Pacific Gas and Electric Company

EPIC Final Report

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Project	***EPIC 1.16 – Demonstrate Electric Vehicle as a Resource to Improve Grid Power Quality and Reduce Customer Outages***
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List of Acronyms

ATS	PG&E's Applied Technology Services
CPUC	California Public Utilities Commission
EM	Electric Motor
EPIC	Electric Charge Investment Program
EPU	Export Power Unit
HHDDT	Heavy Heavy-Duty Diesel Truck
ICE	Internal Combustion Engine
NREL ESIF	National Renewable Energy Laboratory Energy System Integration Facility
PHEV	Plug-In Hybrid Electric Vehicle
UDDS	Urban Dynamometer Driving Schedule
VOGSS	Vehicle On-Site Grid Support System

1.0 Executive Summary

Pacific Gas and Electric Company's (PG&E) Electric Program Investment Charge (EPIC) Project 1.16 *Demonstrate Electric Vehicle as a Resource to Improve Grid Power Quality and Reduce Customer Outages* successfully developed and demonstrated a new work-site tool for utility-grade power export from Plug-in Hybrid Electric Vehicle (PHEV) fleet trucks. This new tool is referred to as a Vehicle On-Site Grid Support System (VOGSS).

As electrification of transportation vehicles becomes more commonplace, there is the potential to further leverage their on-board batteries and sizable electric motors to do more than move a vehicle down the road. The on-board technology of PHEV trucks includes the key elements of a generator set. This project explored the ability to leverage this hardware for the further benefit of grid reliability and resiliency by enabling a stationary vehicle to generate power supporting a local distribution circuit. Whether an outage is planned or unplanned, the on-site presence of power generating trucks enable crews to eliminate or shorten the outage, thus contributing to grid up-time and customer satisfaction.

The integration of a truck system with an external system as complex as the electrical grid is a significant achievement. Traditionally the operators of the grid and the vehicle engineers have independently optimized their system. When a vehicle starts being used in unconventional ways (i.e. as a job-site tool and power generator) there is a disruption to the controlled conditions under which it was originally engineered. As only one example, how to cool the truck at elevated power levels (above idle) without moving down the road forcing air through the radiator. This use was not comprehended in the truck design but this project achieved significant milestones toward enabling it.

From a power generating functional standpoint the VOGSS development is a much more efficient and lower emission method of using and generating temporary power than a standard diesel generator set designed for backup power availability. First, if the need is short or lower output, the engine may not need to run at all, thereby avoiding emissions including noise. Instead, the system will use stored battery energy converted to AC power for output. Next, the engine will only run to replenish the energy and at its most efficient operating point unlike a diesel gen set that will typically run continuously and at mixed efficiency set points. And finally, this operating methodology creates power using lower emissions and higher fuel economy based on these most-efficient set points and the ability to store energy on board, also unlike a typical generator.

In addition to the technical "system" achievement, the VOGSS development has practical significance in terms of cost, capability and convenience as compared to conventional backup power technologies. In an era of advancing vehicle technology for fuel efficiency and emission reductions this project shows extracting further value of these new technology devices for other than a singular (mobility) function. VOGSS is the integration of a nimble distributed generation tool with a critical work tool used daily by crews with minimal incremental cost for the generating function. Using the same chassis, engine and motors that propel the truck in electric and hybrid drive modes to become a generator while stationary avoids separate costs for another engine, motor/generator, control system, fueling system, cooling system and trailer that would otherwise be necessary for the same function in a stand-alone portable generator. With VOGSS, job-site decision making is enabled for the use of the functionality without requiring the additional cost and effort of a trailer-mounted generator.

For this project, three generations of development hardware were installed in eleven vehicles across three project phases: Mule (Early learning – two vehicles), Alpha (Refinements – two vehicles), and Beta

(Further refinement to near-commercial readiness – seven vehicles). The configurations were evaluated at PG&E's Applied Technology Services (ATS) and multiple field locations (some involving public forums). Alpha vehicles were also sent to the National Renewable Energy Laboratory (NREL), a U.S. Department of Energy supported facility in Golden, Colorado, for further evaluation.

The project delivered the intended final proof point that target peak power generation levels could be achieved with the technology installed in vehicle classes 3, 5 and 6[1] and delivering 75kVA, 120kVA and 160kVA peak power respectively. A review of the population and ratings of transformers in the PG&E service territory led PG&E to set these power levels as the target, with a preponderance of distribution transformers of 120/240V split single phase type with the bulk of power ranging between 10 and 160kVA.

The following use cases were successfully demonstrated in the Alpha and Beta phases of the project:

1. Provide power during a transformer replacement to minimize outage time
2. Provide temporary power for an electric vehicle charging station (beneficial for remote special events or where power is less convenient to run from the utility service)
3. Establish or support a microgrid, such as temporary power for an emergency relief area
4. Provide both electric power and specialty equipment transportation at remote sites, such as for electric powered tools in maintenance of gas pipelines

The use of the VOGSS technology for temporary power at emergency relief areas during the 2015 wildfire especially highlight the tangible safety and reliability value of this technology. During the Valley Fire in Lake, Napa and Sonoma counties, the kitchen at an American Red Cross evacuation shelter in Calistoga needed to be moved. One of these exportable-power vehicles was quickly mobilized to provide power so that meals could be served to hundreds of evacuees during the evening hours. Additionally, in September 2015, a church was being used as a relief shelter for several hundred Calaveras County residents. The only generator failed, leaving the evacuees with no power. VOGSS trucks stepped in and provided power for two full days until the replacement generator arrived.

The electric utility industry continually strives for greater reliability in delivering electricity to customers and minimizing the effects and durations of planned or unplanned outages. As work-site assets, such as utility-owned trucks, start having generating capability on board, it is valuable to explore a potential minimal cost scenario to tap this capability. VOGSS is an opportunity to potentially economically increase reliability by powering facilities or residences during planned outages and improve resiliency from unplanned outage events.

Most of the vehicles acquired and modified through the project are still being used in the field. VOGSS has successfully transitioned from a technology development and demonstration activity to a daily crew experience. Job aids were developed and deployed with the trucks and supervision and crew members continue to identify applications and methods that will be captured in a production environment beyond the EPIC demonstration.

[1] Class 3: Light duty trucks with gross vehicle rating 10,0001-14,000 pounds; Class 5: Medium duty trucks with gross vehicle rating 16,001-19,500 pounds; Class 6: Medium duty trucks with gross vehicle rating 19,501-26,000 pounds.

The project has identified a number of potential next steps to be considered in partnership with vehicle manufacturers and other industry stakeholders to further enhance and make use of the technology, including the following key items:

a. Weight reduction for increased payloads on highly loaded applications such as aerial bucket lifts
b. Further testing of the robustness of high power export levels to increases in ambient temperatures. This area is perhaps the most in need of future continued development and validation for a fully-commercialized system.
c. Lower cost through innovative technology advancements and scale (across industries)
d. Investigation of multi-unit connections (multiple vehicles linked) in parallel for larger circuit coverage

The VOGSS project created a solid demonstration as a foundation from which electric utilities, regulators, adjacent industries, policy makers and prospective manufacturers can advance to a fully-commercial product to the ultimate benefit of utility customers. PG&E plans to continue to champion this effort through continued support and presentations at industry meetings and to seek further opportunities to continue to integrate this technology into the work place.

2.0 EPIC Program Introduction

This report documents the EPIC 1.16Demonstrate Electric Vehicle as a Resource to Improve Grid Power Quality and Reduce Customer Outages project achievements, highlights key learnings that have industry value and identifies future opportunities for PG&E and the industry to leverage from this project.

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this project. The CPUC initially issued Decision 11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level*[2], which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued Decision 12-05-037, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020,*[3] which authorized funding in the areas of applied research and development, technology demonstration and deployment (TD&D), and market facilitation. In this later decision, CPUC defined technology demonstration as the installation and operation of pre-commercial technologies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments, to enable the financial community to effectively appraise the operational and performance characteristics of a given technology and the financial risks it presents.

[2] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF.
[3] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF.

The decision also required the EPIC Program Administrators[4] to submit Triennial Investment Plans to cover three-year funding cycles for 2012-2014, 2015-2017, and 2018-2020. On November 1, 2012, in A.12-11-003, PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application at the CPUC, requesting $49,328,000 including funding for 26 Technology Demonstration and Deployment projects. On November 14, 2013, in D.13-11-025, the CPUC approved PG&E's EPIC plan, including $49,328,000 for this program category. Pursuant to PG&E's approved EPIC triennial plan, PG&E initiated, planned and implemented the following project: EPIC Project #1.16 – Demonstrate Electric Vehicles as a Resource to improve Grid Power Quality and Reduce Customer Outages, now referred to as Vehicle-to-Grid Operational Integration. Through the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the progress of the project.

