systems were developed and tested with the in-house developed instructions and software codes at the UCLA testing sites and then installed and used at the demonstration site in the City of Santa Monica. Smart charging was achieved with the developed PEV charging scheduling algorithms and was validated and improved through the interaction and feedback from a mobile application, developed and distributed among participating users for this project. The V2G and V2B system was implemented with a local controller that received commands to change its power flow and current and communicate this instantaneous information to the computers since most chargers

do not provide this capability. Furthermore, lack of V2G standards by car manufacturers combined with lack of open architecture for enabling bi-directional charging necessitated employing our local controller implementation.

In the third phase, the installed hardware and software were used to implement experiments and algorithms designed in the first and second phases. The smart charging algorithm, configuration of the PEV support equipment, and communication network were further refined based on test results and user feedback. The battery energy storage system was assembled and tested to support various grid services.

In the fourth phase, the project team conducted a demonstration in the City of Santa Monica and collected relevant data for 12 months. During this phase, various load curtailment; load shifting; and V2G, V2B, and smart charging algorithms were tested to validate grid services. The data on energy consumption was used to estimate energy cost and validate cost reduction.

This project involved interaction with experts from utilities, industry, sustainability officers, facility management, transportation service organizations, electric vehicle charger manufacturers, and the project's technical advisory committee.

Project Outcomes

Smart Charging: The team developed and refined a flexible smart PEV charger, managed by a cloud-based software system, and connected to a mobile application. Each smart charger was equipped with four PEV connections, so that four PEVs could be controlled at one time. The software controls the charger power output to each PEV simultaneously, based on inputs from the site, user and grid. A key algorithm within the smart charging system incentivized users to maximize using solar energy, allowing better grid control, and reducing the energy cost for the utility consumer by increasing the amount of solar on the grid. This technology increased the number of charging sessions from 56 sessions (average monthly charging sessions of a conventional charger) to 108 sessions at Santa Monica Civic Center parking lot - an increase of about 92 percent use, as compared to a conventional charger; and also increased the total energy delivered from an average of 588 kWh (average monthly energy delivered) to 837 kWh - a 42 percent increase in total energy delivered.

V2G and V2B: Two V2G and V2B systems were used to investigate results from different types of PEVs. The first system, using a Mitsubishi PEV, provided 1.5 kW for discharging and 3.3 kW for charging. Due to its limited power capacity, a higher power system using Princeton Power direct current fast charger (DCFC) was installed and used to provide 30 kW bi-directional power flow. The higher power bi-directional power provided sufficient controllable load to leverage the PEV charging load and PV generation in the parking garage at the demonstration site in the City of Santa Monica. It also provided load shaving resource by supporting building and PEV charging loads, or as an energy source/sink for demand response at ± 30 kW capacity.

Grid Services: Grid services were enabled through the smart charging algorithm residing on the cloud software. The algorithm employed a user-charging pattern prediction model and an actual building load profile, shifting the peak load by scheduling the PEV charging load to a

time when the building load was decreased to a certain threshold. Using this algorithm, the peak power consumption was reduced by 35 percent which would allow a site host to avoid a utility's demand charge and pave the way for demand response -- a key grid service for the utility.

On certain days, especially during spring and fall when grid demand is lower, PV over-generation results in demand collapse in the middle of the day and a steeply rising load curve during the evening hours, making it difficult for the grid operator to balance the generation and load. Controlling this phenomenon can be achieved by the system using the Princeton Power DCFC that receives scheduling signals from the cloud software by messages from the grid operator to charge the PEV at higher power levels in the middle of the day to mitigate the impact of PV over-generation.

A key service to the site host is the ability to use load shifting based on time-of-use pricing, which in turn benefits the utility's load balancing needs. For example, the battery energy storage system, when used in conjunction with the DCFC, provides potential benefit to the site by reducing the cost per charging session by 23 percent via exploitation of time-of-use pricing. In the future, V2G and V2B could itself be used to help PEVs reduce cost through this opportunity.

Using smart charging in the system without the V2G has benefits when the grid operator offers time-of-use pricing, and the customer is paying demand charges. By shifting PEV charging load from peak to off-peak itself has shown a savings of \$2,006 for one year of data collection at the demonstration site consisting of seven level-2 smart PEV chargers (14 plugs) and 16 level-1 PEV chargers.

In addition to the PEV curtailment, the V2G hardware in combination with the stationary battery storage at the demonstration site provided the system with a total of 117 kW of demand response capability which is greater than the minimum of 100 kW required by Southern California Edison (Time-Of-Use-General Service Base Interruptible Program - March 2017). Roughly half of the 117 kW demand response capacity was provided by the V2G system by going from +30 kW to -30 kW or its inverse, resulting in a total controllable load of 60 kW (± 30 kW). Eventually, V2G is expected to cost substantially lower than what it is now as the technology gets standardized (there is almost no standardization today) as well as volume sales, making it far more competitive cost-wise than stationary battery energy storage system. The team also concluded the following as the result of this research:

- The proposed system can be used as a foundation for DER management system in a microgrid system. With a focus on microgrid (grid-tie and islanding) operation, a demonstration project can be the next step from this project.
- This research finds that based on the type of locations and parking limitations, customized scheduling algorithms and power management rules may be required. The scheduling algorithms and rules must be reviewed monthly and improved based on the data obtained.

- The technologies and systems developed in this project, specifically those associated with V2G, are stable and mature. They can be further developed as an energy management product and be commercialized through startup companies.
- For V2G to be scaled up on the grid, advances are necessary in technologies that support communications, data and control standards between the interfacing equipment involved in V2G and that includes PEV, charger, infrastructure and grid. An open and standards-based approach would enable a much faster development of the existing modules to inter-operate seamlessly as well as for innovations to occur to lower the cost eventually leading to mass market adoption.

Benefits to California

This project showed that larger numbers of PEVs can be added to the grid by maximizing the existing PEV charging infrastructure without the need to add large amounts of power capacity. Using smart PEV chargers, the system can save on PEV charging infrastructure cost for site owners. Compared with a single plug electric vehicle support equipment, UCLA's smart PEV chargers allow roughly twice the number of charging sessions per day - benefitting the site host/utility customer by serving a greater number of customers and serving larger amounts of energy per unit capacity.

Using PEVs to participate in demand charge reduction and demand response, improved grid reliability. By smart-control of PEV charging and even before using a V2G and V2B system or storage, the site owner and fleet manager can avoid demand charges, take advantage of time-of-use pricing through peak reduction, and save money. By adding V2G and V2B and storage to the electric vehicle support equipment, the site owner or fleet manager can receive additional rewards annually from demand response incentive programs. Furthermore, using only the battery energy storage system to shift direct current electric vehicle charging can result in additional energy cost saving for the site host.

Utilities can increase grid stability by using smart electric vehicle support equipment systems. These systems would provide various grid services, including load smoothing and demand response event support. Improved grid stability is also achieved by integrating V2G and V2B systems and battery energy storage systems to provide power for buildings and grid support during periods of power shortage. Using an external battery energy storage system reduces the effect of fast chargers on the grid, which also improves grid stability. Using smart charging algorithms to charge PEVs during periods of excess solar generation can also solve the power instability problems caused by over-generation from the renewable energy source.

Greenhouse gases are expected to decline by using PEVs instead of internal combustion engines. Based on the 216 new PEV user accounts created during this project, greenhouse gas emissions can be reduced from 1,241 tons for gasoline vehicles in contrast to the 621 tons of greenhouse gas emissions for PEVs.

CHAPTER 1: Introduction

The California vehicle-grid integration (VGI) roadmap [1] identified the vehicle-based grid services as a key to maximize benefits to the owners of plug-in electric vehicles (PEVs) as well as of the electric grid operator. The California Independent System Operator (California ISO) in coordination with the Governor's Office, California Energy Commission, California Public Utilities Commission, and California Air Resources Board developed this roadmap. It identified three tracks for determining the value of VGI, developing the enabling technologies, and developing the associated policies. While bidirectional PEVs offer a promising cost-effective solution to stabilize the grid, the lack of a proven bidirectional PEV infrastructure that is standardized and an efficient and ubiquitous smart energy management system in the market could limit the widespread adoption of PEVs by consumers.

To demonstrate grid resiliency, cost savings to PEV fleet owners, and benefits to investor-owned utilities (IOUs), the research team developed and deployed an advanced smart and bidirectional PEV charging infrastructure (Figure 1).

Figure 1: Examples of PEV Charging Infrastructure



(a) V2G Station; (b) PMU/PQA meter; (c) Battery cart; (4) Civic Center Level 2 EV charger; (5) BESS integration testing.

Credit: UCLA SMERC © 2014-2018

This infrastructure enabled smart charging (SC) [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] [18], vehicle-to-building (V2B) [19], vehicle-to-grid (V2G) [20] [21], and other promising applications for providing grid services with demand respond (DR) [22] [23] [24] participation. The smart charging hardware and software followed the Society of Automotive Engineers (SAE) J1772 standard (a North American standard for electric vehicles' electrical connectors). The research team tested these advanced technologies in Santa Monica demonstration sites in public settings. Moreover, UCLA's Smart Grid Energy Research Center (SMERC) deployed smart charging and micro-grid technologies at the Southern California Edison (SCE) territory to address the integration of PEVs into the electric grid. Figure 2 shows an example of SMERC's control center that monitors and controls all energy flow of PEV charging sessions.

Figure 2: Example of SMERC Control Center



SMERC's control center monitors and controls all energy flow of PEV charging sessions.

Credit: UCLA SMERC © 2014-2018

SMERC's research team developed the backbone technologies [1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] [18] [19] [20] [21] [22] [23] [24], which include WINSmartEV™ [2] (an intelligence-based bidirectional PEV infrastructure), and WINSmartGrid™ [25] (a wireless communication network). These technologies determined the optimized charging and/or backfill operations based on daily operations, PEV profiles, user preferences, grid-service events, and grid capacities, which maximized benefits to PEV fleet owners and utilities. To predict the grid impact and potential benefit from a large number of V2G capable PEV fleets in the state, demonstrations of grid services were scaled up using various simulations.

The SMERC team collaborated with an advisory board and project partners that supported the project with additional resources, including technical and commercial consultations, guidance and contributions to fleet management, demonstration sites, simulation platforms, and V2G-enabled Nissan and Mitsubishi PEVs, to ensure a successful and cost-effective project.

CHAPTER 2:

Project Objectives

This project developed and demonstrated the functions of smart charging (SC) technology, including:

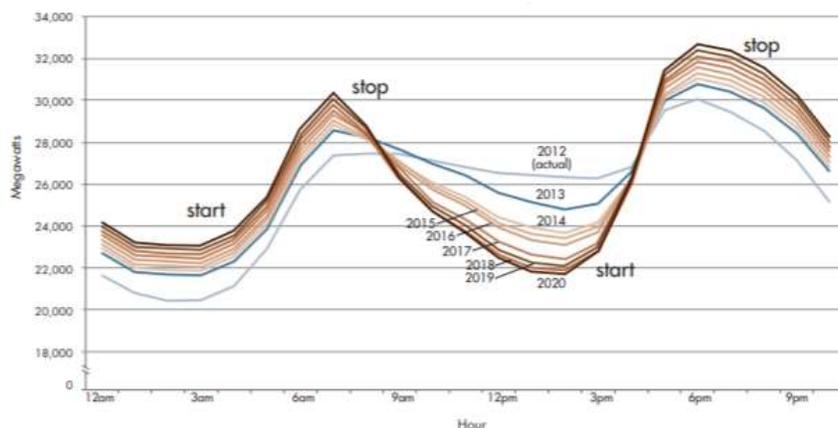
- Smart charging based on energy price, user preference and grid capacities.
- Vehicle-to-grid (V2G) focuses on two-way communication and energy flow.
- Vehicle-to-building (V2B) uses EV fleet storage to support building loads.
- Grid services—mitigate the PV duck-curve with focus on V2G and grid-to-vehicle infrastructure to smooth the over-generation from renewable sources.
- Grid services—automated demand response demonstration that involves both actual and simulated real-time grid services, including demand response program participation by using V2G technologies.
- Grid services—load leveling for Level-3 (fast charging) with battery energy storage system (BESS).
- Grid services—bi-directional EV fleet infrastructure with renewable solar generation and BESS.
- Grid services—peak shaving through SC, V2G, and BESS.
- Grid services—local power congestion minimization through SC, V2G and BESS.
- Cost recovery validation—to maximize the fleet owner's benefits by enabling the SC, V2B, V2G and/or grid-service technologies.

The proposed project aimed to provide a smart comprehensive bidirectional-charging infrastructure that enables PEVs to have a dual-function as energy loads and distributed energy resources. This two-way charging system improves the efficiency, stability, and reliability of the power grid by balancing and leveling the load, as well as enabling grid services, such as peak shaving. This PEV charging system provides three different technologies (SC, V2G, and V2B), which will benefit PEV owners and utility companies.

The SC technology provides power demand optimization and electricity costs reduction by controlling line currents, correcting voltage deviation, and flattening load curves. By investing more into this technology, smart charging could alleviate energy inefficiencies and losses.

The V2G technology allows PEVs to discharge power from their batteries into the grid during periods of high demand to stabilize the grid, reduce overall costs, and reduce the emissions by maximizing the use of renewable sources. In fact, this technology integrates PEVs with smart-charging schedules using low energy consumption at off-peak periods, which will enhance the power system's efficiency, reduce CO₂ emissions, and improve integrating short-term PEV power into the renewable portfolio. Moreover, V2G can help flatten the “duck curve” [26] (a graph of the net power demand during the day, which demonstrates the timing imbalance between the renewable energy production and the peak demand times as shown in Figure 3) by acting as an incentive to improve the consumer behavior.

Figure 3: Net Load Curve with Renewable Energy Product and Load



Credit: California ISO [26].

The V2B technology provides storage capacity that benefits vehicle and building owners by allocating reliable emergency backup power services during outages or blackouts, lowering energy costs for buildings, and offsetting the higher costs of PEVs during off-peak power use. This technology focuses on the time-of-use (TOU) pricing, peak shaving, and demand charge avoidance to generate, store, distribute, and consume the energy smartly.

The proposed smart bidirectional charging system will maximize the benefits for utilities, and meet charging requirements of fleet owners by enhancing the grid services as well as the different technologies including SC, V2G, and V2B. In fact, the V2G concept will smooth energy demand peaks and provide balanced power generation by supplying the grid with energy when it needs it most. Use of this technology by fleet owners allows them to charge their PEVs during off peak hours and sell the energy back to the utility during peak hours, providing fleet owners with economic incentives. The bidirectional charging system will provide management of the buying and selling decisions to ensure the achievement of these benefits.

Developing a smart bidirectional charging system presents macro as well as micro level challenges. Macro level challenges include alleviating the PEV owners' anxiety over battery usage and range reduction, convincing PEV manufacturers to make V2G-ready vehicles, and convincing utilities to provide signaling services of energy needs. These macro obstacles may require government, utility and regulatory agency interventions. Micro level challenges include the technical obstacles to the development of a bidirectional charging system.

In addition, the research team aims to prepare large-scale adoption of V2G by using grid-service simulations based on collection of data. This data, obtained from pilots on fleet vehicles that are charging in predictable locations, along with simulations, predict the grid-wide effects of V2G. The results could be useful for utilities to control rates and provide incentives for V2G, which will reduce carbon emissions and enhance grid stability, energy efficiency, and grid economics.

CHAPTER 3:

Project Approach

Based on the project objectives, UCLA SMERC studied state-of-the-art technology in smart EV charging, renewable integration, power grid impact and integration, available V2G solutions, BESS, demand response, and communication network to create system design, implementation and deployment plans. Experts from various smart grid related fields and the Technical Advisory Board were consulted throughout this project. Feedback from site owners, EV drivers and facility management were considered to implement a UCLA microgrid test bed and Santa Monica demonstration sites. The following sections describe the approaches and tasks conducted to achieve the project goals.

Software and Algorithm Development

UCLA SMERC created a user friendly, grid friendly, and garage friendly EV charging system using technology from WinSmartEV™ program. With the vast amount of data captured through WinSmartEV™ Platform, vital information such as, power consumption, grid impact, and user preferences are inputted into this system using which various EV charging algorithms within the system are tested to determine optimum charging scheduling.

The WINSmartEV™ EV charging network uses a centralized control system to monitor and regulate the network for real-time smart charging services. This smart charging infrastructure uses standard technologies to create a network that facilitates charging services for the end user and provides monitoring and control tasks for site maintainers/operators. The charging services are completely adaptable by way of local or remote charging algorithms. In addition, the architecture incorporates multiplexing capabilities with a unique safety system that integrates safety at all levels of control. Fleet drivers use mobile devices or a kiosk tablet installed at nearby locations to login and activate the chargers. Charging status can be obtained from the mobile app. The drivers can check on the total energy received by their vehicle, expected fully charged time and disconnect the charger remotely if necessary.

User Friendly EV Fleet Charging Management Interface

UCLA SMERC studied and investigated the operations of the PEV fleet by interviewing and/or conducting surveys with fleet drivers. Based on the interview result, mobile apps are implemented to allow smart charging/discharging operations on Android and iOS platforms. The users may start/stop charging, review charging record and specify their charging profiles and preferences shows some screen shots from the mobile app and kiosk system developed.

Figure 4: Screen Shots from EV Mobile Apps and Kiosk System



Credit: UCLA SMERC © 2014-2018

Personalized EV Charging/Discharging Management

SMERC understands that it is not only what the system is capable of doing, but also how the system is presented and used. WINSmartEV™ is distinctly focused on a system that is appealing to modern culture and provides its users with the right incentives. The Personalized EV Charging/Discharging Management Console (EV Control Center) was created to manage EV fleets. Details about this console was included in the deliverable report, *Task 2.2 Personalized EV Charging and Discharging EV Fleet Management System User Manual*.

Modeling and Simulation

To study benefit of smart charging, V1G, V2G operations and conduct cost-revenue analysis, some modeling and simulation tools were used to simulate the scale up impacts.

Grid-Scale Impacts, Opportunities and Predictions

V2G-SIM [27] from Lawrence Berkeley National Laboratory (LBNL) was used to evaluate case studies to predict grid impacts and opportunities for using PEVs. The following five use cases were discussed and proposed for simulation and analysis:

1. Peak Shaving/Valley Filling

As substantial renewable generation (especially solar) is deployed, four important issues attract more and more attention. They are: 1) Low daytime net load or over-generation, 2) High evening net load 3) Sharp mid-morning down-ramps 4) Substantial evening up-ramps. PEVs can maximize its power consumption during the daytime over-generation period (9 am to 2:30 pm) and limit charging or even feed energy back to the grid (V2G)

during the evening peak (around 5 pm) to limit renewable curtailment and mitigating the peak load.

2. Ramping Mitigation

PEV charging load can be adjusted to minimize the ramping rates of the net load profile. For sharp ramp-down periods (7 am to 9 am), this typically results in PEVs transitioning from generating electricity to charging during the hours adjacent to the sharp ramp-down. For sharp ramp-up periods (2 pm to 5 pm), PEVs transition from consuming energy to discharging during the hours adjacent to the sharp up-ramp. With this control objective, ramp-down and ramp-up rates are mitigated to the greatest extent.

3. Emergency Demand Response

PEV is a flexible load which can provide demand response services. It can stop charging when receiving emergency demand response call from the utility company.

4. Demand Charge Mitigation

For business owners, their electricity bill is comprised of two components: energy consumption and demand charges. With electricity consumption on the rise and utilities struggling to keep pace with market and regulatory changes, demand charges can account for a significant portion of business users' utility bills – at times between 25–50 percent. Furthermore, in contrast to rates outside of peak periods, demand charges have been rising steadily, year after year. In this use case, the team studied how smart charging can reduce the peak of charging load.

5. Ancillary services (spinning reserve, frequency regulation, etc.)

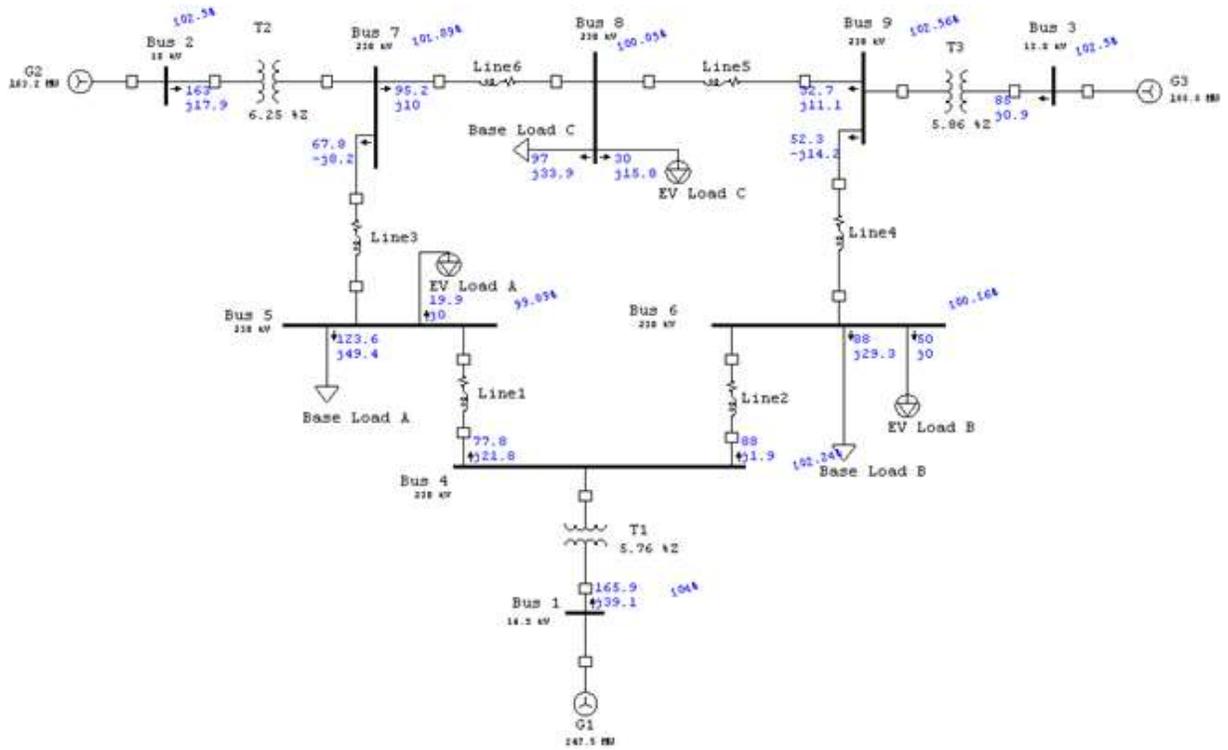
PEVs have high charging and discharging flexibilities, which enable them to work as “battery storages” to provide ancillary services to the grid. The provision of ancillary services must be decided on in advance, with a certain lead-time. Lead-times are necessary to organize available resources (such as PEVs) or to respect current market structures (for example ancillary services co-optimized with day ahead wholesale markets). Once a service is contractually agreed upon, the total power consumption of the collection of vehicles must follow a prescribed reference signal that depends on the nature of the commitment made. In this use case, the benefits of providing ancillary services including frequency regulation up/down and spinning reserve were analyzed. To maximize the total benefits, the team designed the bidding strategy for aggregator to participate into the wholesale electricity market.

Scale Up Emulation of EV Use Cases to Benefit Fleet Owners in IOU Territories

This project developed and used an advanced smart and bidirectional PEV charging infrastructure to demonstrate grid resiliency, cost savings to PEV fleet owners, and benefits to investor-owned utilities (IOUs). The grid services capability is scaled up in simulation to predict the grid impact and potential benefit from a large number of V2G capable PEV fleets in the State. To this end, ETAP® [28] software is deployed for scaled up emulation of EV Use Cases. ETAP® offers an integrated distribution network analysis, system planning and operations solution on the testbed platform to simulate, analyze, operate and scale the EV use cases. To evaluate the grid impact and benefits from a large number of PEVs under managed bidirectional

charging systems, three different base load and EV load profiles are applied to load buses #5, #7 and #9, as shown in Figure 5.