3.0 Project Summary

3.1 Project Objective

The main objective of the EPIC 1.16 project was to develop and demonstrate a Vehicle On-site Grid Support System (VOGSS) with utility-grade power export from fleet trucks to a distribution circuit or independent ("island") load for the purposes of:

- increasing reliability of a local grid circuit (avoiding or minimizing a planned outage event)
- providing unplanned outage relief and resiliency

To advance a power generating and exporting capability, the foundational truck driveline system must be capable of efficiently performing these functions as well as its primary task of mobility for either crew or material transport. PG&E embarked on a collaborative development of fleet work truck hardware in conjunction with up-fit suppliers. It also extracted requirements from utility crew representatives for usability in the field.

The project included specific "field test" operations to validate the practical capability of the truck and systems to perform the relief task; whether for planned outage mitigation, remote electricity availability, or unplanned outage resiliency.

3.2 Issue Addressed

The national response to Hurricane Sandy highlighted the fact that temporary generator capacity in the country to address major emergency outage scenarios can be constrained, especially in large metropolitan areas hit by a major storm. This project demonstrated the possible future flexibility of commercial fleets to support mission critical or relief efforts by using their generation capabilities (i.e. batteries and generating capabilities on commercial work trucks) to provide power on a temporary basis.

The second gap area is the common utility industry practice to incur an interruption (and/or outage) for common preventive maintenance tasks such as transformer replacements on a distribution circuit. Under this project's vision, a vehicle could potentially minimize or eliminate customer outages in specific

[4] Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), and the California Energy Commission (CEC).

planned use-case events. The project demonstrated such capability for power levels up to 160kVA for the highest chosen truck class.

While a standard diesel generator set designed specifically for backup power availability could support the needs identified above, they are less cost efficient for widespread deployment and increase the complexity of tasks for the operators. This is due to the need for another engine, electric machine (generator), mounting platform/trailer, cooling system, cabinet, controls, etc. and the requirement for another vehicle to deploy the asset to a site. In contrast, the integration of this functionality into a plug-in hybrid fleet vehicle exploits the presence of these core components already in the vehicle that can be driven efficiently to a site as a multi-purpose “tool.” Additionally, PHEV propulsion technology reduces the cost of fuel by substituting grid electricity for petroleum in all-electric drive mode.

3.3 Scope of Work

The overall scope of this project was to integrate a fleet truck capable of on-board utility-grade power generation at a job site with a distribution circuit or facility for the purpose of resiliency from unplanned outages or avoidance of planned outages. The project was divided into vehicle and export power hardware phases and operations engagements to gain insight in potential field use and controls preferences. Figure 3-1 depicts the project timeline from Planning stage through closure. Multiple hardware development phases reflect the nature of complex vehicle development and demonstration occurring during this EPIC activity.

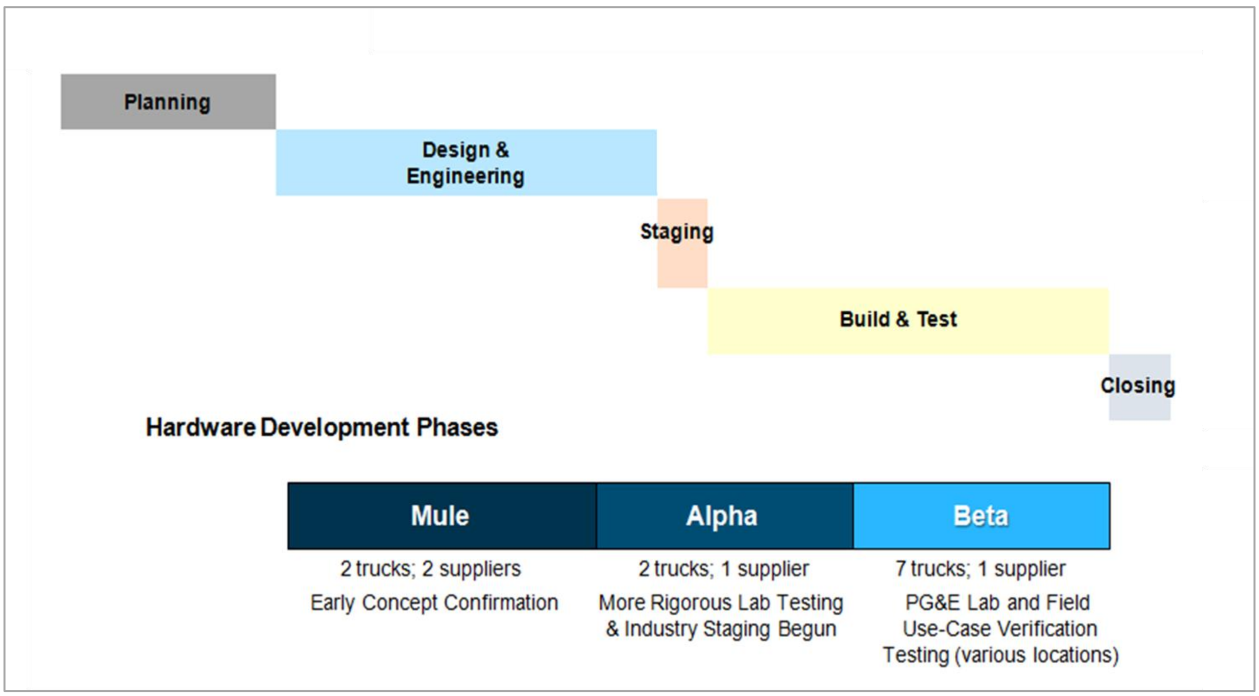

Figure 3-1 Project Summary Timeline

Listed below are brief descriptions of each hardware development phase, which are further detailed in Section 3.4 Major Tasks:

- Mule Phase: Produced learning (or "mule") vehicles for later stage requirements definition. These early vehicles were tested at PG&E's Applied Technology Services(ATS) facility.

- Alpha Phase: Based on improvements identified in the Mule testing, Alpha vehicles were built and tested at both ATS and the National Renewable Energy Laboratory (NREL) in Golden, Colorado, a U.S. Department of Energy supported facility, to provide further system characterization.

- Beta Phase: Beta vehicles were developed to demonstrate a system in a near-commercial readiness state. Further system specific requirements were identified through analysis, workshop, testing at ATS, and robust field use case demonstrations for operator feedback.

3.4 VOGSS Technology

The VOGSS system is comprised of an enabling plug-in hybrid electric vehicle driveline including a fully integrated motor/clutch/cooling structural unit, able to plug and play in the same location as a conventional automatic transmission and a high-voltage energy storage subsystem (battery) (collectively, "Vehicle Technology"). Secondly, an inverter subsystem is employed to convert high-voltage direct current (DC) power into utility-grade alternating current electricity for export from the truck ("Export Power Technology")

Vehicle Technology
As opposed to "strung together" systems, the demonstrated VOGSS drivetrain system was engineered and manufactured as a durable, high reliability electric transmission. However, in order to fully understand the benefits of the system, it is helpful to review the two most common conventional hybrid-electric vehicle system types. In parallel hybrid systems, both the electric motors and the internal combustion engine (ICE) can provide propulsion power simultaneously. The ICE provides power to drive the vehicle, while the electric motor engages as needed, providing additional torque for acceleration and climbing. In most series hybrid systems, the ICE turns a generator, which either charges the battery or provides propulsion power.

The system demonstrated in this VOGSS project is a compact, lightweight, high-efficiency 4-mode, series-parallel, PHEV drivetrain that integrates two electric motors. This advanced series-parallel hybrid PHEV system can deliver all of the benefits of parallel and series hybrid electric vehicle systems, as well as an improvement in fuel economy in comparison with those standard hybrid electric vehicle systems. The ability to exclusively choose stored grid energy (in specific uses) can lead to well over 50 percent reduction in fuel use. For example in a constrained urban stop/go environment such as San Francisco a truck could go an entire work day without the need for the engine to turn on. The average case would be somewhere between this "duty" and a 100-percent engine use of a conventional vehicle. As such, significant fuel efficiency improvements are anticipated as reflected in the Alpha-phase NREL testing (see section 4.2.2).

The system is designed to replace a vehicle's conventional transmission and to operate at maximum efficiency under a wide variety of driving conditions and cargo load point. The system can operate in four modes, as either a conventional hybrid electric vehicle or as a PHEV capable of charging directly from the electric grid or from a typical electric vehicle charge station.

As seen in the figures below, an ICE is connected to clutch #1 (C1). Clutch #2 (C2) is located between electric motor #1 (EM1) and electric motor #2 (EM2). During vehicle launch, driving, braking, and stop scenarios, software controls clutch engagement and disengagement. Depending on the operation mode, the ICE and two electric motors can individually or jointly transfer power to the output shaft, intelligently switching among operating modes as required in order to maximize electric range and minimize fuel usage and emissions.

The first mode, EV Mode is characterized by EM2 operating the vehicle alone with energy from the battery module, as shown below in Figure 3-2.