Figure 5: ETAP Power Grid Simulation with EV Load

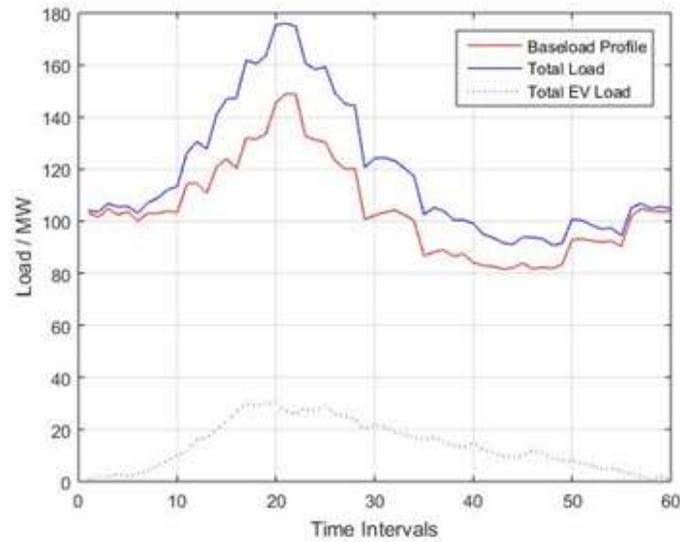


Credit: UCLA SMERC © 2014-2018

For base load modeling, hourly power consumption historical data is retrieved from UCLA facility management and scaled up to the level of a small city with about a population of 50,000, which is comparable to the cities in Los Angeles area such as Culver City and Beverly Hills. Predicting EV user daily traveling schedule and energy demand is carried out based on the historical data in UCLA SMERC smart charging infrastructure collected during the past four years. The EVs assigned to each load bus is 15,000, consisting of 35 percent light duty vehicles market shares as predicted for the year of 2040 [29]. This simulation optimal case showed how EV charging demand scheduling mitigated overloading conditions.

When no charging control is implemented there is the potential that EV charging demand peak overlaps with the grid peak demand (time interval~20), which can propel the system toward intentional load shedding conditions or instability (Figure 6).

Figure 6: Uncoordinated EV Charging Demand

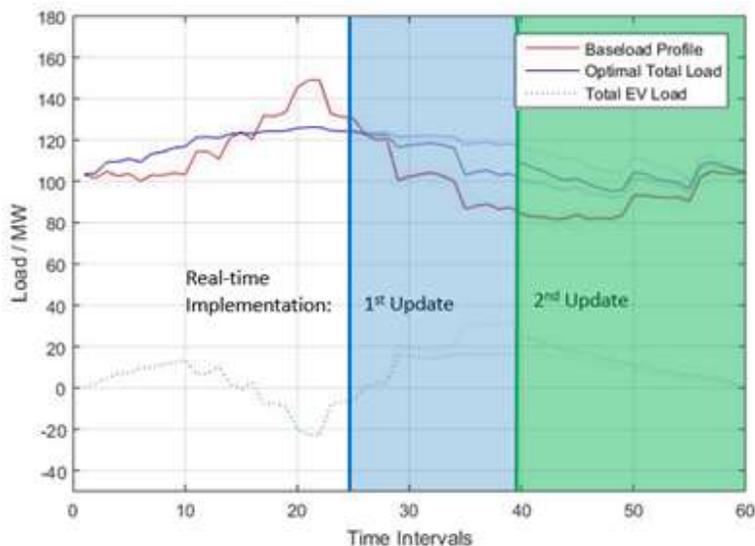


EV load peak overlaps with grid peak demand

Credit: UCLA SMERC © 2014-2018

However, the coordinated charging arranges as much V2G discharging sessions as during grid peak hours, and then coordinates full capacity charging activity over its control network during low load demand time intervals from 35 to 55 (Figure 7). The total load profile also reveals that the peak load after coordinated charging implementation is 125MW, while it is 180MW in the worst case without EV load coordination

Figure 7: Coordinated EV Charging Demand

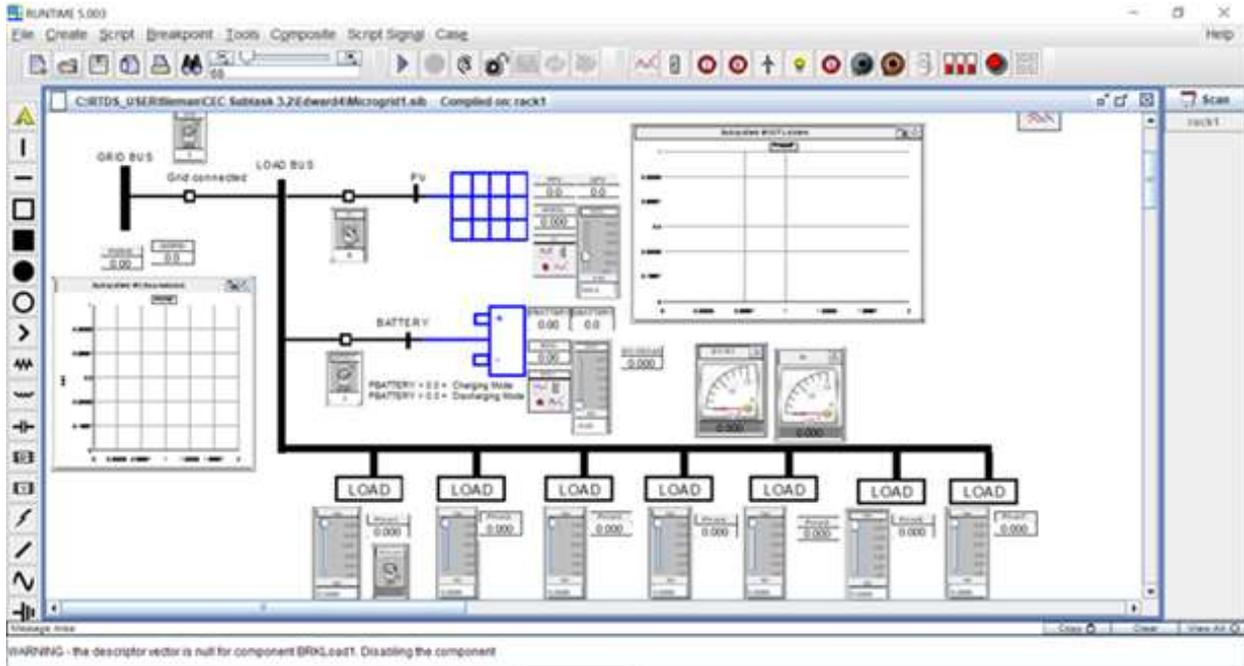


Optimal load profile with shifting EV charging demand.

Credit: UCLA SMERC © 2014-2018

As another case study, Santa Monica Civic Center charging infrastructure is modeled in RSCAD/RTDS real time simulator (Figure 8), to study the impact of V2G and SC on total load demand of the charging infrastructure.

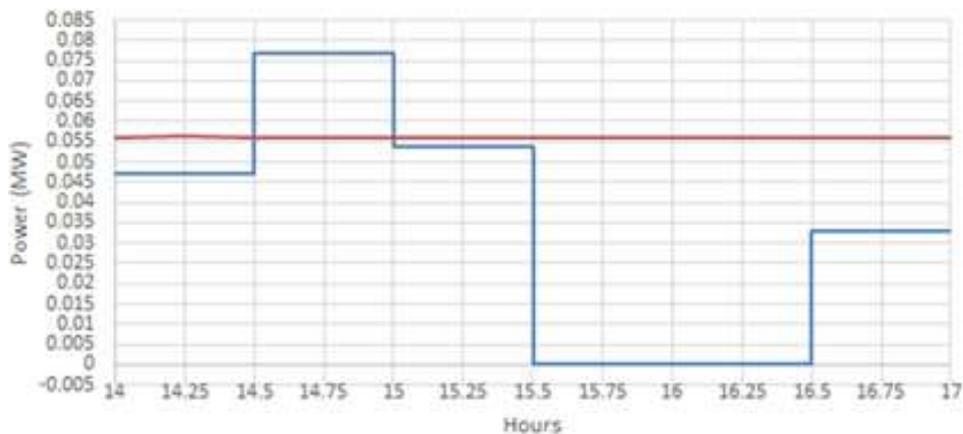
Figure 8: RTDS Simulation Model of Santa Monica Civic Center Charging Infrastructure



Credit: UCLA SMERC © 2014-2018

The case study includes 213 kW solar panel, seven level-2, 6.6 kW EV chargers, and one 30 kW DC fast charger (DCFC). Through the simulation, it is shown how SC in combination with V2G can provide load leveling (Figure 9).

Figure 9: Comparison of System Load With and Without Smart Charging and V2G



Load with (blue) and without (red) smart charging and V2G.

Credit: UCLA SMERC © 2014-2018

SC takes effect at 14:00 wherein the charging rate of the EVs is throttled by 20 percent from 6.6 kW to 5.3 kW. At 14:30, it is assumed that the fast charger begins charging a vehicle at 30 kW, which is more realistic than assuming that a fully charged vehicle is already available to provide V2G services. Consequently, the system load increases from 46.2 kW to 76.2 kW. At this point in time, the price of electricity is still at \$0.68 and is most economical to supply the 30 kW of power. At 15:00, the EV charging rate is reduced to the minimum value of 2 kW. This counteracts the increase in load due to the 30 kW fast charging but not entirely. At 15:30, V2G is engaged and the system load drops drastically from roughly 54 kW to zero. The charging rate is simultaneously increased from 2.0 kW to a larger value to avoid having reverse power flow back to the grid. To avoid any confusion, it should be noted that immediately before 15:30, +30 kW is being supplied to a vehicle, and after 15:30, -30 kW is being supplied. Therefore, there is a change of 60 kW in the system load at 15:30. At 16:30, V2G is deactivated and the charging rate is returned to 2.0 kW to maximize energy cost savings at this time. Load leveling using V2G and SC results in considerable energy cost reduction by shifting the loads from highly-priced time intervals to the periods when electricity price is low.

Developmental Testing in the UCLA Micro-Grid

As of December 31, 2017, the UCLA Micro-Grid Testbed consists of 115 smart EV charging stations, two DC fast chargers, 35 kW PV system, a 76 kWh of Battery Energy Storage System (BESS) and 343 active EV users.

The following project tasks are performed and tested on UCLA Micro-Grid Testbed before their deployment on the demonstration sites.

V2G and V2B Technologies Based on SAE J1772 and CHAdeMO Standards

Currently there are three major standards that support bi-directional power flow charging, also known as V2G technology. They are ISO 15118 [30], SAE combined charging system (CCS) [31] and CHAdeMO [32]. Two V2G systems have been successfully used in the current project Mitsubishi MiEV V2G system and the Princeton Power V2G fast charger. The direct current (DC) fast charger from Bosch has also been installed in UCLA parking structure, which is mainly for testing of SAE CCS standard.

Figure 10 shows the Mitsubishi and Princeton Power V2G system. All of the V2G charging stations are connected with SMERC smart charging network. Charging session data are uploaded to the central server every minute. V2G charging stations can be controlled remotely by a command released from control center. The stations can perform V2G during a demand response event or grid service request.

Figure 10: Mitsubishi and Princeton Power V2G System Setup



The Mitsubishi V2G charging system connecting with a Mitsubishi MiEV and performing bi-directional charging (left).

A Nissan Leaf connected to the Princeton Power V2G charging station (right).

Credit: UCLA SMERC © 2014-2018

Safety and Reliability Analysis of the V2G and V2B System

Mitsubishi and Princeton Power V2G systems have provided several safety features. The V2G system has a grid tie inverter which can convert DC current to AC current and synchronize the phase of AC current to the phase of power grid. It is a UL 1741 (2005) [33] requirement for a grid-tie system to have approved surge protection. If the AC source is irregular or unreliable with power surges (a lower quality generator or inconsistent utility power, for instance), a surge protector is necessary. The surge protector used in Mitsubishi V2G system is FLEXware surge protector FW-SP-ACA.

The Princeton Power V2G system has charge cable electro-mechanical lock and ground fault detection for safety consideration. Before any voltage is applied to the terminals of the charge plug an electronic lock is closed on the plug. This prevents accidental or intentional removal of the plug while dangerous voltages are present at the output. When the plug is inserted properly there is a mechanical indicator window that is green. If the plug is not inserted properly, the indicator is yellow. When the lock is electronically activated, there is a red indicator light on the handle that illuminates to signal that the plug is secured and a charging session is in process. During the shutdown process the lock is only disengaged when the output voltage drops below 10V. The ground fault detection system is capable of measuring 0 to 50k Ohms ground fault. The Princeton Power V2G charger will shut down if the impedance between any of the DC terminals and earth drops below 50k Ohm.

As shown in

Figure 11, the Mitsubishi and Princeton Power V2G charger are enclosed in cabinet with locking and grounding mechanism, preventing any unauthorized access and possibly electric shock.

Figure 11: Exterior Cabinet Enclosure of V2G Charging Station



Mitsubishi V2G Cart (left); Princeton Power V2G DC charger (right)

Credit: UCLA SMERC © 2014-2018

API Deployment of V2G/V2B System Integrated into the Control Center

Integrating the V2G/V2B system into the control center is based on CHAdeMO protocol. Since CHAdeMO is a proprietary protocol, the Mitsubishi V2G system added a layer of DC/AC and AC/DC to allow current control. This reduced the overall efficiency. The Princeton Power can charge and discharge a 2013 (or later) Nissan Leaf with a DC fast charging port. The first benefit of this system is that it uses the CHAdeMO V2G protocol so it could control the on/off status of the system and also control the current of the input/output power.

UCLA SMERC integrated the Princeton Power V2G system with our EV control center to allow remote monitoring and control. The monitoring of the system is accomplished through the power meter that provides energy/power data at 1-minute sampling rate. This is accomplished through TCP/IP protocol and HTTP POST method. The data will first be stored in a MySQL database and then pulled by the web application for presentation on the control center or mobile app. For controlling functions by the users, it is accomplished via a mobile app developed by UCLA SMERC. Princeton Power provides API for control purposes. The control signals are sent through TCP/IP to first pin out a router and use port forwarding to locate a Raspberry PI. On the PI, a python script will be executed to control the system output.

User Incentives for SC, V2G and V2B

To achieve SC, the UCLA SMERC Level-2 smart charger and Princeton bi-directional DC fast charger was used. The UCLA SMERC Level 2 smart charger allows one dedicated circuit to be shared among four EV charging sessions simultaneously.

Figure 12: UCLA SMERC Level 2 Smart Charger



Credit: UCLA SMERC © 2014-2018

On the software side, the project team implemented the smart charging scheme to encourage smart charging of users by observing real-time solar energy generation and other demand response signals, the following incentive scheme is published and implemented.

Regular Operation

In general, PEVs will share the 30 Amp circuit when they are plugged in on the same charger and the users do not need account registration to activate the charger. However, registered users can associate their account with a smart plug to accumulate Solar Score and build up their solar use profile. A registered user with higher solar score will receive higher charging power.

The amperage distribution is shown in Table 1.

Table 1: SC Amperage Distribution Under Regular Operation

Plug #1 \ Plug #2	Not Used	Registered User with Higher Solar Score	Registered User with Lower Solar Score	Unregistered Users
Not Used	N/A	30	30	30
Registered User with Higher Solar Score	0	15 (same score)	12	12
Registered User with Lower Solar Score	30	18	15 (same score)	12
Unregistered Users	30	12	18	15

Source: UCLA SMERC © 2014-2018

Solar Use Profile

A user will have an overall solar use profile based on his/her use of solar energy and overall energy use as shown in equation (1).

$$Solar\ Score = \frac{Solar\ Energy\ Used}{Total\ Charging\ Energy\ used} \quad (1)$$

Accumulate SMERCOINS™ by Using Solar Energy

Users will receive 0.25 SMERCOINS™ per kWh when the vehicle is charged with solar energy.

Using SMERCOINS™ to boost Charging Power

User can use their SMERCOINS™ to boost their charging power to 24 Amp on a level 2 EV charger when both plugs are used. A fixed amount of 25 SMERCOINS™ will be deducted during a boost session. The amperage distribution is shown in Table 2.

Table 2: SC Amperage Distribution Under Boost Operation

Number of Vehicles plugged in	Vehicle # 1 (Boosting Mode)	Vehicle # 2
2	24 Amp	6 Amp

SMERCOINS™ rewards during a DR event

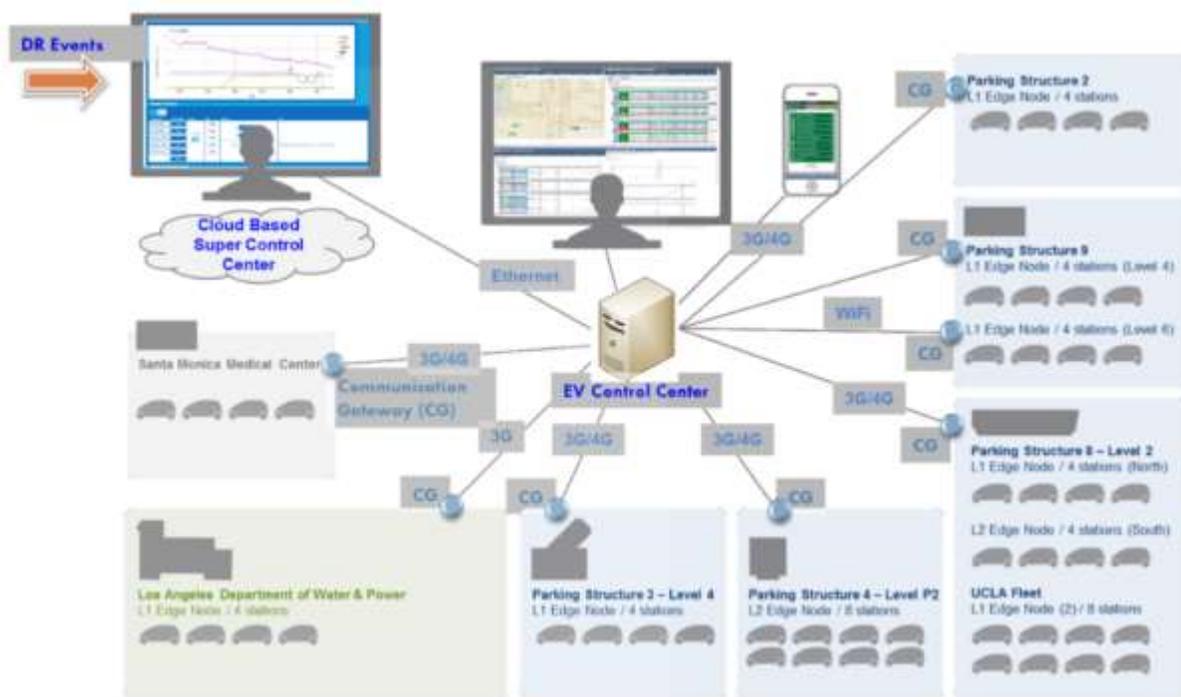
Source: SMERCOINS™

A registered user can choose to manually and completely turn off their charging session from the mobile app during that 30 min and receive SMERCOINS™ Reward during a DR event. A registered DCFC user can also choose to discharge their battery to help the power grid and receive SMERCOINS™ rewards.

Communication Network for EV Fleet

As shown in Figure 13, a sample of EV Communication Network is illustrated. The DR event is received through SCC. The SCC communicates with EV Control Center through Ethernet, the EV Control Center communicates with each individual Communication Gateway (CG) through either Ethernet, 3G/4G, or WiFi, and the CG communicates with each individual EV charging stations.

Figure 13: A Sample of EV Communication Network

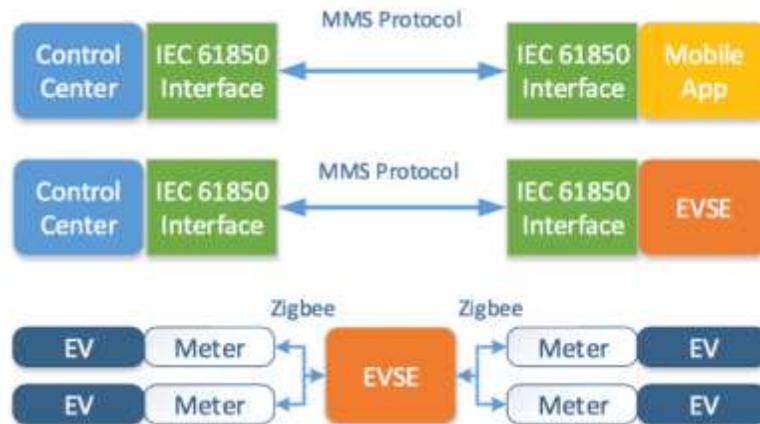


Credit: UCLA SMERC © 2014-2018

Integrating IEC 61850 Standard into Distributed Energy Resources System

Create a communication system where the control center and end devices communicate with an IEC 61850 gateway by exchanging status information. The IEC 61850 Gateway and Client communicate with each other via the Manufacturing Message Specification (MMS) protocol that is required by IEC 61850. The communications between the mobile app, control center and EVSE are standardized by IEC 61850 interface and communicating using MMS protocol which is specified by IEC 61850 (Figure 14). In SMERC's current EVSE communication design, Zigbee protocol was used between smart meters and the communication gateway inside the EVSE. Powerline Communication (PLC) via control pilot line connection is used between EVSE and the connected EVs.

Figure 14: Smart Charging Infrastructure with IEC 61850 Interface



Credit: UCLA SMERC © 2014-2018

IEC 61850 Modeling

The smart charging data and parameter such as user id, charging current, starting timestamp, etc., are mapped into the IEC 61850 system framework. Steps to integrate the IEC 61850 data model into the smart charging infrastructure are:

- Summarize the charging parameters and data transmitted in the Mobile app - Control center - EVSE communication.
- Design an IEC 61850 system framework to describe the components in the smart charging infrastructure.
- Design IEC 61850 data set to map the charging parameters and data into the system framework.
- Write Substation Configuration Language (SCL) file for the system.
- Write C# web service to manipulate variables in SCL file, integrate the IEC 61850 system framework into existing control center program, serving as the communication interface.

IEC 61850 Integration

With the charging data and parameters mapped into IEC 61850 abstract data framework, an SCL file is then written to carry the data. The SCL file is used in the IEC 61850 standardized communication between multiple smart grid devices. The IEC 61850 gateway communicates with the hardware using proprietary protocols and translates the information into the appropriate IEC 61850 format using SCL files. The IEC 61850 client then communicates with the gateway via MMS and provides the data to the control center using proprietary protocols.

Demand Response Participation with Bi-Directional EV Fleet Infrastructures

To implement Automatic Demand Response, the project team adopted a two-layer management structure. Super Control Center receives PV energy data directly from PV panel. EV Control

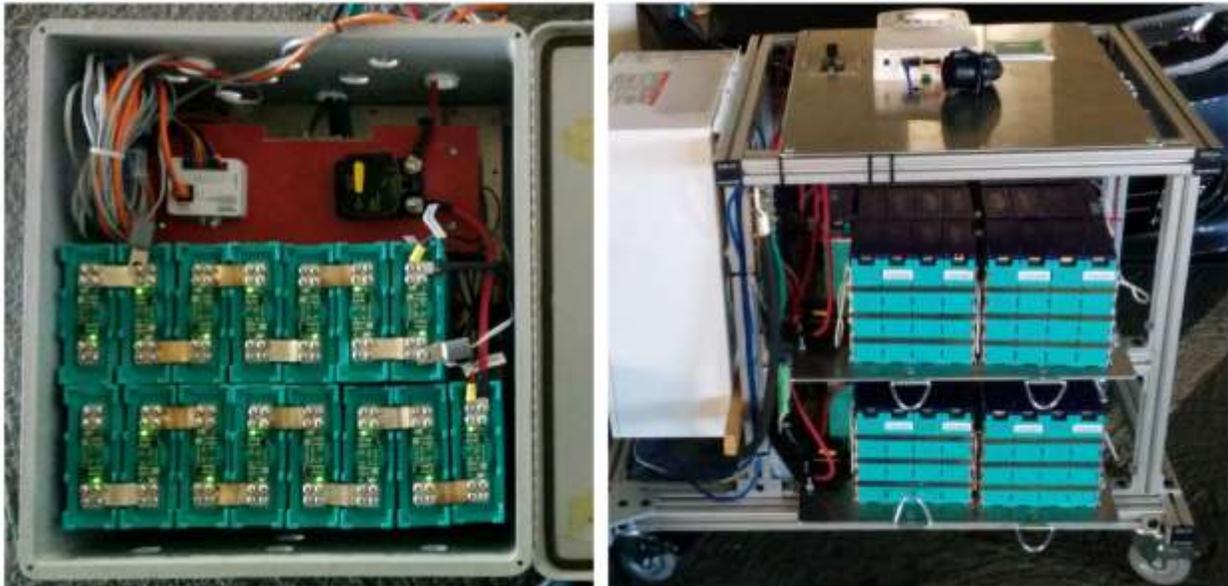
Center works for direct control of charging stations, including energy data collection, command to start/stop/suspend charging. EV Control Center, as an intermediate media, reports aggregated power data on the PS level to the Super Control Center. The Super Control Center can act as a VEN in openADR standard 2.0.