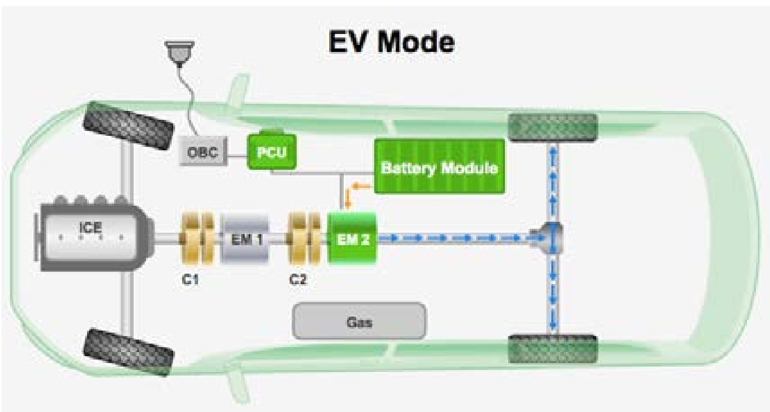

Figure 3-2 EV Mode (Figures Used With Permission From Efficient Drivetrains, Inc.)

The second mode, EV+ Mode, provides additional power by integrating EM1 with EM2 to provide additional torque for acceleration and climbing, as shown in Figure 3-3.

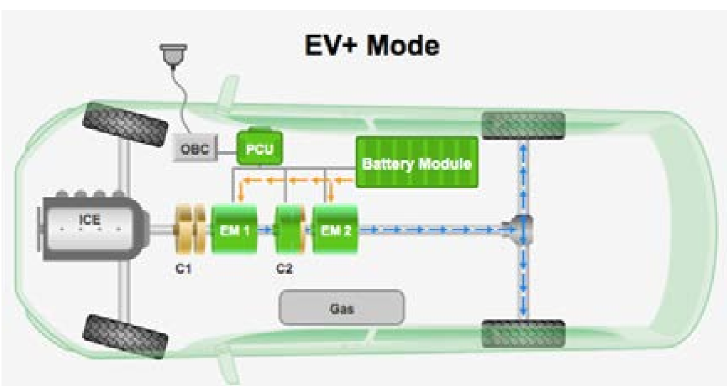

Figure 3-3 EV+ Mode

The third mode, Parallel Mode, uses the ICE to provide power to the drive of the vehicle while EM1 maintains the battery and EM2 provides addition power (Figure 3-4). Parallel Mode is most efficient for continuous high-speed driving.

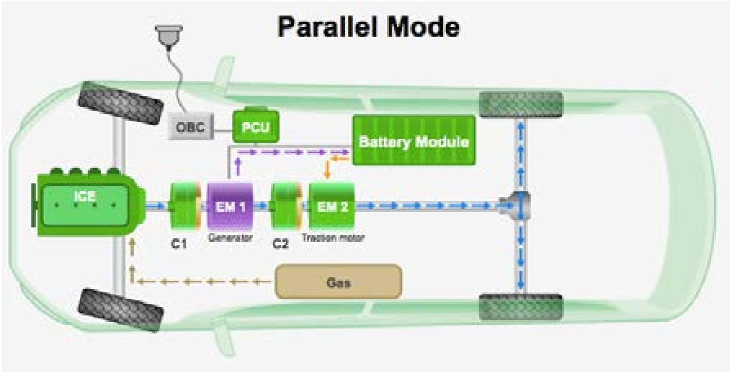

Figure 3-4 Parallel Mode

The fourth mode, Series Mode, uses EM2 to provide power to drive the wheels while the ICE and EM1 maintain the battery pack at approximately 50 percent power (Figure 3-5). Series Mode is most efficient for city or low-speed driving.

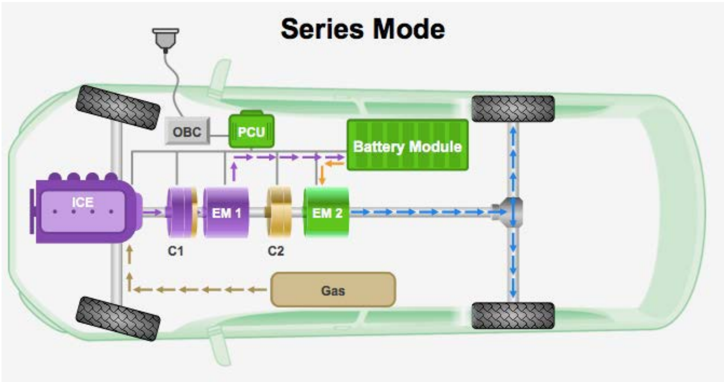

Figure 3-5 Series Mode

A fifth mode uses the electric motors to generate energy to provide stationary vehicle-to-grid export power.

<u>Export Power Technology</u>

The exportable power system enables export of vehicle electricity (generated or battery) for utility power requirements, but also for commercial or consumer power applications. Standard outlets integrated on the vehicle make it easy to plug in job-site tools, while utility scale power production capacity provides up to 160 kVA of synchronized, grid quality, mobile power that can be connected directly to utility distribution lines. In this manner, the system can provide emergency power to neighborhoods or critical facilities, and also provide backup power during planned maintenance activities. Technicians can drive to a jobsite, synchronize power from the truck's battery with the grid, begin exporting power, and then hot-swap the transformer with minimal to zero disruption to the served customers. Reconnecting the main utility grid to avoid a brief interruption is feasible with additional supplier and utility development to coordinate hardware enablers and procedures on the vehicle and the utility side. System functionality also enables bi-directional charging capabilities to support grid management services. Finally, for low power applications, the system can be used to power vehicle accessories or job site tools without idling.

Described below are some of the characteristics of the VOGSS technology:

Power Output Voltages:

- 240 Volt AC Split Phase (1Φ)
- 208 Volt AC Three Phase (3Φ)
- 240 Volt AC Three Phase (3Φ)
- 480 Volt AC Three Phase (3Φ)

Meets Power Utility Industry Standards for AC Power:

- IEEE 519[5] and IEEE 1547[6]
- UL listed inverter UL 1741[7]
- Clean Utility Grade power; <5% Voltage THD measured @50th harmonic

Modes of Operation:

- "Island mode" – Grid Forming
  - Serves as the primary voltage source defining the AC frequency and voltage.
  - Will respond with current based on the load demand up to peak rating of unit.
  - Maintains IEEE standards for phase and voltage of utility grade power.
- "Grid Synchronized mode" – Grid Following
  - Automatically synchronizes to an energized (aka "live") voltage source
  - Controls internal contactors to make final connection to live grid at precise time
  - Automatically detects misconnection, missed wiring, shorted connection, undesired voltage selection, voltage source outside of IEEE spec, voltage present, voltage missing, three phase rotation direction and line to neutral voltage
  - Supports loss of grid power with "Intentional Islanding" feature – the ability to automatically transition from Grid Following to Grid Forming mode if and when grid power is lost but load is still present.
- Grid Charging - the ability to work bidirectional at full power and thus charge the vehicles high-voltage battery very quickly.

Sources of Energy

- Zero Emissions
  - Very quiet
  - Clean (no tailpipe emissions)
  - Much lower heat signature
  - All energy comes from the high-voltage batteries
- Auto Generate
  - Most efficient use of diesel gen' set by pulse charging and optimizing Engine RPM for power needed
  - Handles low loads by using high-voltage battery energy until generator needed
  - Gen' set (diesel generator, combination diesel engine and electric generator) never idles but instead turns off at low or no load situations

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[5] IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.
[6] Standard for Interconnecting Distributed Resources with Electric Power Systems.
[7] Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources.

- Gen' set doesn't need to match phase and frequency of output power
- Gen' set rotation speed and direction not linked to AC power frequency and direction
- Can respond to large transient loads because high-voltage batteries provide transient power
- Will allow 24/7 continuous output operation; diesel fuel permitting

VOGSS Controls and Operator Interface

Export Power Panel (Figure 3-6): Operators connect the cables from the grid to the panel in the cargo area of the truck. There are two grounding connections; one attaching to the green connector, and the other connecting to the truck underbody (chassis) grounding lug under the rear shelf of the vehicle. Line 1 (brown), L2 (orange) and Neutral (white) receptacles are duplicated and connected behind the panel. This enables higher amperage loads.

Figure 3-6 Export Power Panel

Dash Panel (Figure 3-7): A dash-mounted switch will turn the vehicle into a "ready" state for export power and the vehicle status will change from "Not Ready" to "Enabled".

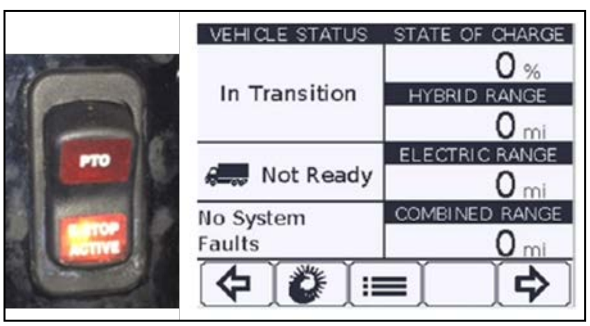


Figure 3-7 Dash Panel

Export Power Unit (EPU) Control Panel (Figure 3-8): When the green start button is pushed, the contactors behind the connectors will close. The display on the export power control panel will only turn on once the grounding cable has been connected and the dash panel enabled. "Island" or "Sync" mode and voltage level can be selected by the operator. When in island mode, the the main contactors within the EPU will only close after the system validates that there are no parallel voltage sources present. Even though the truck engine may not start, power fed by the high voltage battery will be exported through the connectors. The engine will turn off and on automatically depending on load and state of battery charge**.** When the red stop button is pushed, the contactors are open and the export power system is safely brought to a a stop.