Battery Energy Storage System Integrated Level 3 Charging Infrastructure

The DCFC, C1-30 V2X is a 30 kW, 480 VAC, 3-phase charger [34] manufactured by Princeton Power has V2G capability supporting CHAdeMO type connector and is used for level-3 charging station.

UCLA SMERC designed and created a mobile battery storage system (MBSS) which provides a portable modular battery storage system for the EV chargers in this project. MBSS can supply the EV chargers when, due to a problem in the distribution system, the charger gets disconnected from the grid. It can also support grid services such as peak load shaving and load leveling which result in load variance minimization from the grid point of view and energy cost reduction from customer's perspective. To facilitate transportation of the battery and make it modular, the battery modules and their circuit breaker are installed in a compact configuration (Figure 15). Such a portable storage system eliminates the need for costly site inspection, installation and commissioning.

Figure 15: Modular Battery Storage System



Left 2.2 kWh system and right 8.7 kWh system

Credit: UCLA SMERC © 2014-2018

Field Installations

Hardware Installations

As of December 31, 2017, the following hardware was installed in SCE territory:

Santa Monica Civic Center PS	Voltage (VAC)	Max Power (kW)	Plug Points	Connector type	Network/Status
Level 2 Smart EV Chargers	208	43.68	14	J1772	4G LTE, expandable to 28 plugs
Princeton Power DCFC (V2G&G2B)	480 3Ph	±30	1	CHAdeMO	4G LTE, bi-directional DCFC
Mobile BESS Cart	208 V	±6.8		NEMA 6-50	wired, LiFePO4 Batteries
213 kW PV System on the rooftop	480 3Ph	213			PQA Meters
NI PQA/PMU Meters	480 3Ph				3G PI System

Colorado Fleet Yard	Voltage (VAC)	Max Power (kW)	Plug Points	Connector type	Network/Status
level 1 Smart Outlets	120	28.8	16	NEMA 5-15	City WiFi, Fleet Operation

Colorado Fleet Yard	Voltage (VAC)	Max Power (kW)	Plug Points	Connector type	Network/Status
level 1 Smart Outlets	120	28.8	16	NEMA 5-15	City WiFi, Fleet Operation

To conduct research and perform proof of concept, the existing UCLA microgrid testbed composed of the following has also been used.

UCLA Microgrid Testbed	Voltage (VAC)	Max Power (kW)	Plug Points	Connector type	Network/Status
PS 9 floor 4, level 1 outlets	120	1.8	1	NEMA 5-15	Mitsubishi V2G testing site
PS 9 floor 6, level 1 outlets	120	7.2	4	NEMA 5-15	WiFi
PS 9 floor 6, level 2 chargers	208	43.7	28	J1772	4G LTE with WiFi
PS 8 floor 2 North, level 1 outlets	120	1.8	4	NEMA 5-15	3G
PS 8 floor 2 South, level 2 chargers	208	12.48	4	J1772	3G
PS 8 floor 2 North, level 2 chargers	208	12.48	4	J1772	3G
PS 4 floor 1 level 2 chargers	208	10.4	8	J1772	wired
PS 2 level 2 chargers	208	6.24	4	J1772	3G
Sunset Village Parking (fleet)	120	75.6	42	NEMA 5-15	wired and WiFi
University Village, apartment, level 2	208	12.48	8	J1772	MUD
Luskin Center (fleet), level 1 outlets	120	14.4	8	NEMA 5-15	WiFi
Nissan Level 3 Charger (PS 4)	480 3Ph	50	1	CHAdeMO	wired and WiFi, open to public
Bosch Nissan Level 3 Charger (PS 4)	480 3Ph	30	1	SAE CCS	wired and WiFi, testing
Ackerman 35 kW PV system	208 3Ph	35			3G
76 kWh Saft Li-ion battery with OCC	208 3Ph	±30			Modbus, wired
NI PQA/PMU Meters	208 3Ph				wired PI System
PS9 40 kW PV System	208 3Ph	40			4G LTE with WiFi
PS9 60 kW PV System	480 3Ph	60			4G LTE with WiFi
50 kWh MicrovastLi-ion battery	208 3Ph	TBD			Modbus, wired
2.5 kWh Battery cart with 200 W PV	208	3			CANbus, wired

Total of 117 plug points, 2DCFC, 135.2 kW PV, 128.5 kWh BESS

Source: UCLA SMERC © 2014-2018

Software Setup and Installation

The software associated with the demonstration is developed and set-up in-house by SMERC. The software can be divided into three components: front end, back end and data analysis. The front-end software is a mobile app with the interface between the users and server and has five main functions:

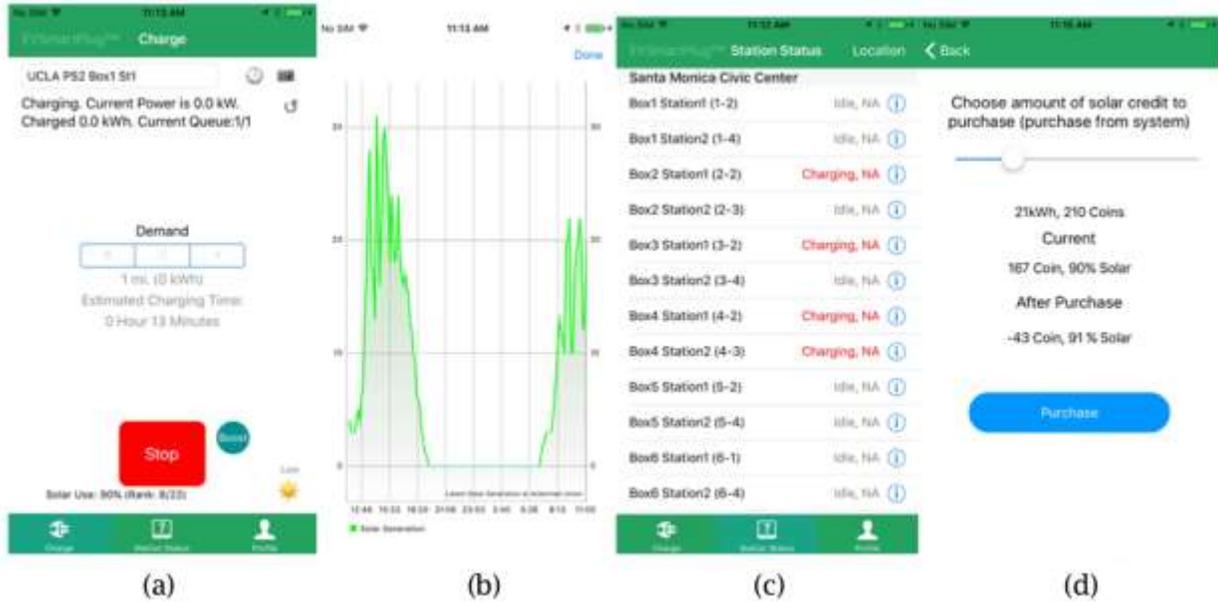
1. *Submit user charging request:* As the main function of the mobile application, the user interface facilitates the process for user to request charging service from the server. The request information includes user id, charger id, time of request, user's estimate energy demand.
2. *Receive charging status updates:* The mobile interface also serves to update users with their charging status, including power, energy charged and, if there is an algorithm in action, their place in the queue.
3. *Real-time solar energy indicator:* In the front tab of the app, it is clearly indicated the current level of solar generation so that users can make informed decision to charge according to the solar generation level, see Figure 16.
4. *Real-time solar credit trading system* [35]: The app also provides easy-to-use interface for users to trade their energy credits with each other described in the previous section. If multiple solar credits with different prices are offered on the market, the app automatically sort the unit price from low to high and provides user a straightforward interface in which user only needs to indicate how much energy he/she wishes to buy then the app automatically computes the lowest price to purchase (assuming people always prefer to buy same credit with less coins). If no user is offering energy credit, buyer can also choose to purchase from system whose price can be higher than peer users' price. When putting credit on the market, users can also choose to sell directly to system without having to wait for other users to buy their credit, but the purchase price of the system can be lower than those peer users pay.
5. *Ancillary services, information and configurations:* The application provides ancillary information related to the charging service including locations of the charging station, station occupancy status and personal consumption information.

Some of the iOS interface snapshots are shown in Figure 16. In addition to iOS app, the project team also provide a similar web-based interface for users.

The back-end software deals with data collection, hardware control and user communications. The main components, SCC and EV Control Center, are introduced in the deliverable report under "Task 5.2 Software Installation Report".

The data analysis is performed using Matlab, Python, and Microsoft Office.

Figure 16: Mobile iOS Interface



(a) Charging Tab; (b) Solar Power; (c) Station Status and (d) Credit Trading

Credit: UCLA SMERC © 2014-2018

Field Demonstrations

UCLA SMERC has been conducting field testing and systematic data collection since January 1, 2017. Field demonstration was first held on January 25, 2017. Subsequent field demonstrations have been held monthly or as needed.

CHAPTER 4:

Project Outcomes

Smart Charging

This section considers smart charging from EV drivers' point of view. The smart charging and peak shaving results based on the needs from utility and garage are presented in the "Grid Service" and "Cost Recovery" sections.

To assess smart charging based on energy price and user preference, the SMERCOINS™ virtual currency was used. Details about this system are discussed in "User Incentives for SC, V2G and V2B" section under "Project Approach." This system encourages smart charging by observing real-time solar energy generation and other Demand Response signals to accumulate SMERCOINS™, which can be used to boost charging power in an urgent situation.

Based on current data collection and interaction with EV users, the following results were obtained. In UCLA micro-grid test bed, all active EV drivers are willing to participate in smart charging by delaying their charging session or reduced charging power. Out of the seven level 2 smart EV chargers (28 plug points), the project team have charged **486 sessions and total of 3,323 kWh** energy in June 2017. **Only 13 sessions and 83.65 kW** was charged under power boosting because of the urgent demand of increased charging power.

In Santa Monica Civic Center Parking Structure, since there is a 4-hour parking limitation, all users request maximum charging power when connected. The power distribution to the four simultaneous charging sessions (specifically. 1.56 kW), are not acceptable for most users and on December 2016 were converted to two plugs per box to deliver 3.12 kW. Table 3 shows EV charging sessions and energy consumed from eight months of data collection.

Table 3: SC Charging Sessions and Total Energy by Month

Santa Monica Civic Center - Seven level 2 smart chargers (14 plugs)			
Month	Sessions	Total Energy	Average kWh per session
January	643	4876	7.58
February	649	5341	8.23
March	707	5197	7.35
April	362	2736	7.56
May	500	3998	8.00
June	532	4634	8.71
July	563	4679	8.31
August	575	5022	8.73
September	622	5090	8.183
October	595	5056	8.50

November	579	5223	9.02
December	444	4101	9.24
January	339	3013	8.89
Colorado fleet yard – 16 dedicated level 1 chargers			
January	82	222.971	2.72
February	142	236.8851	1.67
March	134	280.4667	2.09
April	98	312.1009	3.18
May	93	297.8318	3.20
June	118	347.2627	2.94
July	83	271.9637	3.28
August	98	272.3768	2.78
September	67	292.7597	4.37
October	93	325.1912	3.50
November	80	307.4175	3.84
December	17	78.1669	4.60
January	105	324.6214	3.09
SM Hospital – One level 2 smart charger with 2 dedicated 40 Amp Circuits			
January	200	1493.025	7.47
February	179	1458.278	8.15
March	187	1388.603	7.43
April	212	1945.325	9.18
May	250	2279.737	9.12
June	219	2036.493	9.30
July	215	2033.376	9.46
August	263	2164.368	8.23
September	253	2246.714	8.88
October	267	2387.961	8.94
November	187	2353.34	12.58
December	235	2440.016	10.38
January	293	3455.236	11.79

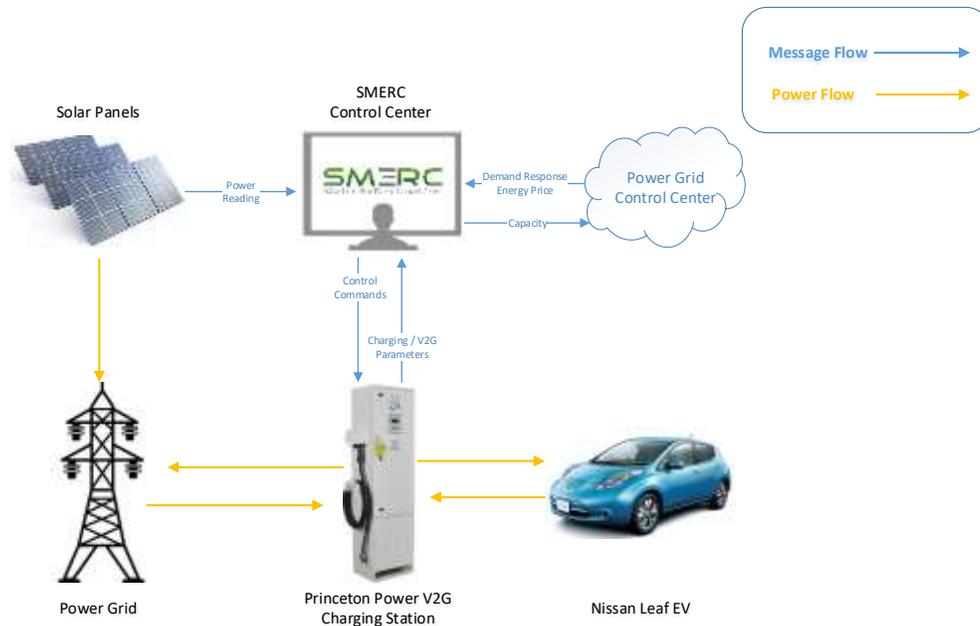
Source: UCLA SMERC © 2014-2018

V2G Focusing on Two-way Communication and Energy Flow

The architecture of the V2G system using Princeton Power charging station is shown in Figure 17. The V2G system is integrated into the SMERC smart charging infrastructure to share data and receive aggregated control signals. The Princeton Power V2G charging station is an

advanced equipment with remote control communication interface and integrated with V2G capability.

Figure 17: Princeton Power V2G System Architecture



Credit: UCLA SMERC © 2014-2018

The Princeton Power V2G charging station has one CHAdeMO charging port. This charging port can perform regular DC fast charging to any vehicle using CHAdeMO EVPS-002 V1.0 standard. V2G can also be performed by the same charging port but currently only limited to Nissan Leaf with V2G technology enabled (model year 2013 and later). Communication devices are built within the charging station so that it can be reached via the Internet. The energy price and demand response signal are coming from the power grid service providers to the SMERC control center in real-time. The local solar panel power generation reading is also recorded. The decision will be made in the control center based on these incoming data to determine how and when to perform V2G. The control commands will then be distributed to the Princeton Power V2G charging station through internet.

The Princeton Power V2G charger uses a Modbus TCP protocol. To realize remote control and data collection, the project team installed a router as a gateway for the network communication and a smart meter to measure power consumption data. The router equipment is installed in the SMERC labeled box next to the charger shown in Figure 18.

Figure 18: Network Communication Equipment Box with Princeton Power V2G Charger



Princeton Power V2G DC charger (left); Router equipment and smart meter within a SMERC labeled box (right).

Credit: UCLA SMERC © 2014-2018

Power consumption data from this V2G fast charger is collected in two ways: 1) Smart meter records the power flow and uploads metering data to the control center via gateway every minute; 2) Charger controller reads status data from the charger API and store the data in a local database in the controller every 1 second. The data uploaded into the control center can be plotted for visualization in web browser and is shown in Figure 19. Based on onsite testing results, the V2G fast charger was able to respond to change of charging current and change of power flow direction commands within 1-2 seconds after the commands are received by the charger.

Figure 19: V2G Power Consumption Data Collected in Local Controller Database



The V2G fast charger was able to respond to change of charging current and change of power flow direction commands within 1-2 seconds after the commands are received by the charger.

Credit: UCLA SMERC © 2014-2018

Initially, when the Princeton Power DCFC was installed, it generated high pitch noise that was unacceptable to the city staff in the office building attached to the parking structure in which the charger is installed. The charger had to temporarily be turned off due to the noise issue. A

noise abatement kit was purchased through Princeton Power and it was installed in August 2017. The noise reduced significantly, however, when charging/discharging at full power (30 kW), the noise was still not acceptable to the city staff. A micro controller was added to reduce the charging/discharging power to be 10kW during office hour and ramp up to 30 kW during evening and weekend hours.

Table 4 shows the testing sessions performed.

Table 4: Charging and Discharging Sessions on Princeton Power DCFC

Date/Time	Testing Type	Total Charging Energy (kWh)	Total Discharging Energy (kWh)	Starting SoC	Ending SoC
2/25/2017 12:25	charging/discharging/incremental	8.8	6.85	30%	40%
3/20/2017 11:00	charging/discharging/incremental	5.87	4.49	64%	52%
4/28/2017 9:28	charging/discharging	21.45	13.6	39%	55%
5/31/2017 11:00	charging/discharging	8.81	4.08	59%	69%
6/28/2017 19:05	charging/discharging	12.31	7.12	76%	77%
7/26/2017 18:14	charging/discharging	8.3	8.2	97%	77%
8/8/2017 15:18	charging	7.91	0	60%	90%
8/24/2017 13:18	charging/discharging	13.5	0.51	30%	90%
9/29/2017 17:05	charging/discharging	6.79	3.76	71%	84%
10/13/2017 18:37	charging/discharging	7.16	1.25	43%	80%
11/30/2017 10:42	charging/discharging	4.87	0.99	57%	78%
12/22/2017 16:24	charging/discharging	5.84	3.95	88%	93%

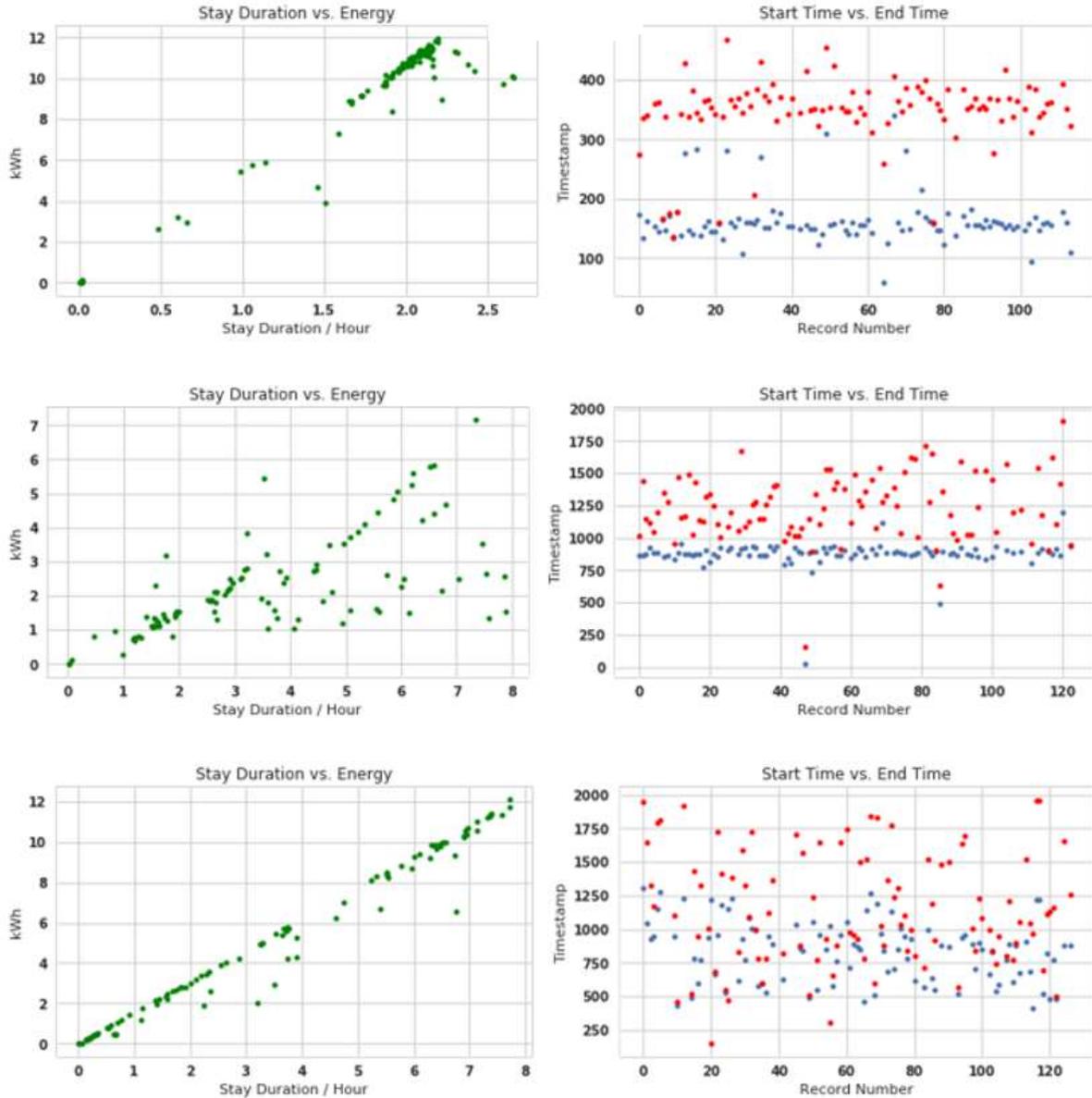
Source: UCLA SMERC © 2014-2018

V2B—Using EV Fleet Storage to Support Building Loads

UCLA Engineering IV building load profile on September 20, 2016 from 7 am to 7 pm is chosen as the baseload for V2B control algorithm. The 12-hour time span is divided into 60 time slots. The historical data stored in the database of the UCLA SMERC smart EV charging system, including 30 EV drivers on UCLA campus, is extracted for user behavior modeling and prediction. Three examples of the user charging record are shown in Figure 20. There are power usage peaks and valleys in the load profile corresponding to the operation of some heavy energy consuming devices in the building. The fleet of 30 EVs will provide grid service to flatten the load under the control of control algorithm. Such grid service can be potentially scaled up

to support a microgrid or a utility service area with enough EV participation—this is a key benefit of EV load control.

Figure 20: Data Example of User Charging Record

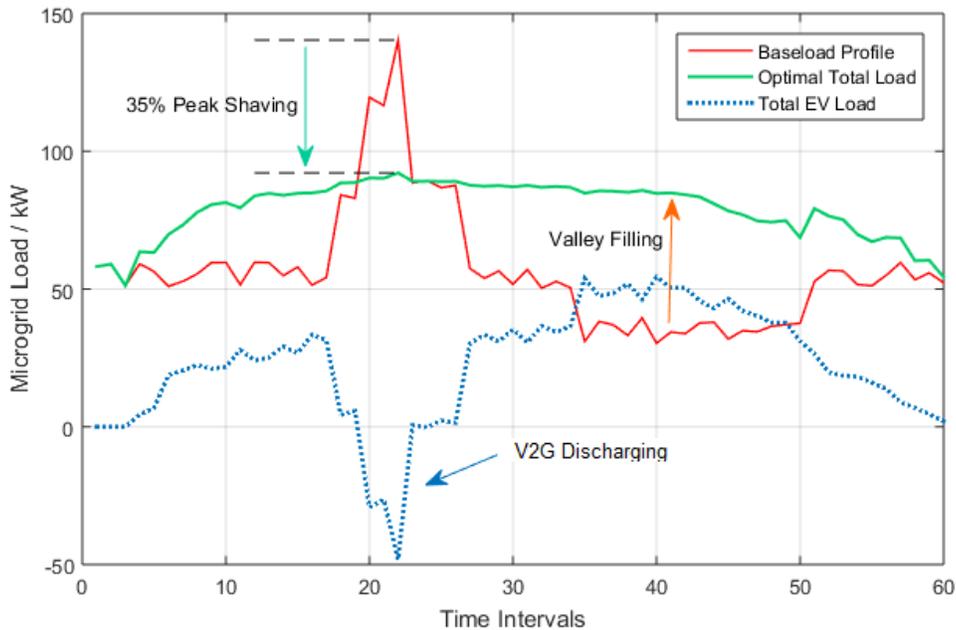


Blue dots indicate starting time and red dots indicate ending time

Credit: UCLA SMERC © 2014-2018

Before implementing the V2B scheduling algorithm, EV user behavior predictions are based on the randomly selected historical charging record data from 30 EV users in the past four years. Charging start time, end time and energy demand are predicted for September 20, 2016 (picked randomly among typical load profiles) and then incorporated in the control algorithm. The algorithm converges to an optimal bi-directional charging strategy which effectively flattens the original base-load by peak shaving and valley filling at 35 percent (Figure 21).