Figure 3-8 Export Power Unit (EPU) Control Panel

3.5 Major Project Tasks

The major tasks for EPIC 1.16 are organized into Planning and Development activities and Demonstration activities, as follows:

- 3.5.1 Planning and Development
  - Hardware Integration
  - Export Power Scoping
  - Field Use Case Development

- 3.5.2 Demonstration of Hardware Integration and Export Power
  - Mule Phase Testing
  - Alpha Phase Testing
  - Beta Phase Testing

3.5.1 Planning and Development

3.5.1.1 Hardware Integration

Vehicle hardware integration is the assimilation of the utility work trucks with the components necessary to enable power generation and conversion for export. This task was implemented in three hardware development phases: Mule, Alpha and Beta. At the onset much was unknown regarding the capability of vehicle systems and their compatibility to enable the necessary functionality. Each hardware phase created a refinement in performance and usability culminating in the Beta phase including three vehicle classes from three original equipment (chassis) manufacturers.

a. **Mule Phase:** This phase was a first look at the capabilities of electric motors in PHEV vehicle power trains to be tapped for the approximate target power levels export. The mule phase included the development of two concept trucks, both with chassis cab service bodies from the same OEM chassis manufacturer, one each from two up-fit manufacturers. One truck included a V10 gasoline stock engine and the other a 6.7L diesel engine. The choice of these configurations was the result of the general performance requirement issued from PG&E to known commercial truck electrification suppliers interested in demonstrating plug-in hybrid technology and the concept of exportable power. The powertrains for demonstration were chosen by the suppliers as stock engines of the vehicle manufacturer, for lowest possible conversion costs (i.e. not requiring an engine replacement), The potential to avoid a diesel as one evaluation scenario is attractive for both lower capital cost and lower criteria and particulate emissions (provided the basic power output can still be achieved efficiently).

b. **Alpha Phase:** In this phase, candidate technologies were narrowed to a basic driveline architecture from one of the two up-fit manufacturers that demonstrated high potential in the Mule testing. Two new vehicle types (from two different OEM truck manufacturers) were built based on the findings from the Mule phase.

c. **Beta Phase:** The Beta phase was intended as the final build within the scope of this project, incorporating learnings to date and demonstrating a vehicle system in a near-commercial readiness state. The vehicles expanded to additional weight classes, body styles and peak export power capability to explore variations in use cases and expand awareness within PG&E and the industry. Seven vehicles were built and tested at this phase at a variety of locations in order to build a robust assessment of user feedback. Multiple units of each vehicle type provided the opportunity to place them in different geographic areas (urban vs. rural) etc. They also provide an opportunity to bring one unit at time in for refinements during the demonstration while continuing to test the other vehicles in the field. Finally, the end use applications may be different for vehicles. As an example, one of the 1 ton pickups is used for underground transformer work while the other is used by PG&E's gas group for induction heating.

   For this phase, PG&E released a Request for Quotation in April 2015 to purchase a select number of "beta" level vehicles including PHEV mobility plus utility-grade power generation in three different classes. In an effort to cast a wide net to prospective capable suppliers for award of hardware build contracts, a common specification document was developed to support the sourcing activity. As customary, quote responses have some variability on core technology fit to the desired specification. The common document allowed for evaluation by prospective suppliers to judge general capability alignment or substantial deviations required in determining whether to quote the project. In addition, the selected supplier would have less speculation on the degree of refinement expected by PG&E on this pre-commercial, limited-volume project.

3.5.1.2 Export Power Scoping

The VOGSS inverter technology converts high-voltage DC stored energy (from the vehicle's high-voltage battery pack) to various forms and levels of AC power for export to the grid, an island load or a distribution circuit with the intent to migrate seamlessly from grid to local energy supply. In general, the truck capabilities and interfaces must match the broad set of intended applications to provide power to a distribution load. Overreach of power output levels (setting the target too high for the truck class and engine system) can result in a vehicle system not capable of generating enough power (or not continuously) without issues such as insufficient system cooling.

Output voltage consisted of both 120V/240V split phase A/C and three-phase power at 120,208,240,277,480 volts. A control panel selector switch was to be used as the means of selecting between power output types and voltages.

While a general framing of the power output level was assumed initially, additional data was gathered prior to the Beta stage to add context to the assumed "most useful" set points based on PG&E's specific system profile and practical limitation of the vehicle systems being used. With a vision of being able to singly (i.e. one truck) power a distribution circuit on the secondary side of local transformers, the team sought to identify the most populous circuit sizes to align the capability to the system.

Minimum output power for different vehicle classes is shown in Table 3-1 below:

Table 3-1 Export Power System Summary

Truck Class	Peak Power (continuous)
3	75 kVA
5	120 kVA
6	160 kVA

A review of the PG&E system profile of distribution transformers indicated the preponderance (in count) of 120/240V split single phase type. The distribution of the transformers across ranges of power (kVA) is indicated below in Figure 3-9. Note that filtering for potential noise in the data was not performed since the project activity only needed approximations or major divisions to verify the large majority of useful power ranges.

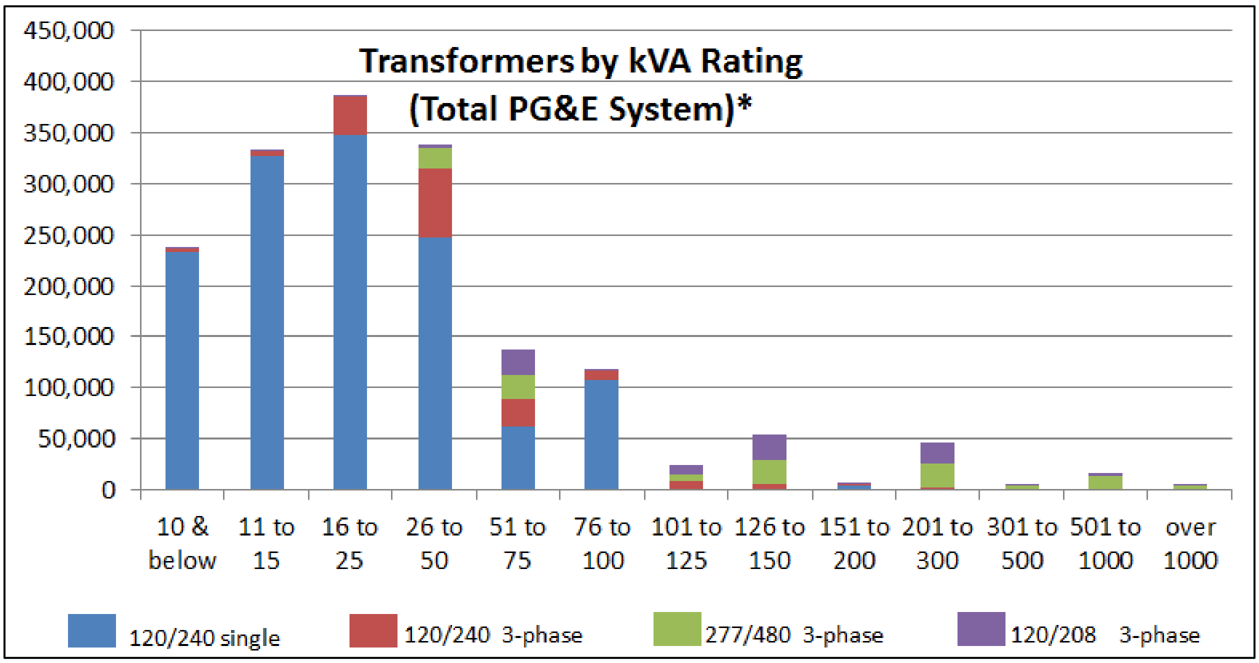


Figure 3-9 PG&E System Transformers by kVA Ranges

Looking beyond the high population of 120/240V split single phase applications, 3-phase applications had a large fall-off between 150 and 200kVA. (see **Error! Reference source not found.**). Practical for power generation in the classes of vehicles selected, 160kVA was chosen to represent the upper end of near-term VOGSS system development.