Figure 21: Base Load Profile Flattened by V2B Scheduling Algorithm



September 20, 2016, 7 am to 7 pm, 30 EV charging sessions + 1 V2G station

The algorithm converges to an optimal bi-directional charging strategy which effectively flattens the original base-load by peak shaving and valley filling at 35 percent.

Credit: UCLA SMERC © 2014-2018

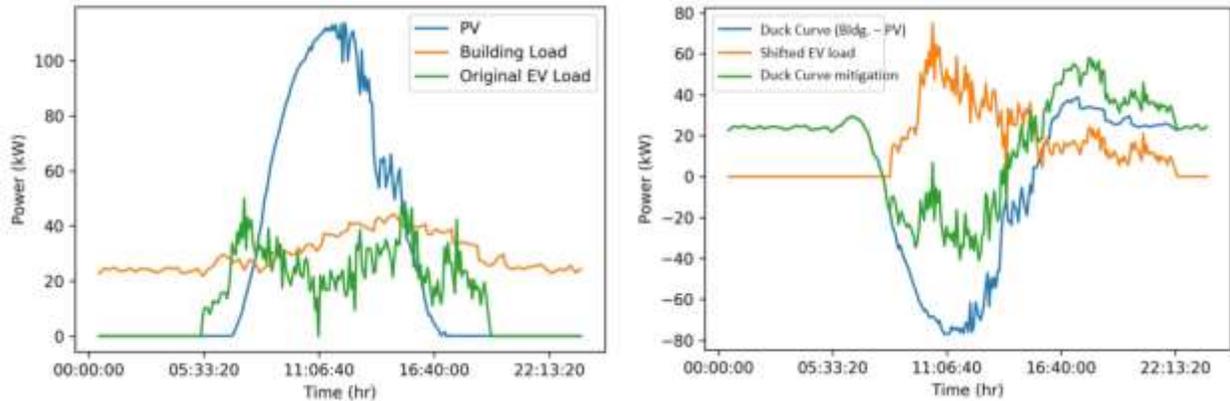
The baseload has power consumption peak from time slot No. 17 to time slot No. 27, and power use valley from time slot No. 33 to No. 50. The optimal decentralized bi-directional charging algorithm precisely tunes charging rate of each EV in the network, changing from high speed charging to discharging according to the trend of baseload profile. **Almost all EVs are performing V2G discharging at baseload peak time, making the peak power consumption drop 35 percent, from a high of 140 kW to a low of 90 kW.** The Optimal total load curve, which is the combination of baseload and EV load profile, has been flattened. The optimal distributed bi-directional charging algorithm demonstrates the capability to integrate EVs into the power grid as DERs, providing various grid services to benefit the power grid.

Mitigating the PV Duck Curve

As PV output usually peaks around noon which does not typically coincide with the peak load, over-generation from this renewable source occurs and could cause problems. By using grid-to-vehicle, also known as G2V or V1G, the project team could mitigate this over-generation. This over-generation is typically known as the Duck Curve. The results from the G2V approach are demonstrated using data from Santa Monica Civic Center PV system and charging stations. The PV output profile of a typical day and a typical load is presented in Figure 22. For the PV data, the project team choose the data collected on a random date (February 1,2017) as an example for discussion. For the typical load, exclusive of the Santa Monica Civic Center building load profile, the project team used the regular EV charging loads in that building as the proxy of the building load. Between 11 am -2 pm the energy generated by solar PV is greater than the

building load. The project team focused on this region and added more EV fast charger load to demonstrate how EV fast charging loads could mitigate the over-generation. This EV fast charging load is with a constant load of 28 kW and significantly eliminates the gap between PV generation and original building load.

Figure 22: PV Generation Against Building Load and Duck Curve Mitigation



Smart Charging Algorithm to solve Duck Curve Problem (February 2, 2017, 7 EV chargers, 213 kW PV). PV output profile of a typical day and a typical load (left); Adding additional EV fast charger load to demonstrate how EV fast charging loads could mitigate this over-generation (right)

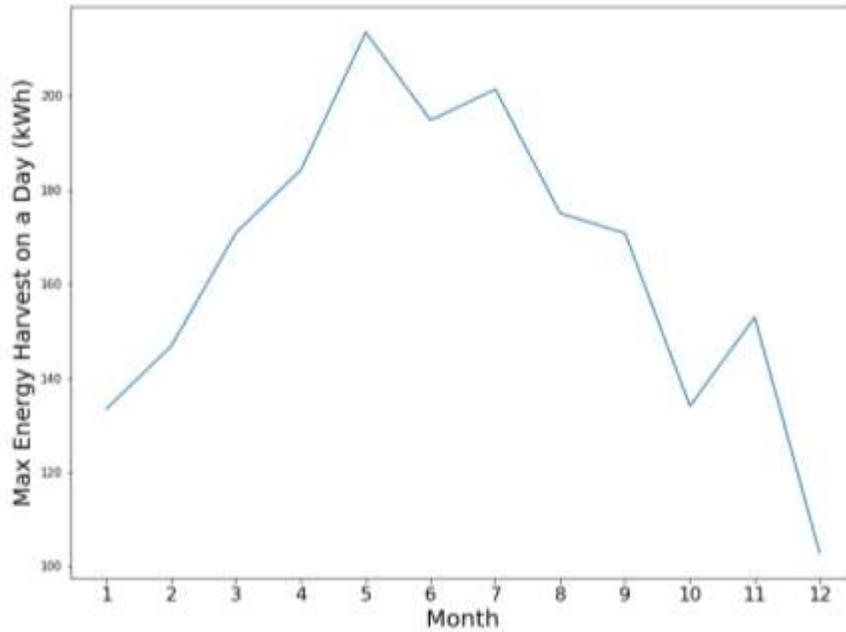
Credit: UCLA SMERC © 2014-2018

For the entirety of 2016, the project team collected 325 days of data and 237,001 kWh energy harvested, with a daily average of 729 kWh. The reasons there are 40 days without data input include monitoring system firmware/software upgrades, on-site metering system running other energy applications, and PV system switched turn-off by the site-host.

Figure 23 presents the maximum instance power by month. Observations can be made that it follows the variation of how much sunshine the PV system is exposed to. Throughout this period, the project team performed 12 sessions of monitored V1G/V2G operations. A typical load profile of V1G/V2G can be found in Figure 24.

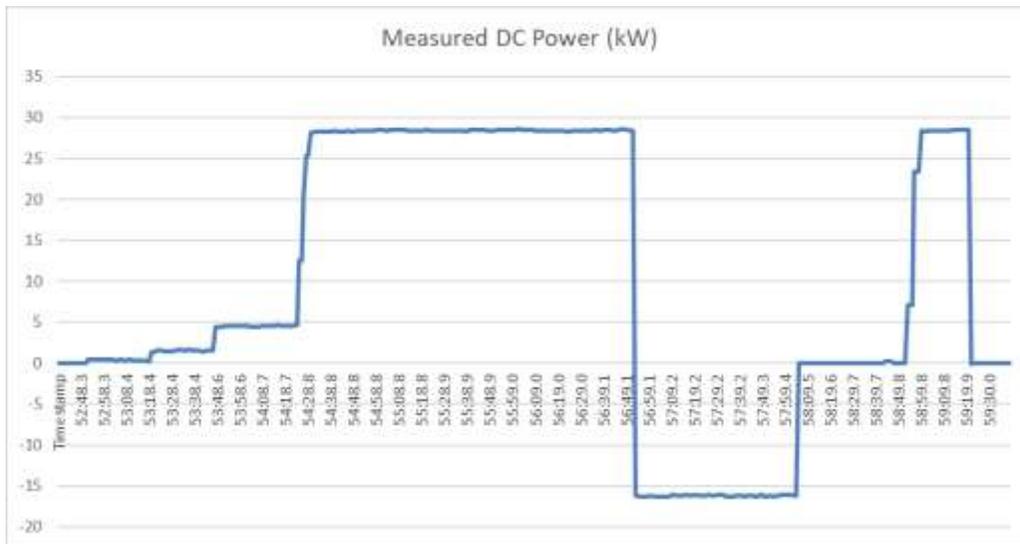
The V1G has the ability to rapidly increase consumption to 28 kW in a short amount of time (two minutes) and is capable of covering the period when the solar output reaches its maximum output. In a typical summer day when the PV system outputs a maximum of 120 kW, this fast charging session accounts for 23.3 percent of the total generation, while in a typical winter day when the maximum is halved, or 60kW, the fast charging session could consume a total of 46.7 percent of the total generation.

Figure 23: PV Maximum Instance Power by Month



Credit: UCLA SMERC © 2014-2018

Figure 24: V2G Operation Load Profile

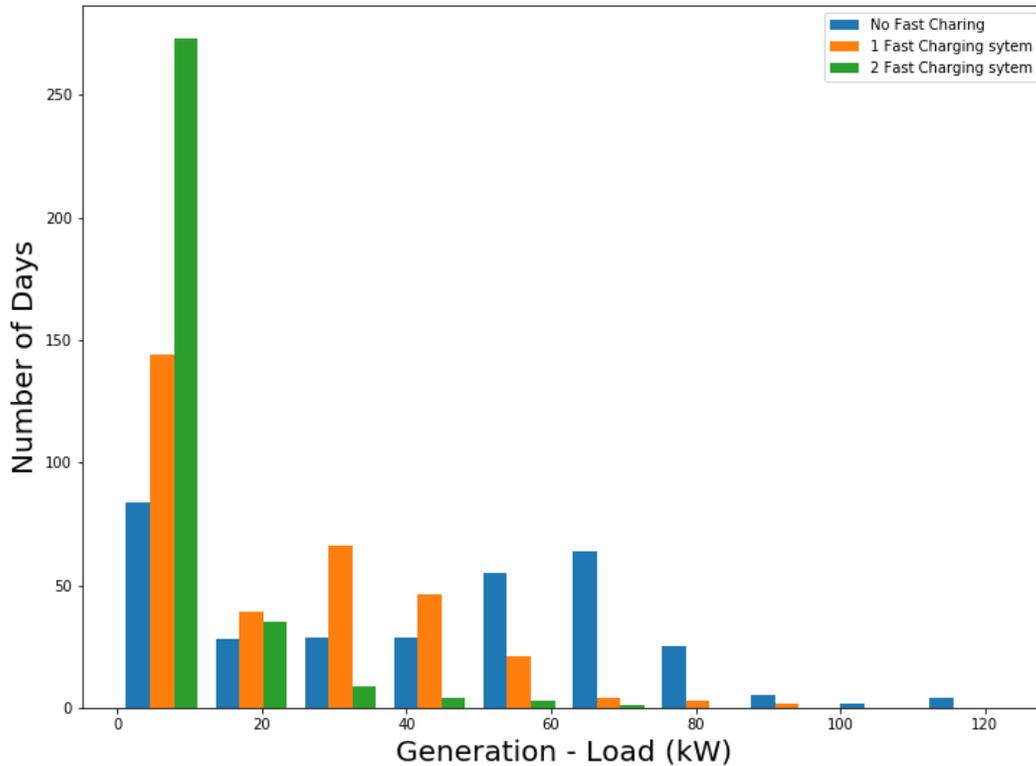


Credit: UCLA SMERC © 2014-2018

From these statistics, simulation is performed. Assuming that the fast charging has the capability ranges from (0, 28) kW. Two fast charging systems are considered in this simulation. The maximum instant power by day for 2017 is extracted, with base load subtracted from it, the distribution of load consumption difference and load balancing can be observed in Figure 25. As could be observed from the histogram, the number of days when the difference between

generation and load being near zero increase dramatically as the number of fast charging system increases.

Figure 25: Over-Generation Damping with Fast Charging



Distribution of load distribution (blue) and load balancing 1 and 2 fast charging systems in orange and green.

Credit: UCLA SMERC © 2014-2018

A conclusion could be drawn that, since the base load is only around 90 kW as shown in Figure 22, the V2G system with proper number of instances being installed (in this case, 2 systems are sufficient), the system should be able to fill the gap between load and generation not just during most of the peak hours, but also most of the time throughout a day.

Automated Demand Response Demonstration

There are two types of DR considered in this analysis: Pure DR and DR with V2G. For pure DR, the power from the charger to the vehicle is reduced to an absolute minimum. For DR with V2G, the discharging power is used to perform reverse power flow and provides effective V2G capability that is more than the pure DR.

The result for pure DR is shown in Table 5.

Table 5: Pure Demand Response Power Reduction

Begin Power (w)	Min Power (w)	Ave. Power (w)	Start Time	Stop Time
14031	3629.63	3303.370787	6/3/17 14:12	6/3/17 14:21
11805.04	2052.17	1636.363636	6/2/17 18:50	6/2/17 18:57
17278.4	4195.05	3854.389722	6/2/17 15:15	6/2/17 15:30
6565.74	3425.46	7092.537313	6/2/17 13:58	6/2/17 14:03
5557.98	2602.64	3904.411765	6/2/17 13:38	6/2/17 13:48

Source: UCLA SMERC © 2014-2018

Begin power is the power when DR is initiated (in units of Watts). Minimum power is the minimum total power consumption for the Civic Center during the DR. Average power is the average consumption power of all stations summed together, calculated from main energy.

The result for DR with V2G is shown in Table 6.

Table 6: DR with V2G Support

Consumed Energy (kWh)	Back feed Energy (kWh)	Start Time	Stop Time	Pure (kWh)
0.76	-2.13	2/25/17 12:10	2/25/17 12:18	-1.37
0	-0.944	2/25/17 12:22	2/25/17 12:24	-0.944
0.6	-4.239	2/25/17 12:40	2/25/17 12:49	-3.639
0.81	-4.49	3/20/17 11:00	3/20/17 11:09	-3.68
1.72	-4.658	4/28/17 9:17	4/28/17 9:26	-2.938
2.14	-4.122	4/28/17 9:40	4/28/17 9:48	-1.982
2.46	-4.815	4/28/17 10:00	4/28/17 10:09	-2.355
0.72	-2.581	5/31/17 11:10	5/31/17 11:16	-1.861
0.56	-1.498	5/31/17 11:22	5/31/17 11:25	-0.938
1.67	-4.545	6/28/17 19:07	6/28/17 19:16	-2.875
0.89	-2.571	6/28/17 19:22	6/28/17 19:27	-1.681
1.64	-4.65	7/26/17 18:21	7/26/17 18:30	-3.01
0.69	-1.979	7/26/17 18:35	7/26/17 18:39	-1.289
0.5	-1.583	7/26/17 18:46	7/26/17 18:49	-1.083
0.09	-0.515	8/24/17 14:01	8/24/17 14:03	-0.425

1.31	0	9/2/17 17:22	9/2/17 17:53	1.31
2.41	0	9/3/17 14:03	9/3/17 14:29	2.41
0.6	0	9/5/17 11:48	9/5/17 11:53	0.6
4.1	-0.001	9/5/17 12:14	9/5/17 12:35	4.099
0.2	0	9/29/17 16:37	9/29/17 16:40	0.2
0.31	0	9/29/17 16:50	9/29/17 17:10	0.31
0	0	9/29/17 17:22	9/29/17 17:34	0
0.7	-1.739	9/29/17 16:41	9/29/17 16:49	-1.039
3.14	-1.547	10/30/17 18:41	10/30/17 19:12	1.593
0.1	-0.573	10/30/17 18:54	10/30/17 18:56	-0.473
2.71	0	11/30/17 10:43	11/30/17 11:04	2.71
0.76	0	11/30/17 11:15	11/30/17 11:20	0.76

Source: UCLA SMERC © 2014-2018

Consumed energy is the energy the Civic Center boxes use during V2G session as kWh. Back feed Energy is the energy that the V2G session discharges in total as kWh. Pure is the total power flow of the charging power and discharging power as kWh.

To compare the effectiveness of V2G, Table 7 shows the power reduction of the V2G sessions.

Table 7: DR with V2G Support (Power Reduction)

Begin Power (w)	Min Power (w)	Ave. Power (w)	Start Time	Stop Time
9072.49	4085.57	8341.608739	2/25/17 10:41	2/25/17 11:32
5786.65	-2887.91	3329.153605	2/25/17 12:28	2/25/17 12:39
18096.87	8938.09	11978.83131	2/25/17 13:44	2/25/17 13:59
23444.26	10723.14	19838.83249	3/6/17 11:29	3/6/17 11:55
15335.33	11369.15	14915.49296	5/1/17 15:30	5/1/17 15:58
5783.82	10980.29	18150	8/24/17 14:01	8/24/17 14:03
3330.18	-4562	2503.184713	9/2/17 17:22	9/2/17 17:53
5741.09	1293.63	5505.076142	9/3/17 14:03	9/3/17 14:29
8885.14	-1497.22	7200	9/5/17 11:48	9/5/17 11:53
8860.78	2749.16	11624.88189	9/5/17 12:14	9/5/17 12:35

5843.03	2363.99	3977.900552	9/29/17 16:37	9/29/17 16:40
5849.7	-31.8	922.3140496	9/29/17 16:50	9/29/17 17:10
0.24	-8229.8	0	9/29/17 17:22	9/29/17 17:34
5852.99	11021.99	18254.46985	9/29/17 16:41	9/29/17 16:49
12186.42	15997.68	8956.050955	10/30/17 18:41	10/30/17 19:12
12945.99	16048.7	20023.1405	10/30/17 18:54	10/30/17 18:56
11513.25	8038.89	7694.006309	11/30/17 10:43	11/30/17 11:04
18073.93	8016.38	9059.602649	11/30/17 11:15	11/30/17 11:20

Comparing Table 5 and Table 7, it is evident that with the integration of V2G power reduction can be achieved more effectively.

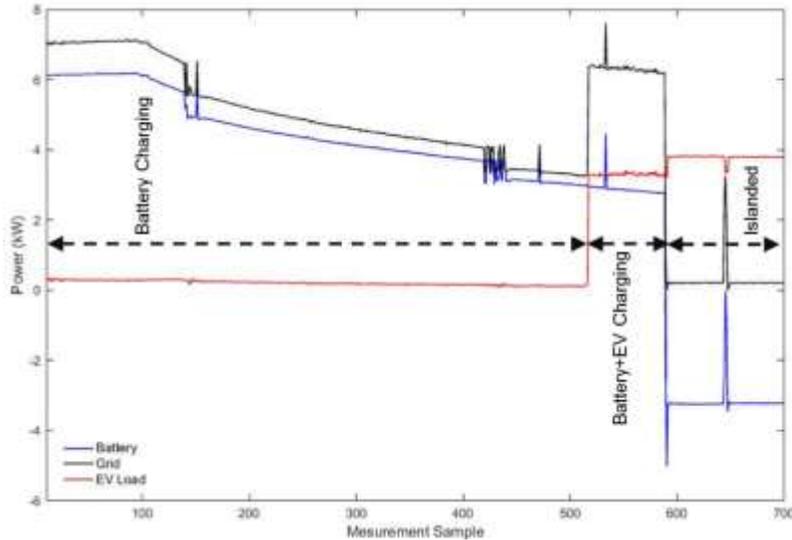
Load Leveling for Level-3

The high power demand by the Level-3 DCFC can affect the power quality and stability locally and this could get exacerbated in large-scale deployments. High power demand can increase the power loss and voltage drop in the distribution feeders. Integrating BESS in the distribution feeder and close to the end customers has the capability to mitigate these negative effects. In this case, BESS can charge when distribution feeder is experiencing low load demand, and subsequently, support the power grid by supplying the load when the overall load demand is at the peak value. BESS integration not only decreases power loss and voltage drop, but also reduces end customers' electricity bill by avoiding demand charges.

In this project, a portable, mobile and low capacity BESS was set up to create and demonstrate a flexible infrastructure where it can provide flexible and on-demand storage capability which is also mobile and can be connected to different points or different phases within a commercial customer's grid site. Although a single low capacity BESS cannot provide load leveling by itself for the whole charging infrastructure, it still shows how BESS can reduce power demand from the grid and reduce electricity cost. Employing larger numbers of these devices would allow simple scale up at the site. The collected data for the 8.7 kWh mobile BESS is shown in Figure 26. The scale of this battery is similar to the size of the Tesla Power wall, with the following differences:

- The system is mobile
- Multiple batteries can be connected within the same infrastructure and logically connected by a software program to aggregate their capability in a flexible manner.
- The software to control and connected the batteries to each other and to other DERs is completely customizable.
- The algorithms driving the controls for multiple batteries would be flexible and adaptable.

Figure 26: Grid Service and Islanding by 8.7 kWh Mobile BESS



Credit: UCLA SMERC © 2014-2018

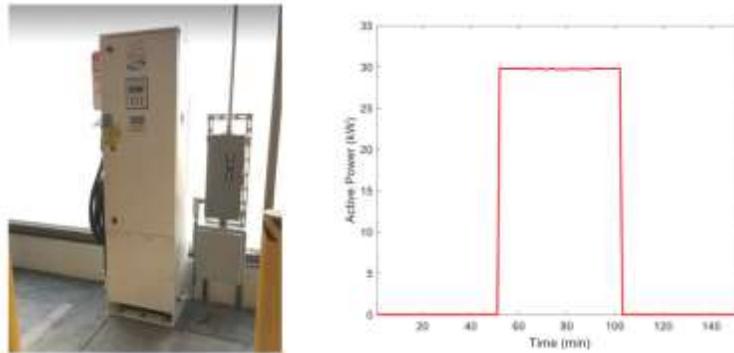
The bi-directional converter interfacing BESS is charging the battery from the first to 500 measurement sample. At that time, level 2 EV charger charges the EV so the bi-directional converter charges BESS and EV. At 590 sampling time, because of a fault in the distribution feeder, bi-directional converter is disconnected from the grid. As BESS has enough energy, it forms an islanded or independent microgrid with the EV charger and starts charging the EV.

Assuming the bi-directional converter as the interface of a microgrid (including EV charger and BESS), when the electricity price is low, EV and BESS are charged from the power supplied by distribution system. However, when the electricity price is high or distribution system is experiencing peak load, supplying EV charging load by BESS can significantly contribute to peak load shaving and demand charge reduction. This can be realized by partially supplying EV by BESS or charging the EV only using BESS, depending on the peak load amount and energy price. In addition, BESS can supply the EVs in the emergency situations where power from grid is not available due to faults in the distribution system. In this situation, BESS, due to islanded operation capability of the bi-directional converter, can charge the EV.

To show how the BESS can provide load leveling for DCFC two components are considered:

- As shown in
- Figure 27, consider a typical DCFC charging profile. The peak value of the DCFC load demand is 30 kW, assuming it takes 50 minutes to fully charge the vehicle, the DCFC will deliver 25 kWh energy for the EV.

Figure 27: Princeton Power DCFC and Load Profile

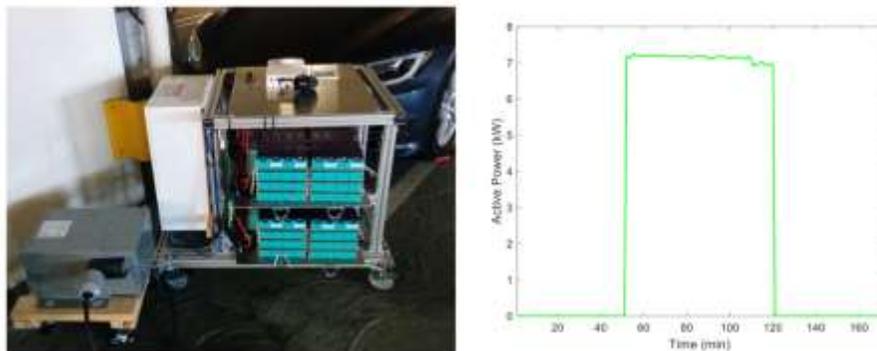


(left) Princeton Power DCFC (left); Load profile of DCFC (right).

Credit: UCLA SMERC © 2014-2018

1. Consider using the BESS developed in this project to support this DCFC charging session. The BESS has a capacity of 8.7 kWh with an average of 7.2 kW charging and discharging power. The BESS and its charging/discharging profile is shown in Figure 28. To support the DCFC charging session (50 minutes specifically 5-6 hrs at 30 kW), a total $7.2 \text{ kW} * 5/6 = 6 \text{ kWh}$ energy will be discharged from the BESS to support this charging session.