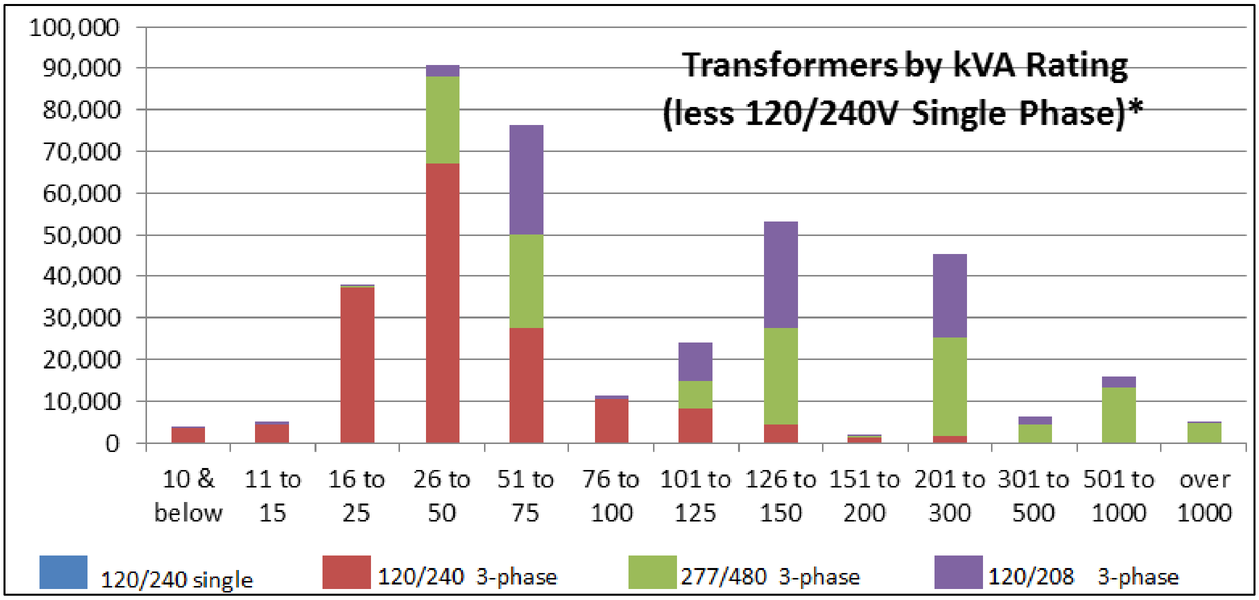


Figure 3-10 PG&E System Transformers by kVA Ranges (Without 120/240V Split Phase)

3.5.1.3 Field Use Case Development

PG&E conducted a series of internal workshops to brainstorm specifics on crew use of the export power capability. The scope of these sessions was limited to user interface definition or feedback to guide the design process for the Beta vehicles. The presentation and type of cable connection points, status indicators/displays/lights, switches and general ergonomics of layout were defined conceptually; mostly to mirror the types of controls seen on portable (e.g. trailer-mounted) generator sets.

VOGSS technology operates in two primary modes:

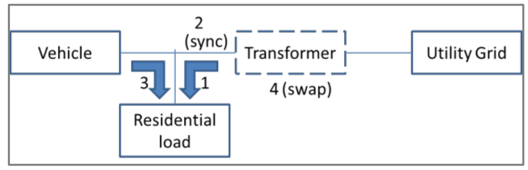
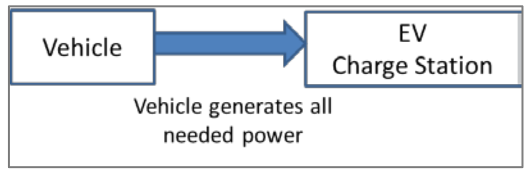
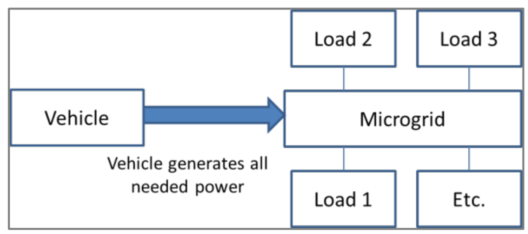
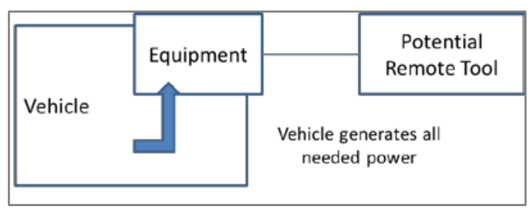
1. **Island Mode:** In island connection mode the truck with its export power unit serves as a surrogate for a grid connection. Customer loads and potentially distributed generation/ local inverters would assume a valid grid connection is present and operate as if the grid could absorb locally generated power (e.g. from a customer's solar array). Island mode is appropriate for emergency power situations where no grid is present or in a remote off-grid site. Also where the primary grid is planned for disconnection, the island mode may be the result of a grid synchronization followed by a transition to purely truck-provided power. To connect the truck for island mode operation a job aid was developed; an example is provided as Appendix F.

2. **Grid Sync Mode:** In Grid Sync mode the truck is connected in parallel to the utility grid, synchronizes to it, then begins exporting power with an intent to transition a local load to exclusively truck generated power. Once the truck picks up 100 percent of the local load, the utility (grid) can be disconnected without the downstream load seeing a disruption. This type of functionality enables the use case of a "hot swap" transformer replacement (replacing the transformer without dropping power to the customers for extended periods).

Vehicles developed in all three phases of Mule, Alpha and Beta were used and continue to be used in several applications, further described below. The continued use of the Alpha and Beta trucks in the field beyond this demonstration will serve to identify an even broader set of use cases as well as user feedback for refinement toward a fully commercialized product capability.

Table 3-2 describes the VOGSS use cases that were demonstrated in the field in EPIC 1.16:

Table 3-2 VOGSS Use Case Summary

Use Case	Description	Connection Diagram / Graphic
Use Case 1 - Transformer Replacement	VOGSS truck connects to the grid, synchronizes and picks up secondary side of the transformer load prior to disconnecting the utility. This allows significant time for a transformer replacement but with minimal disruption to distribution circuit.	
Use Case 2 - Electric Vehicle Charging	At remote special events or where power is less convenient to run from utility service, the VOGSS system provides temporary stored battery energy for a charge station or generates additional power for more continuous use.	
Use Case 3 - Establish or Support Temporary Microgrid	Beyond individual equipment, a site (such as in an emergency relief area) may require temporary power for such uses as refrigeration, air conditioning, lighting, heating, etc. A VOGSS-equipped fleet truck establishes this microgrid circuit to enable multiple device loads.	
Use Case 4 - Remote Specialty Equipment Transport and Powering	At remote sites where both substantial levels of electric power and specialty industrial equipment are needed, a VOGSS truck transports (or have installed) the equipment as well as provides the operating power.	

3.5.1.4 Potential Customer Impact (Per VOGSS Application)

Through analysis of potential localized customer impact on distribution circuits, a summary was developed where a target export power level was mapped to approximate numbers of supported end customers within the PG&E service territory. In this analysis, differentiation was offered between loading of typically coastal geographic regions versus the state's interior areas as shown in Table 3-3.

Table 3-3 Potential Customer Impact Per VOGSS-Equipped Vehicle

Beta Example Vehicle Types	Export Power (3-Phase) [KVA]	Export Power (1-Phase) [KVA]	Approx. Number of Residential Customers (Coastal)	Approx. Number of Residential Customers (Interior)	Approx. Number of Commercial Customers (Coastal)	Approx. Number of Commercial Customers (Interior)
Class 3 Pickup	75	75	77	23	26	19
Class 5 Aerial Bucket	120	120	122	37	41	31
Class 6 Flatbed	160	120	122	37	55	41

3.5.2 Demonstration of Hardware Integration and Export Power

Lab and field tests were conducted throughout the three stages of development to confirm the technical feasibility and value of the VOGSS technology and to continue refinements from each stage to the next.

An overall summary of the phases is described in Table 3-4.

Table 3-4 Development Phase Descriptions

Phase	Truck Chassis/Body Type	Export Power and Purpose	Hardware Integration Testing	Export Power Testing
Mule	Vehicle 1: Class 5 chassis cab, 6.7L diesel Up-fit with PHEV driveline from Supplier #1 Vehicle 2: Class 5 chassis cab, 6.8L V10 gasoline Up-fit with PHEV driveline from Supplier #2	Target: 120kVA peak export A first look at the capabilities of motors in PHEV vehicle powertrains to be tapped for high levels of power export.	Applied Technology Services (ATS)	Applied Technology Services (ATS)
Alpha	Vehicle 1: Class 5 chassis cab w/ 6.7L diesel Vehicle 2: Class 3 Pickup, 6.6L diesel Both up-fit with PHEV driveline from Supplier #1	Targets: 120kVA peak export (Vehicle 1); 50kVA peak export(Vehicle 2). A narrowing of candidate technologies to converge on a basic driveline architecture demonstrating high potential from Mule testing.	ATS & NREL	ATS, NREL & Field Use Cases

Phase	Truck Chassis/Body Type	Export Power and Purpose	Hardware Integration Testing	Export Power Testing
Beta	Class 3 Pickup, 6.6L diesel (2) Class 5 Aerial bucket truck (3) Class 6 Flatbed truck (2) All vehicles up-fit with PHEV driveline from Supplier #1	Class 3: 75kVA peak export Class 5: 120kVA peak export Class 6: 160kVA peak export A field-test integration level with near-commercial configuration ready for use by crews. Required California Air and Resources Board (CARB) certification and/or explicit variances for road use.[8]	ATS and Field Use Cases	ATS and Field Use Cases

3.5.2.1 Mule Phase

Hardware Integration Testing

To confirm the performance of the vehicle system in its power exporting modes in a controlled environment, lab testing of trucks from both suppliers was performed at the ATS facility in San Ramon. The class 5 truck transmissions were replaced and upgraded with a Plug-in Hybrid Electric Vehicle (PHEV) driveline and a mule-level (early prototype) Vehicle On-site Grid Support System (VOGSS) uniquely designed and integrated by two different suppliers. Testing included vehicle component temperature measurements and diagnostics such as battery state of charge, generation versus battery output, and engine coolant temperature.