Figure 28: BESS Charging Profile

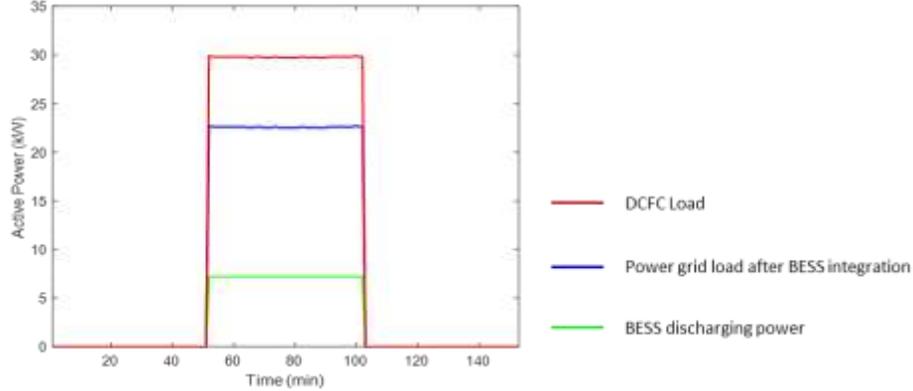


The BESS system (left); charging/discharging profile (right).

Credit: UCLA SMERC © 2014-2018

Figure 29 illustrates load leveling using BESS, where the red line represents the DCFC demand profile without BESS, the green line represents the power output of the bi-directional converter supplying DCFC, and blue line represents the power from the grid supplying DCFC.

Figure 29: Grid Service-Load Leveling for DCFC by BESS



Credit: UCLA SMERC © 2014-2018

Assuming that this energy is delivered to the EV when the energy price is experiencing its maximum value (0.48131 \$/kWh [36]), EV charging costs without BESS support is :

$$\text{EV Charging Cost without BESS support} = 25 \times 0.48131 = \$12.03275 \quad (2)$$

With the support of BESS, the BESS can be charged when the electricity price is very low, 0.01969 \$/kWh [36], BESS charging costs for this 6 kWh is

$$\text{BESS Charging Cost for 6 kWh} = 6 \times 0.01969 = \$0.11814 \quad (3)$$

And, the remaining 19 kWh (25kWh - 6 kWh = 19 kWh), will still need to be supported by the power grid. So, the total cost of this charging session with BESS support would be:

$$\text{EV Charging Cost with BESS support} = 19 \text{ kWh} * 0.48131 + 0.11814 = \$9.2630 \quad (4)$$

This shows a reduction of the charging energy cost by 23 percent (12.03275-9.2630)/12.03275, per charging session.

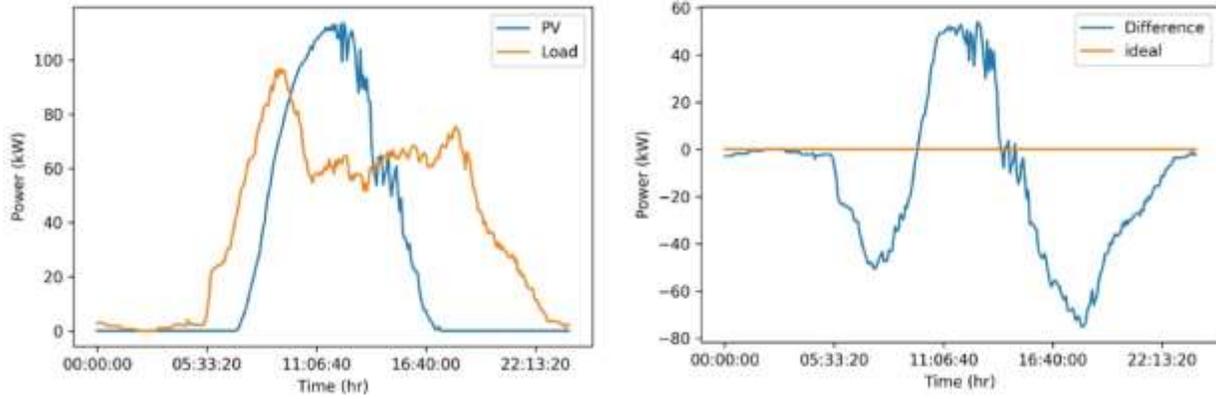
Bi-Directional EV Fleet Infrastructure

With large numbers of V2G enabled EVs, the grid can be dynamically balanced with a combination of V2G and G2V. The team considered a building with solar generation and a base load, sample result from the data collection on February 1, 2017 is shown in Figure 30. Ideally, this difference between generation and base load should be constantly at zero—no power flow to and from power grid. With a fleet of EVs, the peaks can be reduced to fill out the valleys to a greater extent. In this section, the EV fleet sample data obtained from Santa Monica Colorado Fleet Yard on February 2017 was used.

Preliminary data analysis and simulation results are shown in Figure 31 and

Figure 32.

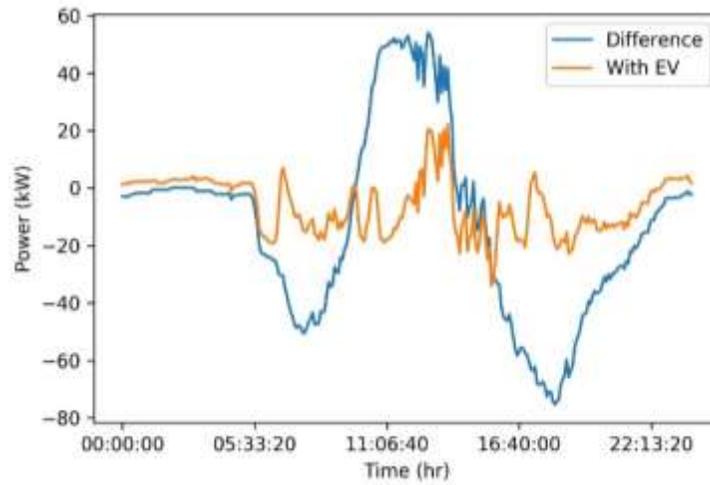
Figure 30: Difference Between Generation and Load



Solar generation and a base load (left); Difference between generation and load (right).

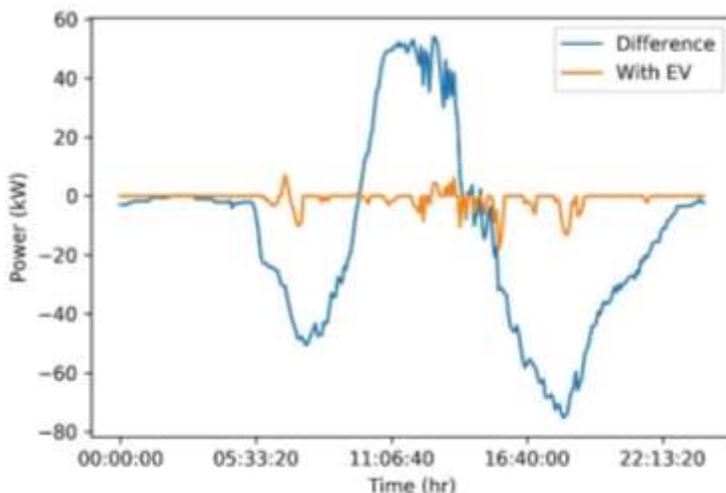
Credit: UCLA SMERC © 2014-2018

Figure 31: Mitigation Through Manipulation of a Fleet of EVs



Credit: UCLA SMERC © 2014-2018

Figure 32: Mitigation Through Manipulation of a Fleet of EVs With a BESS System



Credit: UCLA SMERC © 2014-2018

With one year of data collection (January 1, 2017 - December 31, 2017), the previous simulation results could be extended. For this part, the same data collected from Santa Monica PV system is used, accompanied with EV charging data from Colorado Fleet Yard station. To determine the mismatch between load and generation, the absolute value sum is used. For example, for the day shown in

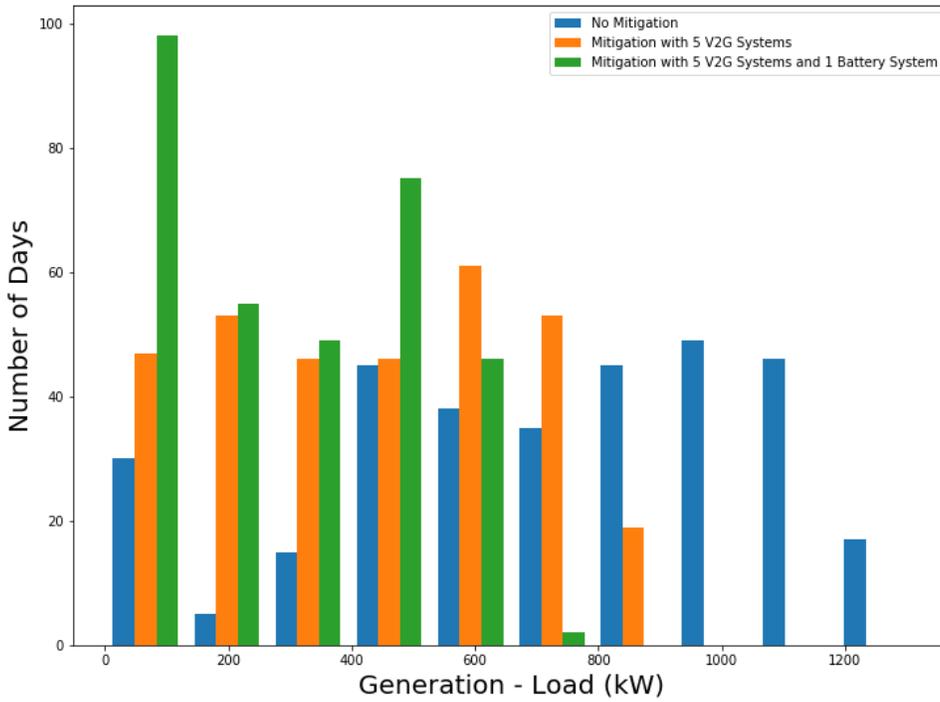
Figure 30, the total mismatch is 633.3 kWh. If five V2G systems are used for integration into the system operating at a maximum of 7 kW, a total of 145.2 kWh mismatch still exists. With an addition of a battery system capable of 20 kW instant power at both direction, this mismatch reduced to 25.1 kWh per day. As such, the distribution of mismatch of data collection period is shown in

Figure 33. The team observed that the combination of V2G plus battery significantly alleviates the overall mismatch between load and generation. However, more of this system could be introduced to further reduce such mismatch and balance the load, as shown in

Credit: UCLA SMERC © 2014-2018

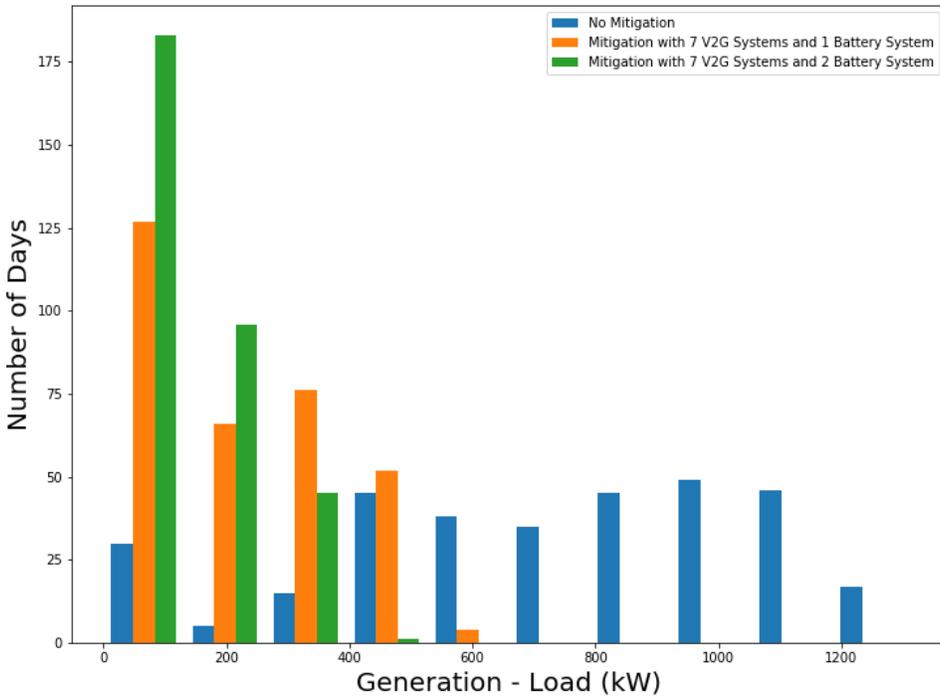
Figure 34, which clearly shows that mismatch is reduced.

Figure 33: Mismatch Distribution with Different Levels of Mitigations



Credit: UCLA SMERC © 2014-2018

Figure 34: More Mismatch Distribution with Different Levels of Mitigations

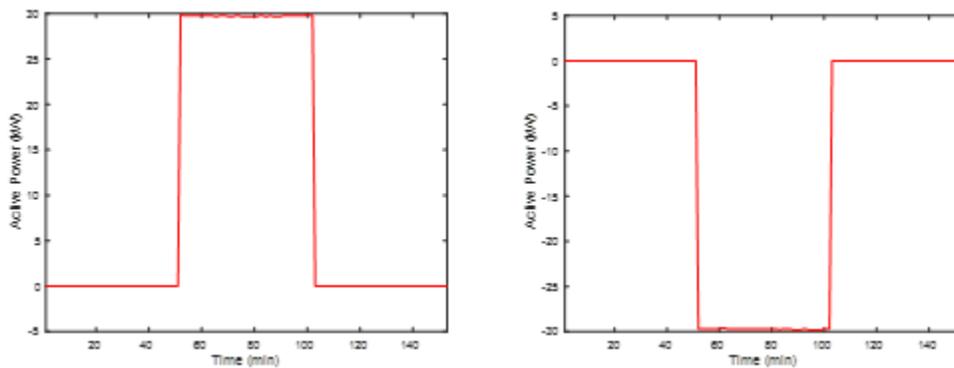


Credit: UCLA SMERC © 2014-2018

Peak Shaving Through SC, V2G, and BESS

V2G capability to perform peak shaving depends upon the availability of the EVs. That is, if EVs are plugged in for an extended period of time, such as fleets used by the City of Santa Monica Transportation Division, they can play the role of BESS and provide peak shaving. In this case, the plugged-in EVs with V2G capability are charged when the load demand in the grid, and consequently energy prices, are low. When the load demand in the grid is high and energy prices are higher, the EVs feed electricity back to the grid to supply the loads close by. However, the EVs should be charged to a minimally acceptable level by the time their owners are ready to drive. Typical charging and discharging sessions as measured in Santa Monica from the EVs with V2G capability are shown in Figure 35 and impact the peak shaving capability.

Figure 35: DCFC With V2G Capability Power Profile

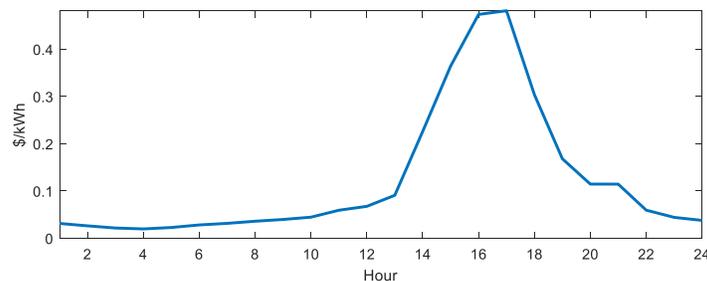


G2V (left), V2G (right).

Credit: UCLA SMERC © 2014-2018

To evaluate the effectiveness of peak shaving by V2G and energy cost reduction, SCE real-time electricity price [36] was used (Figure 36).

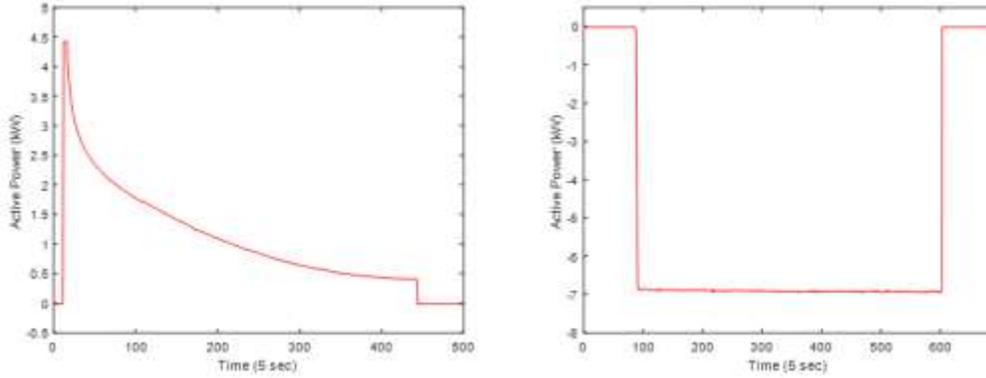
Figure 36: SCE Real-Time Energy Price



Source: SCE [36]

Using BESS to support peak shaving, since there is no restriction on charging the battery by a given time, the potential profit from the stationary BESS is higher. For this case, the mobile battery storage system (MBSS) with the capacity of 8.7 kWh and charging and discharging of 7.2 kW was used. The charging and discharging profiles are shown in Figure 37

Figure 37: MBSS Power Profiles



Charging left, Discharging (right)

Credit: UCLA SMERC © 2014-2018

As the battery is connected to the power grid for the entire time, it can be charged between 3 am and 4 am when the energy price is the lowest, and discharged to provide peak load shaving and energy cost reduction between 4 pm and 5 pm. The profit is evaluated as follows:

BESS charging cost, 3 am- 4 am

$$Cost_{charging} = 8.7 \text{ kWh} \times 0.0216 \text{ \$/kWh} = \$0.18792 \quad (5)$$

BESS discharging cost reduction. 7 pm- 8 pm

$$Cost_{discharging} = 8.7 \text{ kWh} \times 0.4735 \text{ \$/kWh} = \$4.11945 \quad (6)$$

Therefore, even with current small BESS (8.7 kWh @ 7.2 kW), \$3.93 can be saved daily, resulting in \$1,435 saving per year.

The same analysis can be done for V2G, depending on the availability and stay duration of V2G-capable EV (V2GEV). That is, if V2GEV is plugged in during off-peak and on-peak load hours when energy price is low and high, respectively, energy cost saving can be achieved through SC. However, in V2G case, in addition to the uncertainty in availability, stay duration, and available battery capacity of V2GEV, SC should consider the desired departure time of the V2GEV owner, which means V2GEV must be fully charged by a deadline when its owner wants to leave the charging station.

In SC case for Level 2 EV chargers, the cost saving depends on the stay duration of the EV owner. To show how SC can result in reducing costs, it is assumed that an EV, which requires 6.6 kWh energy, is plugged in at 3 pm, with a stay duration of four hours. Considering the power rating of Level 2 EV chargers installed in Santa Monica Civic Center (which is 6.6 kW), it takes 1 hour to fully charge the EV before 7 pm (departure time). If the EV is charged at the time it is plugged in, the total charging cost is:

$$Cost_{charging} = 6.6 \text{ kWh} \times 0.474 \text{ \$/kWh} = \$3.13 \quad (7)$$

However, if it is charged from 6:00 pm to 7:00 pm, the total charging cost is:

$$Cost_{charging} = 6.6 \text{ kWh} \times 0.474 \text{ \$/kWh} = \$1.11 \quad (8)$$

This equates to reducing the charging costs by 64 percent.

Minimizing Local Power Congestion

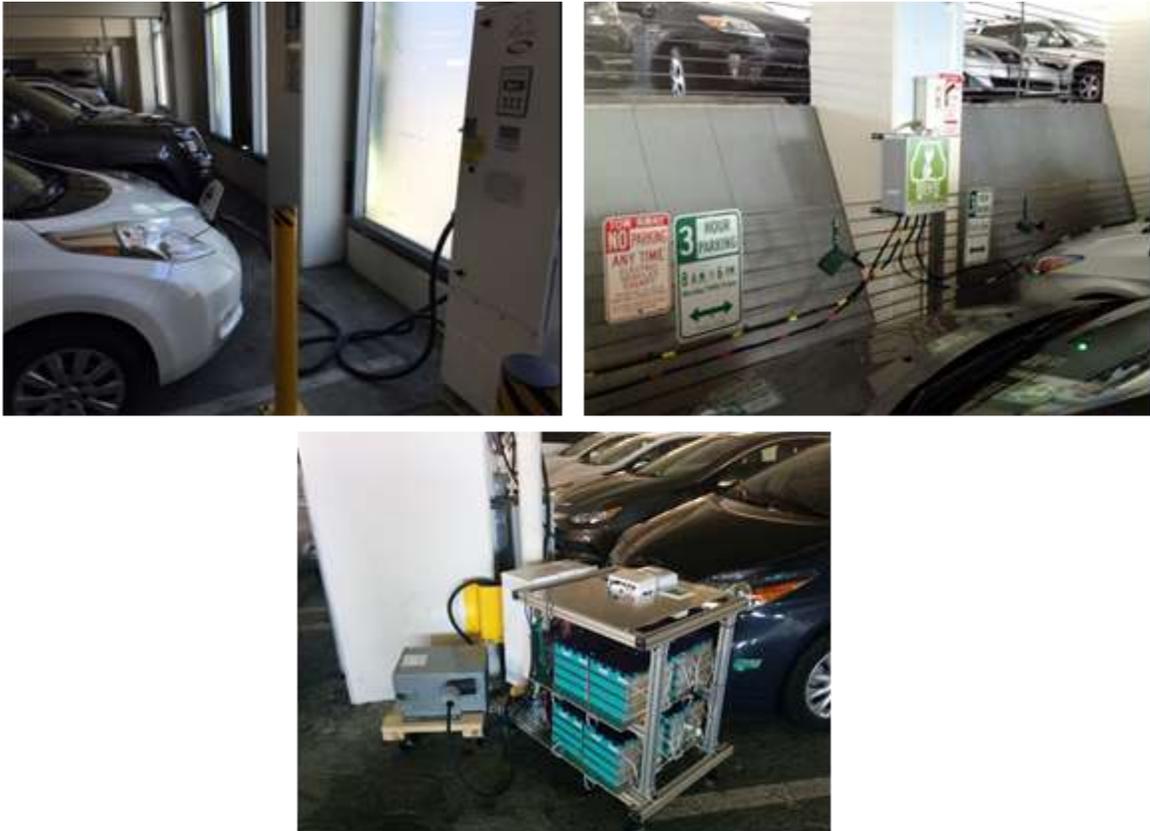
When electricity demand exceeds the system capacity, congestion occurs. Grid congestion not only impacts reliability, it also decreases energy efficiency. During periods of high demand, line losses increase. When lines are congested and operating at or near their thermal limits, they are subjected to significant line losses. A congested system may also lead to a violation of network security limits such as thermal, voltage and/or angular stability. One solution is to upgrade the transmission and distribution system, which is costly, however, BESS, SC, and V2G can defer such investments by providing an alternative. BESS and V2G deployed downstream of congested corridors can be discharged during congested periods to reduce the load burden on the system. SC can also reduce the charging load during congested periods.

In this project, three technologies including BESS, SC, and V2G are used to demonstrate the congestion relief in real testbed platform.

Figure 38 shows the integrated BESS, SC and V2G at the host site.

Under high load conditions, the battery energy storage system can discharge and supply the load locally. It can maximize the local energy utilization and reduce the transferred power from the main grid. The results obtained from the experimental case study are demonstrated in Figure 39. In this experiment, the battery energy storage system is integrated to the distribution circuit in parallel with DC fast charger. DC fast charger is one of the high demand load in this testbed. The results show the battery energy storage system can automatically discharge to reduce the peak demand of DC fast charger.