Export Power Demonstration

Tests at ATS evaluated the basic vehicle power export and utility synch capabilities. A schematic of the vehicle test system is included in Figure 3-11. The test system could be isolated from the utility through control of the island contactor. With the island contactor open, the vehicle could export power directly to a load bank in an islanding configuration. With the island contactor closed, the vehicle was able to synch and export power to the utility/load bank. Step increments of resistive loading were applied to the vehicle during the tests outlined in Table 3-5.

[8] Given the daily crew use intent of these vehicles, the project team made an additional requirement of the supplier to either secure new product emission certification under California law or the appropriate temporary variances for same on the path to certification.

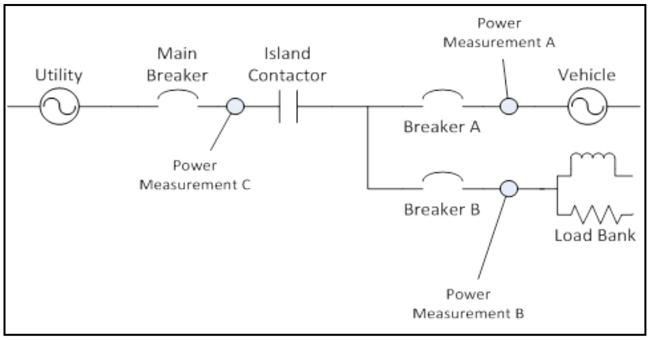


Figure 3-11 ATS Mule Testing Schematic

ATS has experience in evaluating various tools and equipment "off-line" before crews and customers are exposed to new technologies on the live grid. The various tests indicated below (and more fully described in Appendix D) were judged to be the basic performance indicators for this level of early product development guiding feasibility assessments. Not all tests were feasible on the specific hardware (vehicle) based on limiting statements from the supplier or hardware observations.

Tests conducted in the Mule phase included the following. As will be further described in the results section, Supplier 2 testing was stopped after only three test cases were conducted as it became clear quickly that the gasoline engine was overheating with the VOGSS technology.

Table 3-5 ATS Mule Phase Test Cases

Supplier	Test #	Test Name	Test Description
1	1	Peak kVA Export to Island Load (Generator + Battery)	Cycle of short duration (~ 2 min) resistive loads changing in steps. Both the battery and generator were permitted to contribute to vehicle export power.
	2	Peak kVA Export to Grid (Generator Only/Fix Batter %SOC)	Cycle of short duration (~ 2 min) resistive loads changing in steps. Battery SOC was attempted to be maintained throughout the test, with the generator contributing almost entirely to total vehicle export power.
	3	Peak kVA Export to Island Load (Battery Only)	Cycle of short duration (~ 2 min) resistive loads changing in steps. The vehicle was operating in "Eco Mode", as only the battery was permitted to supply power (without the diesel engine running the generator).
	4	Continuous kVA Export to Island Load (Generator + Battery)	Continuous 90kVA load while maintaining thermal equilibrium
	5	Grid Synch & Charge	Synch vehicle to the grid and charge
	6	Transformer Swap Demo – Grid Synch to Island Load Test	Prior to synching the vehicle to the utility, the load bank was set to 120kVA and the island contactor was closed, with the utility serving the 120kVA load exclusively. The vehicle then synched to the utility and gradually exported more power, eventually exporting enough to carry the 120kVA load and export some excess to the utility. The island contactor was then opened and the vehicle carried the load in an island configuration.
	7	Reactive Load Test	Power factors while carrying an islanded load

Supplier	Test #	Test Name	Test Description
2	1	Load Following Test @208V 3Phase	The vehicle was subjected to a load profile to determine its ability to maintain and follow the load. This load profile was intended to represent the load pattern typical of a residential transformer.
	2	Peak kVA Export (Generator + Battery) @208V 3Phase	Cycle of short duration (~ 2 min) resistive loads changing in steps. Both the battery and generator were permitted to contribute to vehicle export power.
	3	Continuous kVA Export (to island) (Fixed Battery %SOC) @208V 3Phase	Continuous 55kVA load while maintaining thermal equilibrium

3.5.2.2 Alpha Phase

Hardware Integration Testing

To test robustness of the export power system at controlled and elevated ambient temperature conditions and to explore efficiency of the driveline, PG&E engaged the expert resources at the NREL facility in addition to tests performed at ATS. The testing at NREL was funded by the U.S. Department of Energy, thus leveraging EPIC funding via 3rd party contribution.

Export Power Demonstration

Alpha vehicles were subjected to a number of demonstrations in the field, including a transformer replacement, electric vehicle charging demonstration, wildfire relief and a sustainable microgrid demonstration. Table 3-6 below lists the locations, timing and activities where field tryouts were conducted for demonstration of VOGSS technology.

Table 3-6 Alpha Field Use Case Demonstrations

Hardware Phase	Use Case	Crew Base Location or Service Location	Activity	Timing
Alpha	Field Use Case 1: Transformer Replacement	Livermore Training Center	Transformer work	Jan 2015
	Field Use Case 3: Establish or Support Temporary Microgrid	Wildfire relief, Valley Fire (Lake, Napa and Sonoma Counties)	Powering relief shelters	Sept 2015
		Santa Clara	VERGE Conference sustainable microgrid	Oct 2015

3.5.2.3 Beta Phase

Hardware Integration Testing

At least one sample from each Beta truck type (class) was delivered first to PG&E’s Applied Technology Services (ATS) for an export power try-out prior to exposure to the electric operations crews. In addition to a general assessment of interconnectivity, power quality, etc., the rated power levels were assessed with supplier participation during development steps or reconfirmed for final delivery.

<u>Export Power Demonstration</u>

In addition to ATS testing, the final proof point in demonstrating the value of the technology was to test the Beta vehicles in specific applications in the field. Several service centers were setup with the trucks for use in field tasks where power would otherwise be disrupted for longer periods or not available without transport of specialized generating equipment.

Table 3-7 below lists the locations, timing and activities where field tryouts were conducted for demonstration of VOGSS technology.

Table 3-7 Beta Field Use Case Demonstrations

Hardware Phase	Use Case	Crew Base Location or Service Location	Activity	Timing
Beta	Field Use Case 1: Transformer Replacement	Oakland Service Center	Transformer work	Aug 2016
	Field Use Case 2: Electric Vehicle Charge Station (setup or operation)	Various	Employee EV ride/drive event support	Various Events
		Bishop Ranch	Electric Vehicle Service Equipment (EVSE) setup remote from power	April 2016
	Field Use Case 3: Establish or Support Temporary Microgrid	Santa Clara	VERGE Conference sustainable microgrid	Sept 2016
	Field Use Case 4: Remote specialty equipment transport and powering	Various (ATS led)	Specialty truck-mounted gas pipeline service equipment	Sept 2016

3.6 Milestones Achieved and Deliverables Produced

All phases of the project were completed with the achievement of intended milestones. At the highest level the milestones can be summarized as follows:

- **Vehicle Integration:** EPIC 1.16 developed the hardware to connect the vehicle to PG&E’s system, explored engineering challenges with high power export with collaborative supplier development to solve, and built vehicles for field testing. VOGSS integrated eleven vehicles in three classes where class 3 can export 75 kVA, class 5 can export 120 kVA and class 6 can export 160 kVA. The hardware development started with Mule and Alpha phases and the test results used to update system specification. The demonstration phases transitioned to Beta phase with a near- commercial design. A project tangible asset list is provided in Appendix B.

- **Specification Development:** EPIC 1.16 developed operating requirements for the vehicle and defined and documented power requirements for different outage/usage scenarios. System requirements including vehicle type/classes, safety systems, operating environment, vehicle propulsion system, export power system and parking brake system were developed and made available to manufactures (Appendix E).

- **Lab and Field Demonstration:** PG&E ATS facility and NREL test results are provided in (Appendices C, D and I). Field tests were performed for variety of applications: transformer replacement, powering Red Cross relief shelter, EV charger. The VOGSS team shared a system demonstration video for transformer swap in Livermore, CA. Appendix A includes further description of VOGSS use cases.

- **Protocol Development:** EPIC 1.16 developed safety and interconnection protocols to connect the vehicle to the grid leveraging existing protocols for temporary local generator set connection. Crews were asked to perform their work with adherence to PG&E Standards and Procedures. It was important to align with either current or potentially new procedure documents for consistent and safe operation. Specific job aids (also a construct in the procedures) were written to explicitly direct field crews on the safe operation of the equipment, both for driving as a plug-in hybrid truck and for grid connecting and exporting power. (Appendices F and G)

4.0 Project Results, Findings and Potential Next Steps

4.1 Overall Results and Next Steps Summary

The VOGSS project successfully delivered the following key results:

- Utility-grade power was generated and exported from a plug-in hybrid drive vehicle system
- A plug-in hybrid vehicle successfully powered decoupled (island) loads for extended periods
- A plug-in hybrid vehicle paralleled the utility grid and converted a distribution circuit from grid supplied power to vehicle supplied power

Vehicle Integration: EPIC 1.16 successfully demonstrated a vehicle driveline system being adapted to a mobile power generator for export. While the project provided proof of technical feasibility, there are improvements and enhancements that PG&E will explore in moving towards full production, such as reducing overall technology costs, mitigating vehicle weight concerns and improving temperature/export load performance. These potential next steps are discussed further in Section 4.2.3.3. Beta Phase Results and Section 4.3 Potential Next Steps for Additional Development.

Export Power Demonstration: EPIC 1.16 successfully demonstrated the capability of VOGSS technology to provide the targeted level of export power in a sustained manner. Several use cases were successfully demonstrated in the field. Testing also illustrated several learnings for potential continued improvements as the technology continues to be used in the field. These potential next steps are also discussed further in Section 4.2.3.3. Beta Phase Results and Section 4.3 Potential Next Steps for Additional Development.

Based on these findings, PG&E will continue to champion this effort through continued support and presentations at industry meetings and exploring opportunities to continue to integrate this technology into the work place.

The following sections provide detailed project results, findings and potential next steps.

4.2 Demonstration of Hardware Integration and Export Power

4.2.1 Mule Phase

4.2.1.1 Hardware Integration Testing (ATS)

The mule phase included two concept trucks (one each from two suppliers) to get an earliest understanding of the practicality of the export power concept and at the approximate target power levels. One truck included a 6.7L diesel engine (Supplier 1) and the other a V10 gasoline stock engine (Supplier 2). Both base vehicles were class 5s from the same truck chassis OEM.

These two early prototype trucks were tested at PG&E's Applied Technology Services (ATS) facility. The tests were intended to evaluate basic vehicle power export and utility synch capabilities as well as identify any thermal concerns.

The gasoline proof of concept configuration had substantial difficulty in achieving export power levels close to a nominal 120kVA target without excessively high vehicle power train thermal conditions, especially tied to the exhaust system. The diesel configuration also had very high system temperatures mitigated in part through an open or "vented" hood and supplemental airflow under the vehicle. Industrial blowers were one device used for the latter.

Testing was performed outside, with ambient temperatures between 75 and 85 degrees Fahrenheit. This is subjectively viewed as "mild" temperature conditions for evaluating system performance. In an ideal testing setup, ambient temperature would be controlled and varied to assess the impact on vehicle thermal management.

4.2.1.2 Export Power Demonstration (ATS)

A brief description of the export power tests performed and key results for the Supplier 1 and Supplier 2 vehicle are included in Table 4-1 below. Detailed results are described in Appendix D.

Table 4-1 ATS Mule Test Results

Supplier 1 Vehicle Testing – Summary of Results (08/21/14 and 08/22/14)

Test No.	Test Description	Result
1	Peak kVA Export to Island Load - (Generator+Battery)	120 kVA
2	Peak kVA Export to Grid - (Generator Only/Fixed Battery %SOC)	100 kVA
3	Peak kVA Export to Island Load - (Battery Only)	120 kVA
4	Continuous kVA Export to Island Load - (Generator + Battery)	80 - 90 kVA
5	Grid Synch and Charge	120 kVA
6	Transformer Swap Demo - Grid Synch to Island Load Test	Synched and Carried 120kVA Load
7	Reactive Load Test	Supported Loads w/ 0.8 - 1.0 P.F.

All testing at 480V, 3phase. Power quality assessment: > 5.0 Total Harmonic Distortion (THD) needs improvement to meet PG&E specifications

Supplier 2 Vehicle Testing (08/25/14 and 08/26/14)

Test No.	Test Description	Result
1	Load Following Test @208V 3Phase	Pass
2	Peak kVA Export (Generator+Battery) @208V 3Phase	~100 kVA
3	Continous kVA Export (to Island) - (Fixed Battery %SOC) @208V 3Phase	Fail

All reported results at 208V, 3phase. Good power quality (THD < 5.0). In Test number 3, the vehicle maintained an approximate 55kVA load for greater than 30 mins before tripping due to high temperature in the inverter box.

4.2.1.3 Mule Phase Key Findings

The following findings were documented in Mule testing and subsequently integrated into Alpha:

1. **Engine and Up-Fit Supplier:** Trucks from both up-fit suppliers were able to perform export power. Due to thermal condition challenges with Supplier 2's gasoline proof of concept, the demonstration moved forward with the diesel power train from up-fit Supplier 1 considered as the base engine to add the plug-in hybrid components for the Alpha and Beta builds.

2. **Thermal Management:** The VOGSS integration required cooling system or generating mode refinements in order to mitigate use of extreme cooling measures ("hood open" or extra cooling units in mule testing that are not acceptable for utility field use). Figure 4-1 below shows vehicles under test at ATS including auxiliary cooling.

3. **Export System Size and Design:** The exporting power subsystem was a physically large device occupying approximately 12 inches immediately rear of cab. The unit was based on a transformer technology and very labor intensive to select specific export power parameters such as single versus 3-phase and voltage levels. The transformer-based export power unit needed to advance to solid-state design to optimize packaging and rapid selection of output power type and voltage.

Figure 4-1 Mule Vehicles Under Test at ATS Including Auxiliary Vehicle Cooling

4.2.2 Alpha Phase

4.2.2.1 Hardware Integration Testing (NREL)

One class 3 pickup and one class 5 chassis cab from different OEM chassis manufacturers were used as Alpha phase units to build on the findings from the Mule hardware development phase and assist in developing the final (Beta) phase specifications. The highest performing up-fit manufacturer from the Mule builds was contracted for the Alpha builds (Supplier 1). Upon build completion, one of the two units was sent to the NREL for testing.

NREL's charter was two-fold:

a) Explore the higher end of ambient thermal effects on export power system performance
b) Provide driveline efficiency testing in a controlled environment (dynamometer) on the plug-in hybrid electric (PHEV) driveline versus a conventional diesel 6-speed automatic F550 configuration.

<u>NREL Elevated Thermal Testing</u>

An Alpha phase truck was provided to the NREL Energy Systems Integration Facility (ESIF) to test robustness of the export power system at controlled and elevated ambient temperature conditions. The facility was capable of absorbing the export power, however not fully equipped to stabilize elevated temperature. Additional facility work would be required to have a fully capable test setup for these purposes. However, several test runs were made to give an indication of the sensitivity of the system to elevated ambient temperature.

The testing at NREL's ESIF facility validated the grid connection capability and ability for the vehicle to sustain a distribution load. It also was successful in providing insights on thermal performance characteristics of the current generation of hardware and the need for robust automotive-grade components and connections.

Figure 4-2 shows the vehicle as placed in the test chamber of the ESIF. A sample of data from a test run is shown in Figure 4-3.