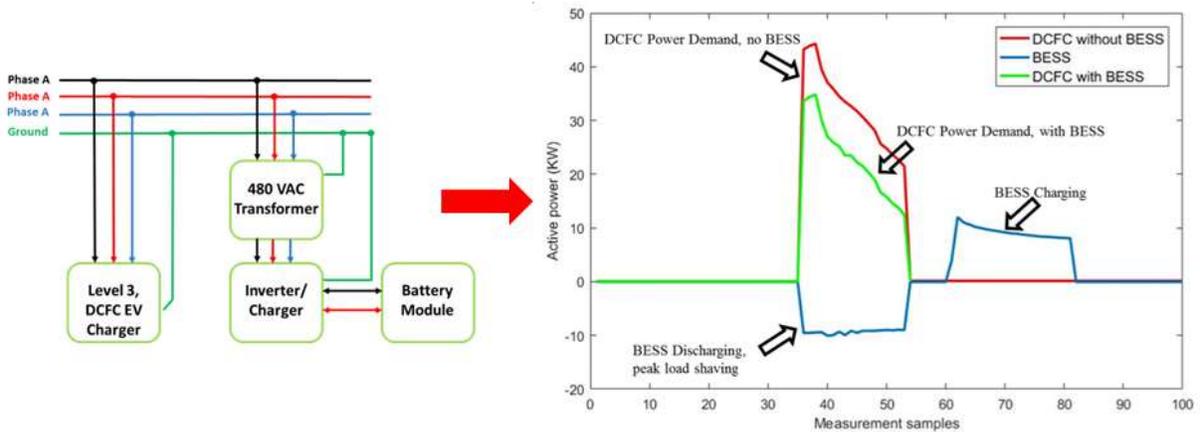
Figure 38: V2G, SC, and Mobile BESS Integrated to the Grid for Congestion Relief



The figure shows the integrated BESS, SC and V2G at the host site.

Credit: UCLA SMERC © 2014-2018

Figure 39: Peak Load Shaving by BESS



The experiment results show the battery energy storage system can automatically discharge to reduce the peak demand of DC fast charger to mitigate the local power congestion.

Credit: UCLA SMERC © 2014-2018

Cost Recovery Validation

EV Charger with SC, V2B, V2G, and grid-service technologies capability has economic benefit in following components to the fleet owners under SCE grid service. In this section, the cost recovery validation of two locations, Santa Monica Civic Center and the Fleet Yard, will be analyzed from January to December 2017.

Load Smoothing to Avoid Higher EV Charge Prices

Since these locations are under Southern California Edison (SCE) territory, SCE EV charges, TOU-EV-4 Rate Schedule [37] for Civic Center and TOU-EV-3-B rate for the fleet yard [37], are applied for an efficient economic benefit. Figure 40 shows the TOU-EV-3-B and 4 rate schedules from SCE, which are referenced in calculating the cost benefit for using Smart Charging system and avoiding higher charge. SCE Demand Charge rate for 3-B is 20 kW and for 4 is 500 kW.

Figure 40: SCE TOU-EV Rate Schedule

TOU-EV-3-B Rate Schedule			TOU-EV-4 Rate Schedule		
	Summer	Winter		Summer	Winter
On-Peak Noon to 6 p.m. weekdays except holidays	33¢/kWh	12¢/kWh	On-Peak Noon to 6 p.m. weekdays except holidays	29¢/kWh	11¢/kWh
Mid-Peak 8 a.m. to noon and 6 p.m. to 11 p.m. weekdays except holidays	14¢/kWh	11¢/kWh	Mid-Peak 8 a.m. to noon and 6 p.m. to 11 p.m. weekdays except holidays	12¢/kWh	9¢/kWh
Off-Peak All other hours	6¢/kWh	7¢/kWh	Off-Peak All other hours	5¢/kWh	6¢/kWh
Facilities Related Demand charge	\$7.23 / kW / Month		Facilities Related Demand charge	\$13.20 / kW / Month	
Customer Charge	.836¢ / Day		Customer Charge	\$198.79 / Month	

[37]

Credit: Southern California Edison (SCE)

Smart charging allows the EV load to shift from peak price periods to lower price period within defined flexible time, 6 am to 8 pm for Civic center and 12 am to 12 pm for the fleet yard. Then, Civic Center EV chargers can avoid On-Peak charge rate, and the fleet yard can avoid Mid-Peak price in the morning. Applying this algorithm allows these savings shown in Table 8 and Table 9¹.

¹ Estimates based on available information. Actual saving may be different based on total building load which is not available at this time.

Table 8: Santa Monica Civic Center Cost Saving from Smart Charging

Santa Monica Civic Center			
Month	Energy Cost Without SC [\$]	Energy Cost with SC [\$]	Savings [\$]
January	583.04	522.68	60.36
February	620.85	553.41	67.44
March	668.71	594.18	74.53
April	451.58	410.43	41.15
May	566.35	505.83	60.52
June	975.43	623.12	352.31
July	1010.07	622.03	388.04
August	1040.65	647.94	392.71
September	1007.85	636.14	371.71
October	624.03	568.88	55.15
November	644.54	578.83	65.71
December	544.18	496.33	47.85

Source: UCLA SMERC © 2014-2018

Table 9: Santa Monica Fleet Yard Cost Saving from Smart Charging

Santa Monica Fleet Yard			
Month	Energy Cost Without SC [\$]	Energy Cost with SC [\$]	Savings [\$]
January	16.61	16.09	0.52
February	17.91	16.96	0.95
March	21.12	19.73	1.39
April	26.12	22.43	3.69
May	22.77	20.99	1.78
June	25.64	21.74	3.90
July	20.56	16.48	4.08
August	19.24	16.53	2.71
September	22.23	17.44	4.79
October	24.97	22.62	2.35
November	23.65	21.40	2.25
December	6.59	5.93	0.66

Source: UCLA SMERC © 2014-2018

A total of \$2006 savings (from January 1, 2017 to December 31, 2017).

SCE Demand Response Program Incentives

Table 10 shows SCE TOU General Service Base Interruptible Program Reward Rate for meter between 2kV and 50kV [38]. The event is limited to one per day, 10 per calendar month, up to 6 hours each for a maximum of 180 hours a calendar year and it must commit to curtail at least 15 percent of the Maximum Demand, which is not less than 100 kW, per period of interruption.

Table 10: SCE TOU General Service Base Interruptible Program Reward Rate

	Reward Rate [\$/kW/Month]
Summer Season – On-Peak	22.43
Summer Season – Mid-Peak	6.75
Winter Season – Mid-Peak	1.4

Source: UCLA SMERC © 2014-2018

In this project, all EV chargers used are smart chargers and can be turned off during a DR event and the DCFC and Battery system can stop charging and back-feed their power to the power grid. This provides 43.68 kW (Level 2 chargers) + 30 kW (DCFC G2V) + 30 kW (DCFC V2G) + 6.8 kW (Battery charging) + 6.8 (Battery discharging) = 117.28 kW. The demand curtailment at Colorado Yard (28.8kW) and Medical Center (12.48 kW) does not qualify for this reward as their curtailment capacities are less than 100 kW.

For this project, the maximum benefit (for all hardware/equipment installed) will be **\$11,835.90** a year [(\$22.43/kW/month * 4 summer months/year) + (\$1.4/kW/month *8 winter months/year)] * 117.28 kW = \$11,835.9/year². If mid-peak summer season is used, \$6.75 instead of \$22.43, the reward will be **\$7,646.66/year** [(\$6.75/kW/month * 4 summer months/year) + (\$1.4/kW/month *8 winter months/year)] * 117.28 kW = **\$7,646.66/year**.

² Based on optimum and maximum benefit scenarios.

CHAPTER 5:

Conclusions

Through the current project, UCLA SMERC has successfully developed and demonstrated the advanced technologies to achieve the goals of the project: **PEV Smart Charging and Storage in Supporting Grid Operational Needs**. This section describes the conclusions from the project, the lessons learned and key obstacles encountered through the project.

Major Take-aways

- While most current PEVs only support unidirectional charging from grid to vehicle, V2G and V2B technology allows power to flow in the reverse direction so a PEV can act as a battery energy storage system.
- The software developed through this agreement can aggregate large numbers of vehicles into a single load and allow the grid operator to draw significant amount of power. For Example, if 10 percent of California’s 35 million vehicles are PEVs and were used for vehicle-to-grid and vehicle-to-building, when aggregated they would provide support for roughly 50 percent of the California’s peak load of 50 GW.
- PEVs can provide support to the utilities for reliability, stability, renewable portfolio standards, etc. The research showed that PEVs can be used to mitigate over-generation by using vehicle-to-grid, vehicle-to-building, and grid-to-vehicle smart infrastructure during the early afternoon periods to mitigate the “duck curve”. Integrating smart charging, vehicle-to-grid, vehicle-to-building, and battery energy storage system, PEVs can help to shave peak loads and minimize local power congestion by participating in automatic demand response or other utility programs.
- This agreement also provided validations in cost recovery for using smart chargers, vehicle-to-grid and vehicle-to-building and battery energy storage systems. When PEVs are used in fleets, installing additional EV charging stations is essential to support PEV fleet operations, but can also become a financial burden to fleet owners if PEV charging schedules are not properly managed.

The next section describes the lessons learned.

Lessons Learned

The lessons learned can be categorized into the following:

1. Technology issues

Challenge of lack of standardization in V2G: Due to lack of commonplace standards, V2G technologies were found complex and difficult to implement. The additional work was as a result of the researchers having to build communications and controls interfaces at multiple levels. As a conclusion, while the V2G technology did function effectively and successfully at a

technical level, for it to get scaled up, it needs to be supported by interface technologies that are standard and rich in their ability to carry information on status, control, safety, etc.

VIG Technology Matured with Potential for Commercialization: The technologies and systems developed in this project for VIG and their integration with other DERS in a microgrid were found to be relatively stable and mature at the level of control and reliability. They could be further developed as an Energy Management Product and be commercialized through the process of starting a company.

2. Site host, fleet and microgrid considerations

The needs of the site hosts or microgrid operator (application) require customization of algorithms: This research finds that based on the type of locations and parking limitations, customized scheduling algorithms and power management rules provide best value for the site host. For example, if the functionality is that of a fleet, the rules would be somewhat different to that of workplace charging or even public charging. Fleets are more predictable from a scheduling standpoint, and homogeneous from the technology and user understanding standpoint, and therefore, can be integrated with the grid needs more easily. Most workplaces, being controlled environments, tend to be closer to fleet conditions as compared to public charging.

Fleet Operations: The researchers learned that fleet drivers look for simplicity in use. At project initiation, the project required the fleet drivers to log a user id and password into a kiosk so that the energy consumed by driver could be tracked and algorithms could be customized based on needs of specific drivers. Over time, the team realized that the fleet drivers became increasingly unwilling to use the kiosk and eventually had to remove the kiosk. Extrapolating this behavior implies that in the future if customized algorithms by driver are required, the ID of the individual driver must be determined directly from the connection established between the vehicle and the charger. In the future, this would mean that the car manufacturers must be willing to provide either user ID or VIN number through the charging connector's communications port. Open architecture between the charger, the car, and the grid operator would enable such a capability and our team is planning to work on that actively as the next major area of research - an outcome of the findings of the current project.

Stationary Battery Technology expensive to deploy in commercial environments: The cost of integration, commissioning, and installation of batteries with inverters and BESS is still expensive and therefore as V2G becomes standardized and open architecture based, and therefore more economically deployable, there will be little need for stationary battery storage in parking structures across California.

3. Utility Considerations

PEV Smart Charging Technology as a basis for microgrids distributed energy resources (DER) needs: The proposed system - PEV Smart Charging and Storage - can be used as a foundation

for DER management within a microgrid. With a focus on microgrid (grid-tie and islanding) operation, a scaled-up project involving multiple microgrids forms the potential next level of technology demonstration in the future.

4. User Issues

Constant refinement of algorithms based on driver needs: The team determined that scheduling algorithms and rules need to be periodically (monthly) reviewed and improved based on the data obtained. The reason for this is several fold and includes the following: (1) the constant increase in the number of vehicles in California was resulting in continuously greater pressure on the PEV charging infrastructure, and therefore, rules that were developed at a given point in time were not as applicable at a later time; and (2) the users themselves were becoming more sophisticated as they learned from each other and also developed an understanding of algorithms and adapted their behavior based on the scheduling algorithms. The understanding of a user's capability to act in a certain manner was no longer valid later in the project.

Obstacles Encountered

The team also concluded that in a complex project such as the current one, outcomes are not always predictable and encountered several obstacles.

- *Lack of acceptable V2G standards by car manufacturers.* Few PEV manufacturers supported or openly supported V2G capability. This resulted in a challenge in selecting PEV models.
- *Lack of open architecture or open standards for enabling bi-directional charging.* A lack of open architecture and open standards results in compatibility and limitations when integrating bi-directional chargers with DER for energy management.

Multiple DCFC standards (Combo CCS versus CHAdeMO): Since there continued to be two separate DCFC standards prevailing during the project, Combo CCS and CHAdeMO, there was lack of maturity of tools in either one resulting in additional efforts to develop and integrate V2G capability into the solution. While Combo CCS had been gaining traction in the duration of the project, existing vehicles with CHAdeMO ports and newer vehicles with the port continued to come into the market, making DCFC standardization a challenge for the industry as a whole.

- *Risk management.* Risk management involved trying to determine and manage risks associated with DCFC, V2G/V2B, and using the algorithms for smart charging with V1G. Getting sign off by all parties with respect to risk management given that there was new and untested equipment resulted in challenges in deployment and participations from users. While risk management departments are often conservative, it was found individual PEV drivers and owners are much more risk taking just so that they can participate in advanced research and technological innovation. Perhaps, one reason is that they would get free electricity for doing so. This implies that people are willing to take risks provided they are incentivized and this therefore may help regulators and rule makers when setting policies on incentives.

- *Procurement and installation delay for battery systems due to complexity in determining installation site within a parking structure and high cost of installation.* The complexity in finding a location within a parking structure as well as the high cost of installation of stationary battery within a parking garage resulted in an innovation in this project—the development and deployment of a portable mobile battery enabling DER integration in our site. The approach to having mobile battery energy storage systems within parking structures is a potential area for future investigation.
- *Lack of integrated communications and controls standards between batteries, BMS, inverters, and other DER assets.* While the team investigated a variety of standards as outlined in the project reports, the actual hardware assets of batteries, inverters, solar, PEV, etc., were rarely supported by the same standards required to build interfaces between the various DER assets. DER integration is, therefore, expensive and cumbersome, and is an area for future research and investigation.
- *Lack of adequate VIG capabilities by car manufacturers.* Certain vehicles did not support current control. This resulted in certain vehicles starting to beep when subjected to a control modulating signal to initiate VIG. This is yet another area where the car companies can enhance the battery and charging managements systems within their vehicles.

Project outcomes

- **Smart Charging.** Flexible smart PEV charger technology was developed and managed by a cloud-based software system connected to a mobile app used by the PEV driver. The smart charger controls the charger power based on inputs from the site, user and grid. The charger uses one input power circuit and shares the power with four output circuits. The four output circuits are controlled simultaneously. The power was shared dynamically and based on smart charger’s algorithms. A key algorithm within the smart charging system was one that incentivized users to maximize using solar energy allowing better grid control, and reducing the energy cost for the utility by increasing the amount of solar on the grid. This technology increased the number of charging sessions to about 92 percent as compared to conventional charger and almost twice the number of PEVs charged at any site.
- **Vehicle-to-Grid/Vehicle-to-Building.** Two vehicle-to-grid and vehicle-to-building systems were used to investigate results from different types of PEVs. The first system, using a Mitsubishi PEV, provided 1.5 kW for discharging and 3.3 kW for charging. Due to its limited power capacity, a higher power system using Princeton Power DCFC was installed and used to provide 30kW bi-directional power flow. The higher power bi-directional power provided sufficient controllable load to leverage the PEV charging load and PV generation in the parking garage at the demonstration site in the City of Santa Monica. It provided grid services as a load shaving resource by supporting building and PEV charging loads or as an energy source/sink for demand response.

- **Grid Services.** Grid services were enabled through the smart charging algorithm residing on the cloud software. The algorithm employed a user-charging pattern prediction model and an actual building load profile, shifting the peak load by scheduling the PEV charging load to a time when the building load was decreased to certain threshold. Using this algorithm, the peak power consumption was reduced by 35 percent which would allow a site host to avoid a utility's demand charge and pave the way for demand response - a key grid service for the utility.
- On certain days, especially during spring and fall when grid demand is lower, PV over-generation results in demand collapse in the middle of the day and a steeply rising load curve during the evening hours making it difficult for the grid operator to balance the generation and load. Controlling this phenomenon can be achieved by the system using the Princeton Power DC fast charger that receives scheduling signals from the cloud software by messages from the grid operator to charge the PEV at higher power levels in the middle of the day to mitigate the impact of PV over-generation.
- A key service to the site host is the ability to use load shifting based on time-of-use pricing, which in turn benefits the utility's load balancing needs. For example, the battery energy storage system when used in conjunction with the DC fast charger, provides potential benefit to the site by reducing the cost per charging session by 23 percent via exploitation of time-of-use pricing. In the future, V2G/V2B could itself be used to help PEVs reduce cost through this opportunity.
- Using smart charging in the system without the V2G has benefits when the grid operator offers time-of-use pricing and the customer is paying demand charges. By shifting PEV charging load from peak to off-peak itself has shown a savings of \$2006 for one year of data collection at the demonstration site consisting of 7 level-2 smart PEV chargers (14 plugs) and 16 level-1 PEV chargers.
- In addition to the PEV curtailment, the V2G hardware in combination with the stationary battery storage at the demonstration site provided the system with a total of 117 kW of demand response capability which is greater than the minimum of 100 kW required by Southern California Edison (Southern California Edison, "Time-Of-Use-General Service Base Interruptible Program," March 2017). Roughly half of the 117 kW demand response capacity was provided by the V2G system by going from +30 kW to -30 kW or its inverse, resulting in a total controllable load of 60kW (± 30 kW). Eventually, V2G is expected to cost substantially lower than what it is now as the technology gets standardized (there is almost no standardization today) as well as volume sales, making it far more competitive cost-wise than stationary battery energy storage system.

CHAPTER 6:

Recommendations

Additional scaled up demonstration and tests should be performed to validate the results obtained in this project.

The following is a summarized list of major project outcomes:

- Developed and deployed a flexible smart PEV charging system along with the mobile app to allow smart charging. Each input plug of the PEV charging system was interfaced with four outputs leading to 92 percent greater number of charging sessions.
- Developed two smart charging algorithms that can prioritize PEV charging cost minimization or renewable energy usage maximization.
- Used novel incentive concepts such as virtual currency and priority charging to encourage users to charge PEVs during time periods of higher solar energy. It was determined that using incentives resulted in increase of the local solar consumption by 37 percent.
- Designed and installed the V2G systems to support bi-directional power flow which can be a very effective asset to support demand response and other power grid services such as PV “duck curve” reduction or demand charge avoidance, etc.
- Designed and installed a mobile battery storage system which is portable, low-cost, and modular to charge PEVs and support grid services such as peak shaving and load leveling. This is a unique innovation with potential for scale in commercial buildings to connect with PEV chargers and to offer flexibility in power management and cost savings.
- Integrated mobile battery storage system with DC fast charger to mitigate voltage drop problems and reduce electricity bill of the site host by \$2.77 per charging session.
- Installed DC fast chargers to charge PEVs during times of over-generation and mitigate the PV duck-curve for load smoothing.
- Automated demand response via the use of V2G demonstrated that V2G can offer demand response (DR) which can be a substantial fraction of the typical load of a parking structure.
- Designed and implemented a local controller for the V2G station with fast power ramping (1-2 seconds) and ± 30 kW of power flow.
- Demonstrated that V2G, battery energy storage system and smart charging can be used for peak shaving, load shifting, and cost reduction. (\$2.77 per direct current fast charging session for a Nissan Leaf).

- Designed and deployed centralized control center with demand response interface and various scheduling algorithms to support grid services.
- Validated cost benefits for PEV fleet owners within investor-owned utility (IOU) territories - annual savings of \$2,006 through exploiting time-of-use (TOU) pricing and maximum of \$11,836 rewards annually for demand response incentive program.
- Collected 12 months of data in the City of Santa Monica and supported more than 216 PEV users in their daily PEV charging needs.
- Filed three patents on the smart charging algorithm and control of battery energy storage system, published five journal/ conference papers, and held two technology workshops on April 13, 2016, and September 26, 2016.

CHAPTER 7: Public Benefits to California

Increase EV Charging Infrastructure

Based on comparison of regular commercial PEV chargers with the hardware and software developed in this project, current UCLA SMERC PEV smart chargers provide additional flexibility with control of charging power and allowing for additional PEV charging sessions simultaneously within a single charger connected to multiple vehicles. Based on initial tests when the first smart PEV charger was installed in January 2016, SMERC’s smart PEV chargers provide an average of **92.17 percent more charging sessions** and **43.26%** more energy delivered than a traditional charger (Figure 41). SMCCP01 is the first UCLA SMERC Level 2 smart PEV charger as compared to Level 2 regular Clipper Creek PEV chargers (SMCCP02 to SMCCP07) at same parking lot and same time frame.

Figure 41: Comparing Regular EV Chargers and SMERC’s Smart EV Charger

Parking Lot: Civic Center Parking Lot Address: 333 Civic Center Dr, Santa Monica, CA 90401				
Box Name	SMCCPL1			
Station Name	Number of Sessions	Served Energy (kWh)	Average Energy Per Session (kWh)	Total Energy Consumed (kWh)
SMCCP01	108	836.929	7.749	852.845
SMCCP02	54	660.116	12.224	667.972
SMCCP03	62	618.641	9.978	624.683
SMCCP04	60	683.706	11.395	692.181
SMCCP06	56	513.318	9.166	519.899
SMCCP07	49	465.284	9.496	471.833

From 2016-01-01 To 2016-01-31

SMCCP01 is the first UCLA SMERC level 2 smart EV charger as compared to level 2 regular Clipper Creek EV chargers (SMCCP02 to SMCCP07) at same parking lot and same time frame.

Credit: UCLA SMERC © 2014-2018

Energy Cost Reduction

When the City of Santa Monica chooses to participate in SCE’s demand response incentive program, they can avoid SCE demand charge by peak saving of \$2006.55 (from January 1, 2017 to December 31, 2017) and \$11,835.9 annually. Using the BESS (8.7 kWh), during peak demand times can save energy costs of up to \$1,435 annually.

Stable Power Grid

In this project, the project team achieved these technical outcomes providing a more stable power grid.

- Load smoothing, which helps avoid peak power impact.
- Interface to the grid by an integrated control center to support grid-originated DR events.
- Capability for power quality monitoring and initiate peak shaving as necessary.
- Time shifting to address the Duck Curve phenomenon.
- The ability of V2G and BESS in providing emergency power for building and grid support.
- Reduce the peak power from DCFC with a BESS.

GHG Emission Reduction

Benefits to California include reductions in greenhouse gas emissions and air emissions such as oxides of nitrogen from using PEVs. For this project, there were publicly accessible smart chargers to accommodate an increase of 216 PEVs users between 2015 and 2017 during this project. Argonne's alternative fuel life-cycle environmental and economic transportation (AFLEET) Toll [38] estimated life-cycle greenhouse gas emissions and vehicle air-pollutant emissions for these additional 216 PEVs. This tool estimated emissions from gasoline light duty vehicles and compared them to that of light duty EVs. The following assumptions are used:

1. Annual average mileage per vehicle of 12,400.
2. Fuel economy of 26.2 mpge for gasoline, 72.1 (miles per gallon equivalent) mpge for PEVs.
3. Los Angeles, California as the location for emissions basis.
4. Average passenger car lifetime of 15 years.
5. One EV increase per user account request.
6. For each new user account created in current project, it is assumed that a new PEV is purchased and used.

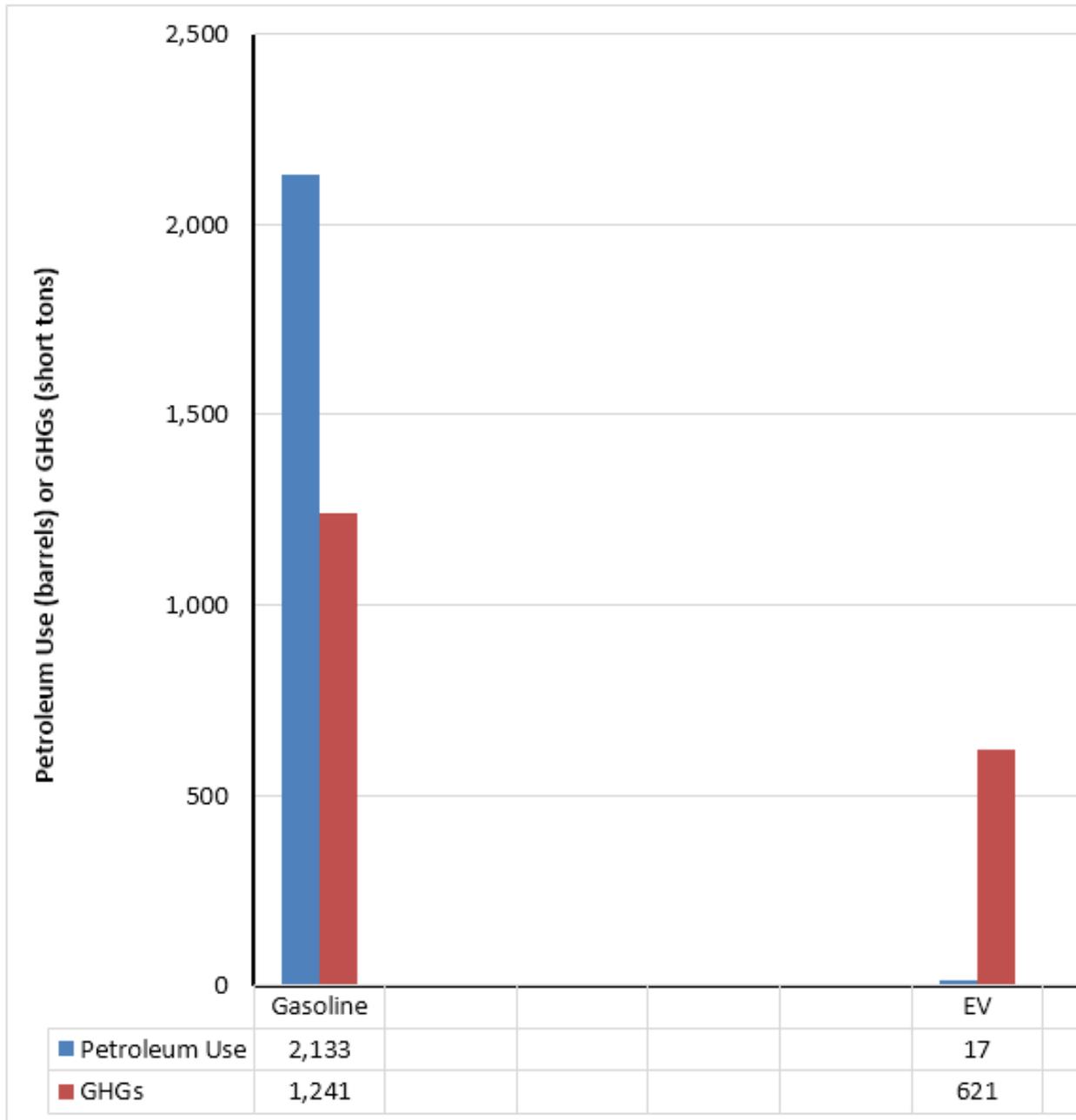
The results as presented in Figure 42 and Figure 43. They show substantial reductions in petroleum use, GHG, and air pollutant emissions by using additional 163 PEVs in place of gasoline passenger cars:

The annual petroleum use is 2,133 barrels, and GHG emissions is 1,241 short tons for gasoline vehicles. In contrast, the annual petroleum use is 17 barrels and GHG emission is significantly reduced to 621 short tons for PEVs. Being scaled up to the lifetime cycle for the petroleum use, 216 gasoline passenger cars have up to approximately 31, 990 barrels compared with the PEVs' 251 barrels.

The calculated annual air pollutant emissions include CO (9,564 lb), NO_x (489 lb), PM₁₀ (195 lb), PM_{2.5} (45 lb) and VOC (531 lb) for gasoline vehicle operations, however, the PEV can reduce the pollutant emissions to PM₁₀ (177 lb) and PM_{2.5} (24 lb). Further, the PEV has zero-emission of CO, NO_x and VOC.

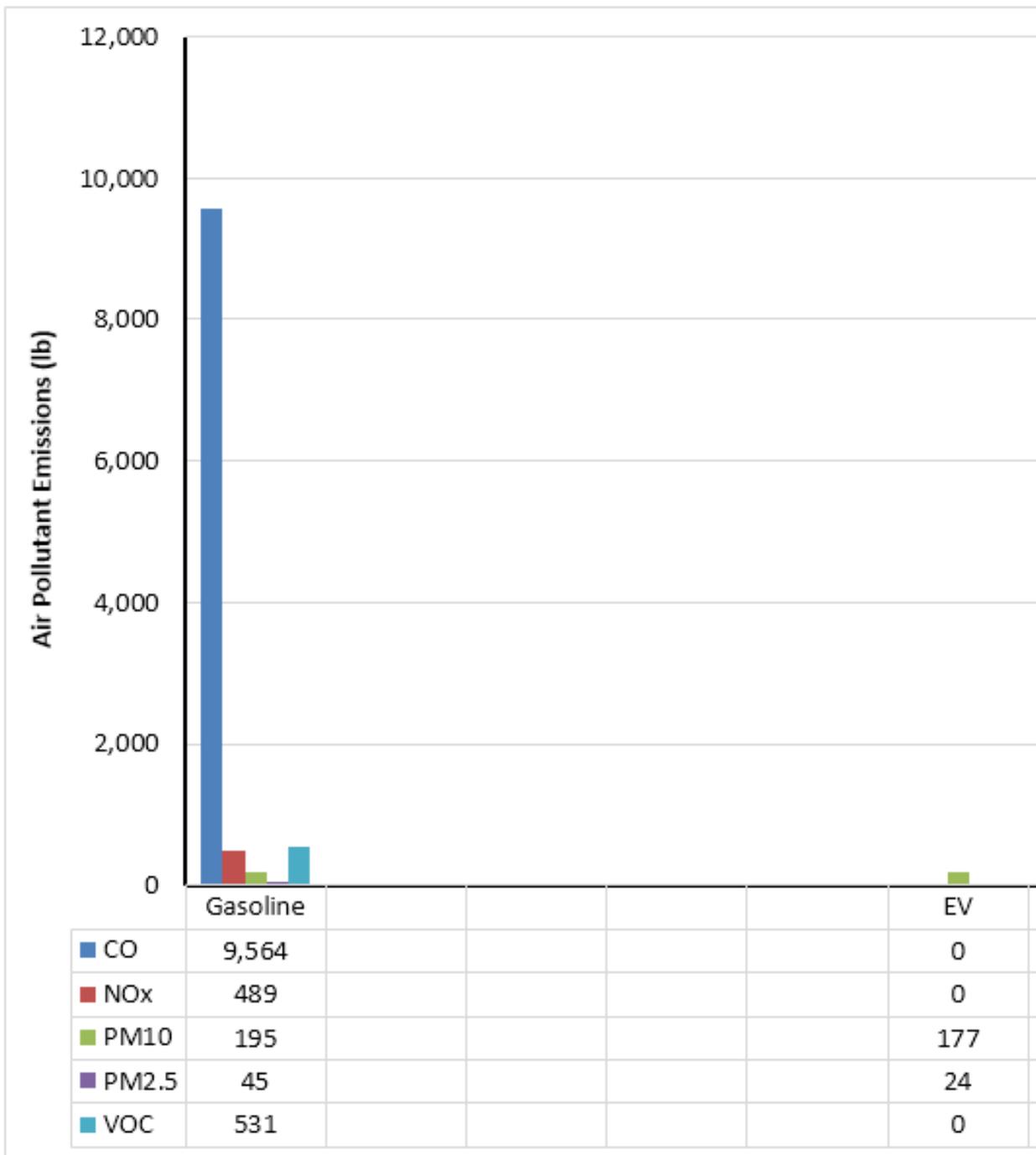
The PEVs can substantially reduce the lifetime air pollutant emissions to PM10 (2,657 lb), PM 2.5 (354) compared with the PM10 emission (2,918 lb) and PM 2.5 (663 lb) emissions of 216 gasoline cars.

Figure 42: Annual Well-to-Wheels Petroleum Use and GHGs for 216 Gasoline/EV Passenger Car Fleets



Credit: Argonne National Laboratory

Figure 43: Annual Vehicle Operation Air Pollutants for 216 Gasoline/EV Passenger Car Fleets



Credit: Argonne National Laboratory

GLOSSARY

Word/Term	Definition
API	Application Programming Interface is a set of clearly defined methods of communication between various software components
BESS	Battery Energy Storage System
CAISO	California Independent System Operator
DCFC	Direct Current Fast Charging supersede Level-1 and Level-2 charging, and are designed to charge electric vehicles quickly with an electric output ranging between 50 kW - 120 kW.
DER	Distributed Energy Resources
DR	Demand Response is defined as: “Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.”
EV	Electric Vehicle
EVSE	EV Supply Equipment. It is commonly called as charging station or charging dock. It is built into the EV charging standard for electrical safety
G2V	Grid to Vehicle describe the power from the grid to a plug-in EV.
GHG	Green House Gas is a gas in an atmosphere that absorbs and emits radiant energy within the thermal infrared range.
IEC	International Electrotechnical Commission
IOU	Investor-owned utility
LBNL	Lawrence Berkeley National Laboratory
MBSS	Mobile Battery Storage System
PEV	Plug-in Electric Vehicle
PV	Photovoltaic
SAE	Society of Automotive Engineers
SC	Smart Charging is the intelligent charging of EVs, where charging can be shifted based on grid loads and in accordance to the vehicle owner’s needs.
SCE	Southern California Edison
SMERC	Smart Grid Energy Research Center
V2B	Vehicle to Building describes a system in which EV can communicate with a building to sell demand response services by either delivering electricity into the building or by throttling their charging rate.
V2G	Vehicle to Grid describes a system in which plug-in EV communicate with the power grid to sell demand response services by either returning electricity to the grid or by throttling their charging rate.
VGI	Vehicle-Grid Integration

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1. UC-2017-213-2FP, Gadh R., Zhang T., Chung C.-C., Chu C-Ch., Automated EV Charging Station Identification Process with Mobile Phones and Other Automation Processes. Provisional submission of patent document to US patent office.
2. R. Gadh, H. Nazaripouya, P. Chu, "Plug and Play Battery Energy Storage Control System for Voltage Regulation", Sep 10, 2017, disclosure for patent submitted to UCLA Office of Intellectual Property and Industry Sponsored Research (OIP-ISR). Document available for review.

APPENDIX A:

Technical Transfer Plan

As the project continued to progress by way of showing the technologies to key stakeholders including utilities, industry, regulators, researchers, etc., and, as additional data was collected and the systems were modified based on data collection, analysis and feedback from stakeholders, the tech transfer plan needed to be updated. UCLA has updated the plan and submitted a final updated version at the end of the project.

Various technologies have been developed and they are being used to gather data. Based on this data, the technology would be continuously refined. The technologies resulting in systems been discussed in various reports already submitted and other reports to be submitted.

These systems would, prior to project completion, either be copyrighted or patented through the UCLA intellectual property (I.P.) office. The I.P. would then be either licensed or sold by UCLA or it would be spun off by way of a startup company. The team (Dr. Gadh and Dr. Peter Chu) has significant experience spinning off startups from a university. The most recent startup that was spun-off was the smart EV charging technology called WINSmartEVTM and it was based on technology developed at UCLA (via three patents) and funded in part by the Department of Energy/Los Angeles Department of Water and Power (LADWP) Smart Grid Demonstration Regional Program (SGRDP) program (DOE funded LADWP SGRDP to the tune of \$60 million and another \$60 million was provided as cost share by LADWP and its partners on this project including UCLA). Dr. Gadh and his team went through the various steps and were able to successfully spin off the startup company two years ago.

The startup team worked closely with the UCLA's Anderson School of Management, UCLA Office of Intellectual Property and the UCLA's Institute for Technology Advancement - who collectively helped develop the business plan and introduced the team to potential commercial partners. This was critical to the success of the startup.

In addition, the startup team worked with Silicon Beach entrepreneurs here in the Los Angeles region as well as the Los Angeles Cleantech Incubator (which Dr. Gadh is an advisor to) to take the business plan developed by UCLA business team and make it practically executable. The support structure within UCLA and from the business community has been very helpful. Most recently, SMERC technology was picked as a Finalist for the Los Angeles Business Journal Patrick Soon-Shiong Awards Innovation Awards in November 2016 (news item appeared on Los Angeles Business Journal News -

http://www.cbjonline.com/a2labj/supplements/InnovationAwards_20161128.pdf.

The startup is now in operation and installing its technology in Southern California and Northern California in the territories of PG&E and SCE. Dr. Gadh and Dr. Chu are advisors to this startup.

By virtue of having the technology installed, tested and demonstrated at various sites and within the territories of different utilities, the team was able to understand the strengths and weaknesses of the technology and so were able to refine it constantly. The team was able to work with the utilities in understanding the value of the technology to utilities. The team was able to work with site hosts and understand how to customize the technology to maximize value to site host and the EV drivers. The following were the test sites in Southern California where the technology was installed prior to the commercialization:

- a. UCLA
- b. Los Angeles Department of Water and Power (LADWP) headquarters in Los Angeles
- c. Southern California Edison (SCE), Pomona EV Test Labs (SCE signed an agreement with UCLA to test the system in their test labs).
- d. Port of Los Angeles (LADWP)
- e. City of Pasadena (Pasadena Water and Power)
- f. City of Santa Monica (SCE)

With the success and excitement of the first startup, a second technology that's being investigated for commercialization that also came out of the SGRDP is that of software-based battery control. One patent has been filed from this technology and it is expected that additional patents will be filed. SMERC has been selected as a winner of the NSF I-Corp award with funding of \$50,000 entitled: "Software/Hardware Controller for Real Time Control of Battery Energy Storage System in a Grid" to work with utilities and energy companies and investigate the market potential of the software-based battery control. The award will enable SMERC to meet and interview 100 experts across California and the USA - to determine how to position the product in the market. The primary goal of NSF I-Corps is to foster entrepreneurship that will lead to the commercialization of technology that has been supported previously by NSF-funded research. I-Corps prepares scientists and engineers to extend their focus beyond the laboratory, and broadens the impact of select, NSF-funded, basic-research projects. This program teaches NSF grantees to identify valuable product opportunities that can emerge from academic research, and offers entrepreneurship training to participants by combining experience and guidance from established entrepreneurs through a targeted curriculum.

Given that the team has substantial experience now in commercializing UCLA technology using the ecosystem in UCLA and the surrounding communities that exists to create startups, the project team is confident about creating new technology that's valuable (by engaging the utilities via the TAC and the site host, i.e., the city of Santa Monica, that also serves on the TAC).

APPENDIX B:

Engaging with Subject Matter Experts

There are variety of classes of subject matter experts and the team is constantly engaging with them. Subject matter experts are external and internal.

Externally, the persons from the team who are engaged with the subject matter experts are Rajit Gadh, Peter Chu and Michael Boehm.

Internally, the persons from the team who are engaged with the subject matter experts are Rajit Gadh, Peter Chu, Hamid Nazaripouya, Behnam Khaki, Yingqi Xiong, Tianyang Zhang, Ethan Cao, Yu-Wei Chung.

External subject matter experts are from academia, industry, utilities, industry, government and regulatory bodies.

Internal subject matter experts are faculty, researchers, staff managing the UCLA power grid and UCLA's natural gas co-generation power plant in campus, experienced electrical installers, etc.

Various meetings, conferences and workshops were held since the start of the project with various subject matter experts, two major conferences are as follows and later in the document several others are discussed:

i. 4/13/16 Innovation Thought Leadership Forum

Key participants:

- Patricia Hoffman, Assistant Secretary, Department of Energy
- Doug Kim, Director, Southern California Edison
- Lee Krevat, Director, Sempra US Gas and Power
- Nancy Sutley, Chief Sustainability and Economic Development Office, Los Angeles Department of Water and Power
- David Wollman, Deputy Director, Smart Grid and Cyber-Physical Systems Program Office, NIST.

ii. 9/20/2016 1st Annual ESMART Consortium Review

Key participants:

- Cotton Ching, Vice President, Energy Delivery, Hawaiian Electric Company
- Dhaval Dagli, Principal Manager of Regulatory Policy, Regulatory Affairs, Southern California Edison
- Mike Gravely, Team Lead - Energy Systems Research Office, California Energy Commission
- Jim Parks, Program Manager, Energy Research and Development, Sacramento Municipal Utility District.

APPENDIX C:

Technical Advisory Committee

Responsible person - Rajit Gadh

Purpose - To engage the California utilities, to present this approach and technology to them, and to get feedback from California-based utilities.

In addition to exchanging information with the Technical Advisory Committee (TAC) the team have engaged a variety of utilities in the California region, and, the following utilities have visited as since the start of the project:

- Carlos Arevalo, SCE
- Jay Bhakta, SCE
- Chris Chen, Manager of Intellectual Capital, SDG&E
- Cotton Ching, Vice President, Energy Delivery, Hawaiian Electric Company
- Dhaval Dagli, Principal Manager of Regulatory Policy, Regulatory Affairs, SCE
- Dale Fontanez, SoCalGas
- Kevin Garrity, Manager, LADWP
- Mike Gravely, Manager - Energy Systems Research Office, California Energy Commission
- Erik Johnson, Pasadena Water & Power
- Brian Koch, LADWP
- Kit San Lai, LADWP
- Kenny Li, SMUD
- Jim Parks, Program Manager, Energy Research and Development, Sacramento Municipal Utility District
- Khaled Salem, SDG&E
- William Zhang, LADWP
- Doug Kim, Director, Southern California Edison
- Lee Krevat, Director, Sempra US Gas and Power
- Nancy Sutley, Chief Sustainability and Economic Development Office, LADWP

The Technical Advisory Committee was formed on December 2016

- Daniel Ohlendorf (PG&E);
- Dean Kubani (City of Santa Monica);
- Jordan Smith (SCE);
- Robert Sherick (SCE);
- Terry Brungard (LADWP);
- Lee Krevat (Sempra Energy).

Barriers to getting these experts on TAC?

Given that UCLA's Smart Grid Energy Research Center has ongoing relationships with the utilities in California, they were invited to participate and they accepted in a few weeks after they were invited. Overall, there were minimal barriers to getting these experts on TAC.

How many TAC meetings to date?

One - December 14, 2016.

Ten stakeholders inside California that would be interested in this info

1. Electric Vehicle Manufacturers
 - a. Nissan
 - b. Tesla
2. Battery Energy Storage System Manufacturers
 - a. Tesla
 - b. Kokam
3. Solar Panel Manufacturers
 - a. Sunpower
4. Solar Project Planning and Execution Companies
 - a. Solar City
5. IOU and other utilities
 - a. SMUD
 - b. Burbank Water and Power
 - c. Glendale Water and Power
6. Power equipment manufacturing companies
 - a. Siemens
7. Software companies operating in the energy technology space
 - a. Microsoft
 - b. Google
8. High-tech companies in the energy and power sector
 - a. Intel
 - b. HP
9. Smart meter manufacturers
 - a. Itron
10. Companies developing communications technologies
 - a. Cisco
 - b. Qualcomm

Five organizations outside California that would be interested in this info.

1. General Electric
2. Hawaii Electric
3. Department of Energy
4. Con Edison
5. Schneider

APPENDIX D:

Publications

- Tianyang Zhang; Chi-Cheng Chu; Rajit Gadh, *A Two-Tier Energy Management System for Smart Electric Vehicle Charging in UCLA: A Solar-To-Vehicle (S2V) Case Study*, Innovative Smart Grid Technologies - Asia (ISGT-Asia), 2016 IEEE
- Tianyang Zhang; Xiangyu Wang; Chi-Cheng Chu; Rajit Gadh, *User Demand Prediction and Cloud-Based Smart Mobile Interface for Electric Vehicle Charging*, Power and Energy Engineering Conference (APPEEC), 2016 IEEE PES Asia-Pacific
- B Wang, Y Wang, H Nazaripouya, C Qiu, CC Chu, R Gadh, *Predictive Scheduling Framework for Electric Vehicles with Uncertainties of User Behaviors*, IEEE Internet of Things Journal 4 (1), 52-63
- Y Xiong, B Wang, C Chu, R Gadh, *Distributed Optimal Vehicle Grid Integration Strategy with User Behavior Prediction*, arXiv preprint arXiv:1703.04552
- Y Wang, W Shi, B Wang, CC Chu, R Gadh, *Optimal Operation of Stationary and Mobile Batteries in Distribution Grids*, Applied Energy 190, 1289-1301

The team is working on several publications internally which would be submitted once completed.

News media has published the following - <http://patch.com/california/santamonica/santamonica-teams-ucla-install-experimental-ev-fast-charger>.

APPENDIX E:

Outreach During This Project

What is the reliance on media office to disseminate info on this project?

The California Energy Commission Media Office is typically made aware of the various activities so that they may share the information to others. UCLA media office does a good job of covering these activities.

The UCLA media office is aware of the Energy Commission project and the project was mentioned on the UCLA news site - <http://www.mae.ucla.edu/rajit-gadh-santa-monica-teams-up-with-ucla-to-install-experimental-ev-fast-charger/>. This project was recently highlighted by a local newspaper - <http://patch.com/california/santamonica/santa-monica-teams-ucla-install-experimental-ev-fast-charger>.

The project team is looking forward to sharing the developments with the Energy Commission media office as well.

In addition to the media office, UCLA hosts several conferences and workshops and disseminates information through these.

UCLA also publishes papers which enable others to read about our work.

Finally, the web site of the Smart Grid Energy Research Center is used to disseminate the latest news from the center.

SMERC and the work done at SMERC is covered by a substantial amount of local media. In addition, SMERC has through its own media marketing through its web site and its social media outlets, been active in promoting its research, meetings, visits, outreach, etc. The following are some of the key news items that have appeared since the start of the project. Next to each news item, the particular social media outlet through which the news item was broadcast to the public is also listed.

2015

1. July 17, 2015 - **UCLA SMERC paper currently most popular on IEEE Transactions on Smart Grid.** SMERC was in the news because a paper by the UCLA SMERC team published in IEEE Transactions on Smart Grid (Vol. 6, Issue3) "Distributed Optimal Energy Management in Microgrids", was ranked No.1 most popular article based on downloads and is featured in the IEEE Xplore Digital Library.
http://smartgrid.ucla.edu/news_071715.html

2. September 8, 2015 - **Power Systems Certificate from the MS Online program at UCLA.** SMERC launched via UCLA's Master of Science in Engineering Online program a Power Systems Certificate. It is comprised of three courses with the first course being offered

in Fall 2015 and is open for registration. UCLA SMERC director, taught the first course, Design and Analysis of Smart Grids, along with other instructors who will be teaching the second and third course. Two of the co-instructors came from Southern California Edison. The program presents a modern curriculum on the power grid and the IOUs are sending their employees to register for the certificate.

http://smartgrid.ucla.edu/news_150908.html



3. September 11, 2015 - **SMERC to participate at 2015 AltCar Expo, Santa Monica.** SMERC participates in the panel discussion "PEV Collaborative/ SCE MUD and WorkPlace Charging". The discussion included the latest projects, products and options for both Multi-unit Dwelling (MUD) and Workplace charging.

http://smartgrid.ucla.edu/news_150911.html



4. September 18, 2015 - **Greener, Greener, Gone. Argonaut Online coverage of SMERC presentation.** At one of the 10th annual AltCar Expo's panel UCLA professor and SMERC director, Rajit Gadh, says "infrastructure is probably the most critical point," when it comes to the future of green transportation. Gadh is partnering with the city of Santa Monica to maximize the availability and efficiency of electric vehicle charging locations. Gadh's research will go into a new study to help optimize EV charger energy output to avoid taxing the power grid during peak demand hours.

http://smartgrid.ucla.edu/news_150918.html



5. September 28, 2015 - **SMERC Director to speak at event with notable speakers including Carol Browner (former head US EPA), Mary Nichols (Chair, CARB), Kevin de León (President pro Tempore, California State Senate), etc.** SMERC director, joined notable roster of speakers such as Randy Howard (General Manager, NCPA), Carol Browner (former head US EPA), Mary Nichols (Chair, CARB), Kevin de León (President pro Tempore, California State Senate), at the NCPA Annual Conference 2015. Gadh's talk, "Work Smart, Not Harder" discusses the cutting-edge research he is leading that will help develop the next generation electric grid - capable of integrating renewable sources and electric vehicles.

http://smartgrid.ucla.edu/news_150928.html

http://smartgrid.ucla.edu/news_151005.html



6. October 12, 2015 - **When Will We Get Smart Grids? MIT Review Article.** Widely implementing dynamic electricity prices will require adequate funding to educate consumers, says a report released by Department of Energy last September. Sometimes the notifications that customers have received about electricity prices have been too frequent and confusing, it says. But new home appliances and electric vehicles that can

get real-time data about pricing could free consumers from even having to make such decisions—devices can be configured to turn on or charge their batteries only when the price of electricity is low. UCLA's Smart Grid Energy Research Center is using data gathered from about 130 electric-vehicle charging stations around campus to develop algorithms that use a person's price preferences to determine when the cars should charge. The model is described in a paper presented at an Institute of Electrical and Electronics Engineers conference in February.

http://smartgrid.ucla.edu/news_151012.html



7. October 14, 2015 - **U.S. Secretary of Energy and Los Angeles Mayor announce Climate Change Report.** On Friday Secretary of Energy, Ernest Moniz, alongside Los Angeles Mayor, Eric Garcetti, announced the release of the report "Climate Change and the U.S. Energy Sector: Regional Vulnerabilities and Resilience Solutions". The project will equip the first fire station pilot with solar and battery storage backup energy system it would need in the event of a disaster. SMERC director, Rajit Gadh, spoke with them at the event.

http://smartgrid.ucla.edu/news_151014.html



8. October 19, 2015 - **Delegation from Dubai visits SMERC lab.** SMERC hosted a delegation from Dubai's Electricity and Water Authority (DEWA) that included H.E. MD & CEO Saeed M. Al Tayer (DEWA), and Secretary General Ahmed Al Muhairbi from the Dubai Supreme Council of Energy (DSCE). The delegation toured the SMERC lab after a discussion on smart grid technology with the center's director, Dr. Rajit Gadh.

http://smartgrid.ucla.edu/news_151019.html

9. November 4, 2015 - **SMERC director to participate in panel discussion at the Regional Pravasi Bharatiya Divas (RPBD) Los Angeles.** SMERC director participates in a panel discussion at this year's RPBD Los Angeles, whose theme is "The Indian Diaspora: Defining a New Paradigm in India-US Relationship". The panel, Investment opportunities in Clean & Renewable Energy sector in India, will discuss the trends and challenges in investments & collaborations in Renewable energy in India, the new technologies, financing & scaling up innovative business models in the renewables space in India. Other speakers include Ambassador of India to the United States, Mr. Arun Kumar Singh, Consul General of India, San Francisco, Mr. Venkatesan Ashok, and, Mr. AK Agarwal, Secretary, Ministry of Overseas Indian Affairs.

http://smartgrid.ucla.edu/news_151105.html



10. November 23, 2015 - **Innovations to fight climate change. Interview appears in CBC (Canadian Broadcasting Corporation) News.** As part of a package of special coverage of

climate change issues by CBC News, Prof. Rajit Gadh, was interviewed about the innovations at the SMERC lab that are designed to help reduce emissions from batteries that store solar energy to smart appliances that sell power back to the grid and smart electric vehicle chargers.

http://smartgrid.ucla.edu/news_151123.html



11. December 7, 2015 - **SMERC director hosts delegation from ASEAN (Association of Southeast Asian Nations)**. During the visit of a delegation from ASEAN (Association of Southeast Asian Nations), SMERC Director Rajit Gadh talks with Ronnie Aperocho, First Vice President and Head of Networks for Meralco, the largest electric power provider in the Philippines, whose service territory is the Metro Manila area. Also, on the delegation were energy ministers and electric power utility executives from the ASEAN countries, Indonesia, Malaysia, Myanmar, and Vietnam. ASEAN delegation members included: Dr. Tuan Anh Nguyen, Director General of the Electricity Regulatory Authority of Vietnam (seated second from right) and Tran Dinh Nhan, (seated far right) Chairman and General Director of Vietnam's Central Power Corporation. Dr. Gadh also spoke with Indonesia's Dr. Agung Wicaksono, Deputy Head of the Project Management Office for 35000 MW Electricity Construction, within Indonesia's Ministry of Energy and Mineral Resources.

http://smartgrid.ucla.edu/news_151216.html



12. December 8, 2015 - **SMERC director speaks at DEWA's Fifth Innovation Conference, news item in Thompson Reuters – Zavya News**. Prof. Rajit Gadh was a featured opening session speaker at Dubai Electricity and Water Authority (DEWA) Fifth Innovation conference. International experts participated in the conference to discuss innovation in sustainability, renewable energy and water.

http://smartgrid.ucla.edu/news_151208.html



2016

13. January 7, 2016 - **Smart Grids and Microgrids Team Up for a Smarter World, in “The Atlantic”**. In a recent The Atlantic article on the advancement and importance of the Internet of Things and Smart Grids, the work at UCLA SMERC lab was discussed.

http://smartgrid.ucla.edu/news_160107.html



14. January 25, 2016 - **Inaugural UCLA-Tata Global Forum Discusses Future of Sustainable Energy, New Delhi, India**. Hosted by both UCLA Chancellor Gene Block (with Dr. Gadh being an organizer and speaker) and Mr. Ratan Tata, chairman of Tata Trusts, the UCLA-Tata Global Forum 'Innovating for a Sustainable Energy Future' brought together policy makers, academic and business leaders for a discussion on the future of sustainability.

Sustainable megacities, the integration of solar power into smart energy grids and sustainable biological fuels were some of the topics on the agenda. Among the speakers were Dr. Gururaj Deshpande, president and chairman of Sparta Group LLC and chairman of Tejas Networks, and Smriti Zubin Irani, Indian minister of human resource development who delivered keynote addresses.

http://smartgrid.ucla.edu/news_160125.html



15. February 4, 2016 - **UCLA-SMERC director to participate in The Knowledge Foundation's 6th Annual Next-Generation Energy Storage 2016, San Francisco.** Dr. Rajit Gadh will be instructing a workshop, 'Grid to EV and EV to Grid - Technologies to Enable Energy Storage on the Grid', on Vehicle-to-Grid (V2G) technologies at The Knowledge Foundation's 6th Annual Next-Generation Energy Storage 2016 Conference.

http://smartgrid.ucla.edu/news_160204.html



16. March 1, 2016 - **Tata Power Delhi Distribution Limited and SMERC Collaborate to Deliver Innovative and Sustainable Technology to Electric Utilities.** MOU signed between UCLA and Tata Power to collaborate on innovations and usable commercial products resulting from research.

http://smartgrid.ucla.edu/news_160301.html



17. March 8, 2016 - **UCLA professor develops smart grid technology to tackle energy shortage.** **Daily Bruin News** - Gadh, the director of the UCLA Smart Grid Energy Research Center, is spearheading the development of a new energy distribution network, called smart grid technology. He intends to improve the technology in India through a new partnership between the Smart Grid Energy Research Center and an energy distribution company in New Delhi, UCLA officials announced Jan. 29.

http://smartgrid.ucla.edu/news_160308.html



18. April 13, 2016 - **Photo Recap: SMERC DC Forum.** SMERC hosted a forum in DC at which utilities such as LADWP - Assistant GM Nancy Sutley - were represented as speakers as were leaders from DOE - Assistant Secretary Patricia Hoffman was a speaker. It was attended by government leaders - especially from DOE, industry and utilities.

http://smartgrid.ucla.edu/news_160413.html



19. May 4, 2016 - **The Smart Grid Living Lab at UCLA and its Automated Demand Response Program.** Talk given to local IEEE Chapter - Buena Vista, at California

Lutheran University and was open to the public. Presented SMERCs initiatives, the Automated Demand-Response (ADR) technology research program that aims to showcase different levels and modalities of automation in load curtailment, control models and secure messaging schemes leveraging multiple communication technologies and maintaining interoperability between the Smart Grid automation architecture layers.

http://smartgrid.ucla.edu/news_160426.html



20. April 18, 2016 - **Lighting the Way: Getting Smart About Electricity**. SMERC director Rajit Gadh participated in Southern California Edison's "Lighting the Way: Getting Smart About Electricity". The UCLA Anderson School of Management event offered a panel of experts who shared the latest on topics such as smart grids, smart cars, demand response, energy storage, and new sources. This included a conversation between Rajit Gadh and SCE President Pedro Pizarro. The panelists at the event included Lisa Cagnolatti - Vice President, Business Customer Division, SCE, Oded Rhone - Vice President, Strategic Planning, Edison International, Rajit Gadh - Professor, UCLA and Director of UCLA's Smart Grid Energy Research Center, and was chaired by Matt Smith - Project Manager at San Diego Gas & Electric.

http://smartgrid.ucla.edu/news_160503.html



21. May 26, 2016 - **New natural gas projects spark debate**. Prof. Rajit Gadh was quoted in a The San Diego Union-Tribune article discussing the future of where the California's energy will come from. The results of a court hearing could have an impact on four major proposed natural gas power plants.

http://smartgrid.ucla.edu/news_160526.html



22. May 31, 2016 - **UCLA SMERC director, Rajit Gadh, quoted in LA Times article on California's Energy future**. The LA Times article on May 25, 2016 focused on whether the future of Southern California's energy be from only renewable sources or still include fossil fuels. Current plans for more natural gas powered gas power plants are at the center of debate.

http://smartgrid.ucla.edu/news_160531.html



23. June 14, 2016 - **Delegation from Finland Visits UCLA Smart Grid Energy Research Center**. A team of visitors from Finland consisting of industry, government and academic personnel visited SMERC. Delegation was led by Juha P. Markkanen, Consul General of Finland (ambassador), Consulate General of Finland in L.A. UCLA demonstrates technologies to the delegation.

http://smartgrid.ucla.edu/news_160614.html



24. June 15, 2016 - **Director of SMERC visits Greece and meets with Dr. Nikos Hatziargyriou, CEO of HEDNO, The Largest Distribution Utility in Greece.**

http://smartgrid.ucla.edu/news_160615.html



25. August 21, 2016 - **UCLA Impacts the World.** “UCLA's accomplishments don't just include a portfolio of almost 3000 inventions, and more than 140 companies created base on technology created at the university, but also includes faculty, alumni and researchers. Among those faculty is engineering professor, Rajit Gadh, who has developed technology that is revolutionizing the consumption of energy.”

http://smartgrid.ucla.edu/news_160821.html



26. September 15, 2016 - **SMERC director speaks at The Electric Vehicle-Utility Industry Nexus Conference in San Diego.** Event was attended by several utilities including SCE, PG&E and San Diego Gas and Electric.

http://smartgrid.ucla.edu/news_160915.html



27. September 20, 2016 - **Brazilian Delegation visits UCLA and tours SMERC's Living Labs.** Various regulators, energy companies and utilities participated. Some members in the delegation included Guilherme Syrkis (Special Advisor to the Minister of Energy), André Pepitone da Nóbrega (Commissioner, ANEEL), Lucas Lucena (Manager, BNDES), Miguel Nery (Director, ABDI), Ana Christina Mascarenhas – Energy Efficiency Director, NEOENERGIA). As a team member of the Sustainable LA Grand Challenge, SMERC researchers met with and gave presentations to the delegation. The delegation also toured the SMERC lab gave tour of SMERC's various research living labs in Parking Structure 8 that houses both Level 1 and Level 2 charging stations as well as the newly installed solar panels and Level 2 stations in Parking Structure 9.

http://smartgrid.ucla.edu/news_160920.html



28. September 20, 2016 - **Kickoff of UCLA ESmart (Energy for a Smart Grid) Consortium Gathered Top Energy Distribution Thought Leaders Sharing Ideas for the Future.** Adrienne Grier from ComEd of Chicago, shared details of the utility's journey to the grid of the future. California ISO's Tom Doughty gave a rousing presentation about the power of renewable energy transmitted via smart grids to transform our society. Peter Schwartz of the Lawrence Berkeley National Laboratories explains LBNL modeling of the potential for cost-competitive Demand Response (DR) to provide up to 6 gigawatts by 2025. Peter Schwartz of the Lawrence Berkeley National Laboratories, who spoke about technology, policy and innovation that is changing the face of smart grids and pointing

the direction to how they can be implemented most effectively in the future. Martha Symko Davis, the Director of Partnerships – Energy Systems Integration, at the National Renewable Energy Laboratory, shared an informative talk about NREL's strategy for their ESIF (Energy System Integration Facility) located in Golden, Colorado, just west of Denver. Schneider Electric's Mark Feasel presented his company's viewpoint about the new energy landscape. He noted a megatrend, the huge growth forecast for variable renewables, detailing that 50% of the new capacity additions in 2030 will be solar PV and storage, and also that a decade earlier, by 2020, the Internet of Things will connect 50 billion devices. Jim Parks of the Sacramento Municipal Utility District, shared a presentation with consortium meeting attendees. It featured SMUD's lessons learned during their smart grid regional development project funded by the DOE.
http://smartgrid.ucla.edu/news_160920b.html

29. September 25, 2016 - **SMERC director interviewed by Talking Tesla Podcast.** UCLA SMERC director, Rajit Gadh, was recently interviewed by Talking Tesla podcast host Robert Rosenbloom at this year's AltCar Expo in Santa Monica. The interview focused on the advancements of electric vehicle charging and microgrids. The 52nd episode of the Talking Tesla podcast, "8.0 Countdown" has already been downloaded more 6,700 times within 24-hours. You can listen to the interview with Prof. Rajit Gadh at the 1:12:30 mark into the episode.

http://smartgrid.ucla.edu/news_160925.html



30. October 11, 2016 - **Secretary of Energy tours SMERC (Smart Grid Energy Research Center) Living Labs.** U.S. Secretary of Energy, Ernest Moniz, met with researchers and toured two labs on the UCLA campus during his visit to Los Angeles. Attendees included: UCLA - Provost Scott Waugh, UCLA - Interim Vice Chancellor of Research, Ann Karagozian, UCLA - Professor Rajit Gadh, LA City - Lauren Faber, LA City - Matt Petersen, LADWP - Marvin Moon. Gadh and Moniz also discussed on how to reduce solar energy costs. Moniz's team tweeted about SMERC - Totally geeking out @UCLA @UCLA_SMERC energy research center on how to continue to drive down solar costs.

http://smartgrid.ucla.edu/news_161011.html



31. October 27, 2016 - **Rajit Gadh: Smart grids could be the route to a truly renewable energy system (The New Economy interview).** SMERC Director was interviewed by The New Economy in the recent article "Smart grids could be the route to a truly renewable energy system". Gadh discussed the role of data in making smart grids more efficient."

http://smartgrid.ucla.edu/news_161027.html



32. November 27, 2016 - **SMERC director quoted in FastCodeDesign article on Tesla's latest product.** The FastCodeDesign article discusses how Tesla's new solar roof power

energy can feed Tesla car batteries which in turn feed Tesla energy facilities. They could also potentially feed into backup battery plants made up of older batteries. See excerpt below: Rajit Gadh, UCLA professor and founder of the school's Smart Grid Energy Research Center, has 100 EV charging stations set up on a mini grid around campus. There, he has successfully proven that using such hookups could siphon energy from cars directly into homes. "These vehicles sit around 80% to 90% of the time. I'm excited about those batteries," says Gadh. Indeed, the smallest Tesla battery of today could power a home for two days. If the grid just sipped on the energy of those parked cars now and again, the added capacity to the entire grid could be enormous, and EVs may be able to absorb the needs of peak demand.

http://smartgrid.ucla.edu/news_161127.html



33. December 5, 2016 - **SMERC participates in UCLA Anderson School of Management lunch round table.** SMERC Director participated in a lunch round table with guest speaker Deborah Reed, CEO of Sempra Energy at UCLA Anderson School of Management.

http://smartgrid.ucla.edu/news_161205.html



2017

34. January 23, 2017 - **Santa Monica Teams Up with UCLA to Install Experimental EV Fast Charger.** News - City of Santa Monica and UCLA's Smart Grid Energy Research Center (SMERC) have teamed up to install an experimental Level 3 charger in the Civic Center parking structure. The project, funded by research grant from the California Energy Commission, will allow SMERC to manage and monitor the flow of energy between the structure's rooftop solar system, onsite battery storage and city electric vehicles.

http://smartgrid.ucla.edu/news_170123.html



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 : <https://plus.google.com/110878830740003868678>

 : https://www.youtube.com/channel/UCs4uMMzE5fHpen5qciI7_8A

APPENDIX F:

Presentation at Energy Commission and CPUC Meetings

Dr. Gadh has given one talk at a CPUC meeting in San Francisco on Grid Planning and two talks at California Energy Commission meetings on this project in Sacramento.

- November 16, 2015 - ACADEMIC PERSPECTIVE ON CALIFORNIA'S DISTRIBUTION GRID PLANNING EFFORTS, CPUC conference room, CPUC, San Francisco, CA.
- Dec 3, 2015 - EPIC Innovation Symposium organized by Energy Commission, Folsom, CA. Gave presentation on the project.
- Dec 14, 2015, California Energy Commission research review workshop, Sacramento, CA. Gave presentation on the project.

APPENDIX G: Questionnaire

DEVELOPMENT STATUS QUESTIONNAIRE

California Energy Commission Energy Innovations Small Grant (EISG) Program PROJECT DEVELOPMENT STATUS	<h1>Questionnaire</h1>
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Answer each question below and provide brief comments where appropriate to clarify status. If you are filling out this form in MS Word the comment block will expand to accommodate inserted text.

Please Identify yourself, and your project: PI Name <u>Rajit Gadh</u> Grant # <u>EPC-14-056</u>	
Overall Status	
Questions	Comments:
1) Do you consider that this research project proved the feasibility of your concept?	<i>Yes, various technologies were successfully developed and demonstrated with quantitative results.</i>
2) Do you intend to continue this development effort towards commercialization?	<i>Yes.</i>
Engineering/Technical	
3) What are the key remaining technical or engineering obstacles that prevent product demonstration?	<i>The prototypical system needs refinement by way of a larger deployment and verification and UL certification before it becomes a commercial product.</i>
4) Have you defined a development path from where you are to product demonstration?	<i>Yes, the developmental path requires a scaled up demonstration within a larger microgrid site that combines EVs, V2G, Solar Generation, BESS and building loads - all connected to our software control system.</i>
5) How many years are required to complete product development and demonstration?	<i>Approximately two years</i>
6) How much money is required to complete engineering development and demonstration?	<i>\$500,000</i>
7) Do you have an engineering requirements specification for your potential product?	<i>Yes, the initial draft is formed.</i>

Marketing	
8) What market does your concept serve?	<i>Parking Facility Owner, Workplace EV charging, Multi Unit Dwelling (MUD) management, Fleet operator, Distribution utility.</i>
9) What is the market need?	<i>The need of EV charging infrastructure is fast growing, garage owners hesitate to invest due to high infrastructure cost and impact to electric bill.</i>
10) Have you surveyed potential customers for interest in your product?	<i>The team had informal conversations with potential customers about the product.</i>
11) Have you performed a market analysis that takes external factors into consideration?	<i>No, the official market analysis has not been performed yet.</i>
12) Have you identified any regulatory, institutional or legal barriers to product acceptance?	<i>Yes, UL certification is needed. Also, regulatory markets need to be created at the intersection of V2G, G2V, BESS and solar - today these markets and regulations are separate and independent.</i>
13) What is the size of the potential market in California for your proposed technology?	<i>Qualitatively, the customers that constitute the market include: Parking Facility Owner, Workplace EV charging, Multi Unit Dwelling (MUD) management, Fleet operator, Distribution utility.</i>
14) Have you clearly identified the technology that can be patented?	<i>Yes.</i>
15) Have you performed a patent search?	<i>Yes.</i>
16) Have you applied for patents?	<i>Yes, the following patent disclosures have been filed: (i) UC-2017-213-2FP, Gadh R., Zhang T., Chung C-.C., Chu C-Ch., AUTOMATED EV CHARGING STATION IDENTIFICATION PROCESS WITH MOBILE PHONES AND OTHER AUTOMATION PROCESSES. Provisional submission of patent document to US patent office. (ii) R. Gadh, H. Nazariyouya, P. Chu, "Plug and Play Battery Energy Storage Control System for Voltage Regulation", Sep 10, 2017, disclosure for patent submitted to UCLA Office of Intellectual Property and Industry Sponsored Research (OIP-ISR). Document available for review.</i>
17) Have you secured any patents?	<i>Not yet</i>

18) Have you published any paper or publicly disclosed your concept in any way that would limit your ability to seek patent protection?	<i>Several papers have been published. The list of these papers is available from UCLA. These papers do not limit our ability to see patent protection.</i>
Commercialization Path	
19) Can your organization commercialize your product without partnering with another organization?	<i>Our organization can commercialize and has on numerous occasions commercialized technology developed by it by way of either licensing the technology to a company or by way of assisting and supporting the technology generators to form startup companies. This requires partnering with various types of organizations including technology companies, entrepreneurs, investors and venture capitalists, government agencies offering grants, electric utilities and others.</i>
20) Has an industrial or commercial company expressed interest in helping you take your technology to the market?	<i>Two of our graduate students have expressed an interest in commercialization by way of doing a startup company.</i>
21) Have you developed a commercialization plan?	<i>The commercialization plan has not been developed as of yet, but it is planned.</i>
22) What are the commercialization risks?	<p><i>Commercialization risks include the following</i></p> <ol style="list-style-type: none"> <i>1. Potential elimination of the automotive and energy storage rebates.</i> <i>2. Potential risk in getting the UL certification of the entire system as this technology is very new.</i> <i>3. Inability to get funding in the near future.</i>
Financial Plan	
23) If you plan to continue development of your concept, do you have a plan for the required funding?	<i>Not yet, but it is planned to do so.</i>
24) Have you identified funding requirements for each of the development and commercialization phases?	<i>Yes, we have an approximate idea of the funding requirements for development and commercialization.</i>

<p>25) Have you received any follow-on funding or commitments to fund the follow-on work to this grant?</p>	<p><i>Yes, we received a \$50,000 NSF I-CORP grant to investigate commercialization of the battery energy storage component of our system - https://nsf.gov/awardsearch/showAward?AWD_ID=1700775&HistoricalAwards=false. This grant is currently active and through this we have interviewed dozens of companies that are in the energy storage space. We plan to continue pursuing further funding - especially from the NSF SBIR program.</i></p>
<p>26) What are the go/no-go milestones in your commercialization plan?</p>	<p><i>Go/no-go milestones are:</i></p> <ol style="list-style-type: none"> <i>1. Getting a real pilot site with a pilot customer that is willing to pay some money</i> <p><i>Obtaining certification for the system</i></p>
<p>27) How would you assess the financial risk of bringing this product/service to the market?</p>	<p><i>Given the reaction to our installed system and our conversations with the site host, we firmly believe that the financial risk is medium to low.</i></p>
<p>28) Have you developed a comprehensive business plan that incorporates the information requested in this questionnaire?</p>	<p><i>We do not have a comprehensive business plan as of yet.</i></p>
<p>Public Benefits</p>	
<p>29) What sectors will receive the greatest benefits as a result of your concept?</p>	<p><i>Commercial sector, Multi-unit dwelling, large buildings with parking structures.</i></p>
<p>30) Identify the relevant savings to California in terms of kWh, cost, reliability, safety, environment etc.</p>	<p><i>See details in section "Public Benefits to California" in this report.</i></p>
<p>31) Does the proposed technology reduce emissions from power generation?</p>	<p><i>Yes, see details in section "Public Benefits to California" in this report.</i></p>
<p>32) Are there any potential negative effects from the application of this technology with regard to public safety, environment etc.?</p>	<p><i>Not at this time.</i></p>
<p>Competitive Analysis</p>	
<p>33) What are the comparative advantages of your product (compared to your competition) and how relevant are they to your customers?</p>	<ul style="list-style-type: none"> <i>• Maximized EV infrastructure utilization through smart EV chargers developed.</i> <i>• Flexible and scalable EV charging infrastructure to include various components in the power grid.</i> <i>• Cloud based centralized high-level management system with local intelligence to manage immediate and offline power needs for a commercial facility/site.</i>

<p>34) What are the comparative disadvantages of your product (compared to your competition) and how relevant are they to your customers?</p>	<ul style="list-style-type: none"> • <i>The need of communication network as compared to standalone EV chargers.</i> • <i>Customers need to be educated on the system and its capabilities for managing charging and storage in an intelligent manner using software-based controls.</i> • <i>May take a longer time and additional costs to deploy as compared to standalone chargers.</i>
<p>Development Assistance</p>	
<p>The EISG Program may in the future provide follow-on services to selected Awardees that would assist them in obtaining follow-on funding from the full range of funding sources (i.e. Partners, PIER, NSF, SBIR, DOE etc.). The types of services offered could include: (1) intellectual property assessment; (2) market assessment; (3) business plan development etc.</p>	
<p>35) If selected, would you be interested in receiving development assistance?</p>	<p><i>Yes, market assessment and business plan development.</i></p>