Figure 4-2 Alpha Vehicle in NREL ESIF Facility

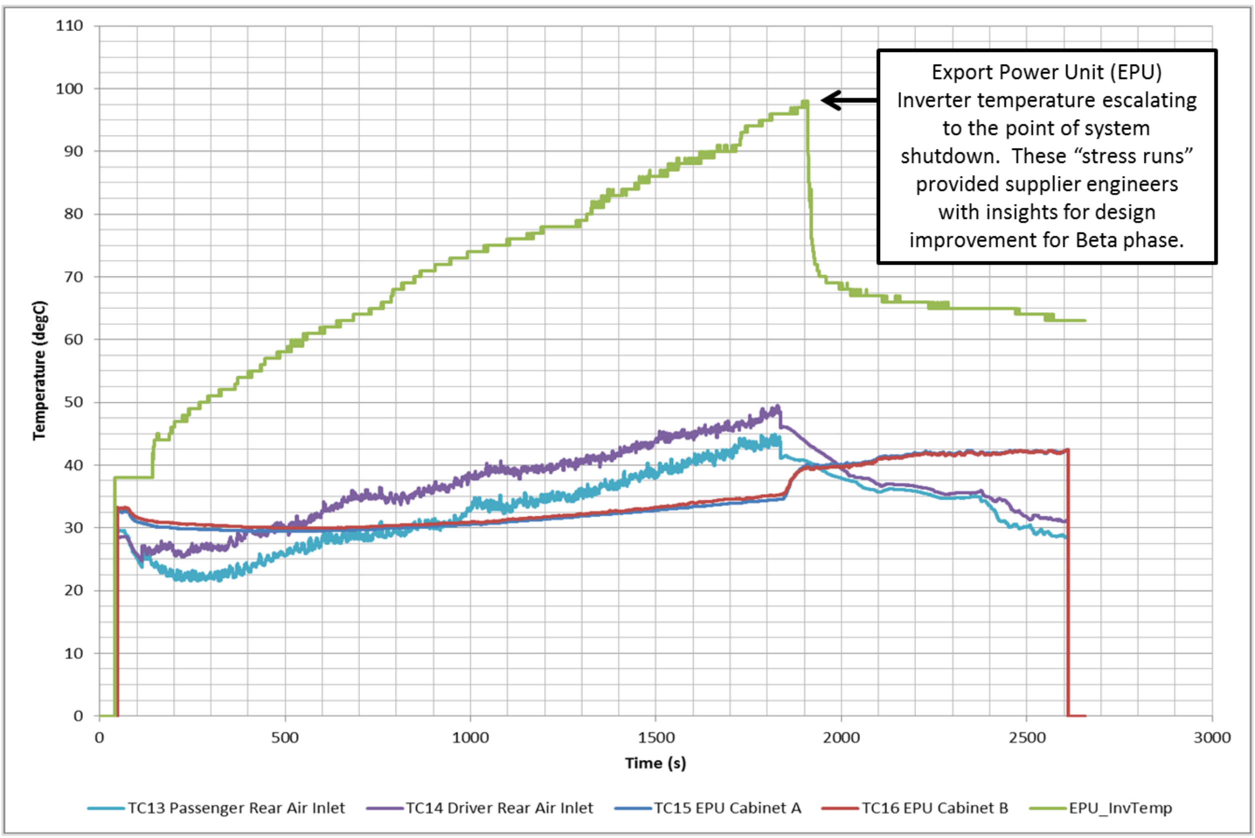


Figure 4-3 Example Export Power Data Under Elevated Ambient Temperature Conditions

<u>NREL Driveline Assessment</u>

PG&E was able to partner with NREL (funded by the Department of Energy) to test the foundational driveline efficiencies of the VOGSS concept trucks in comparison to baseline production trucks. NREL leverage chassis dynamometer testing – a stationary method for evaluating vehicle driving energy efficiencies and resulting emissions..

NREL also collected data on a set of PG&E work trucks to establish a potential custom drive cycle indicative of a "typical" PG&E trouble truck. Added to this custom cycle were the standard Urban

Dynamometer Driving Schedule (UDDS)[9] and the Heavy Heavy-Duty Diesel Truck (HHDDT)[10] schedules as shown in Figure 4-4.

This initial testing and supplier review led to further refinement of driveline algorithms in the VOGSS concept trucks for subsequent efficiency gains.

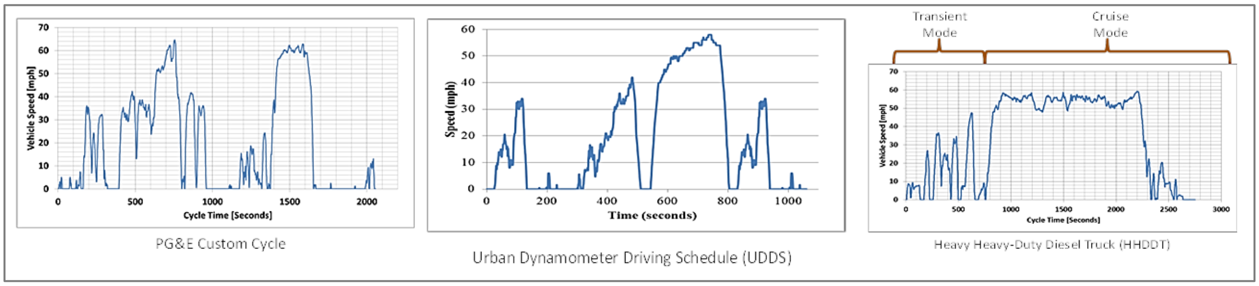


Figure 4-4 Drive Cycles Used at NREL for PHEV Driveline Testing Versus Conventional Vehicle

The following summary Table 4-2 represents the drive cycle test results from the NREL refuel lab testing on three drive cycles:

Drive Schedule	Baseline Fuel Consumption Avg. (grams/mile)	Supplier “alpha-level” Fuel Consumption Avg. (grams/mile)	Percent Improvement (Deterioration)
PG&E Custom	314.5	306	2.7%
UDDS	329	311	5.5%
HHDDT	241	263	(9.1%)*
* Note: In this driveline execution, hybrid system required higher steady-state engine speed during sustained “highway” driving resulting in deterioration in this non-hybrid friendly drive condition versus conventional.			

Table 4-2 Fuel Consumption Test Results for HEV Modes Only (Not Including All-Electric Range Benefit)

Figure 4-5 shows the baseline production truck and a PHEV drive truck undergoing this drive line testing.

Figure 4-5 National Renewable Energy Laboratory (NREL) Refuel Lab Chassis Dyno Baseline Truck (left); PHEV Driveline Up-Fit Vehicle (right)

[9] UDDS: US Environmental Protection Agency mandated dynamometer test on fuel economy that represents city driving conditions which is used for light duty vehicle testing.
[10] HHDDT: Chassis dynamometer test developed by California Air Resources Board (CARB).

4.2.2.2 Export Power Demonstration (Field)

The following field tryouts were conducted leveraging Alpha-level VOGSS trucks:

Use Case	Crew Base Location or Service Location	Activity	Timing	Discussion
Use Case 1: Transformer Replacement	Livermore Training Facility	Transformer work	Jan 2015	Successfully demonstrated a grid sync transitioning to truck-supported island mode.
Use Case 3: Establish or Support Temporary Microgrid	Wildfire relief, Valley Fire (Lake, Napa and Sonoma Counties)	Powering Red Cross relief shelter	Sept 2015	Similar to supporting a normal residential distribution circuit, temporary usage was successful at a temporary site during a time of emergency disruption. Generator failures often leave critical needs unmet where VOGSS can be prioritized to most critical use for fast mobile power. Use of battery for part of cycle time provided much quieter operation on average.
	Santa Clara	VERGE Conference sustainable microgrid	Oct 2015	

<u>**Wildfire Relief**</u>
During the Valley Fire in Lake, Napa and Sonoma counties, the kitchen at an American Red Cross evacuation shelter in Calistoga needed to be moved. One of these exportable-power vehicles was quickly mobilized to provide power so that meals could be served to hundreds of evacuees during the evening hours. Additionally, in September 2015, a church was being used as a relief shelter for several hundred Calaveras County residents. The only generator failed, leaving the evacuees with no power. VOGSS trucks stepped in and provided power for two full days until the replacement generator arrived.

Figure 4-6 Alpha Phase Field Testing

4.2.2.3 Alpha Phase Key Findings

The following findings were documented in Alpha testing and continuous improvements made during Beta design and test phases:

<u>NREL Testing</u>

1. **Thermal Management:** The power export system was more robust in nominal ambient conditions than the vehicles in the Mule phase through supplier design modifications of physical packaging, airflow and controls/software. The testing experienced "outside" temperatures of

over 91 degrees F. But at system air inlet locations the air was measured up to 120 degrees F. As a result of the Alpha testing, the supplier changed underbody component placement, heat exchanger (radiator) designs and cooling air flow locations and paths. The changes made Beta-level vehicles more robust; however, the project scope did not include re-testing these improvements in a controlled lab environment (such as NREL). For a production design, additional testing is required to ensure vehicles perform at peak power target in elevated outside temperatures. For example, in typical automotive product development additional time and standardized tests at specific environmental conditions would be planned and executed to ensure a wide range of field performance. Such testing allows a supplier to have confidence in their product performance for high reliability and lower warranty costs.

2. **Fuel Efficiency:** As described in the technology (Section 3.4) the efficiency gains of using stored electric grid energy can exceed 50%; in the most optimal uses avoiding turning on the engine all together. Heavy use of vehicle in a non-hybrid-friendly drive cycle (such as sustained highway use) could potentially deteriorate fuel efficiency versus a conventional diesel drive train. The NREL drive cycle testing led to further refinements of the supplier's hardware and control algorithms. For example, the rear axle ratio was changed as were operating points for choosing specific hybrid modes.

   As is customary in vehicle product development, the first physical test results allow engineers and software developers to see real results, compare to simulations/assumptions and refine the overall system for the intended usage. In this case, to optimize the use of stored or captured energy in the battery pack, varying behaviors (modes) of the hybrid driveline are required depending on the known or best-assumed driver need combined with the state of the vehicle system (such as battery charge level, speed, road grade, etc.)

Field Testing and Core Team Observations

For field testing and operator workshop (with the core team) activities, the VOGSS truck designs continued to be refined in functionality, convenience and robustness. Overall, users found the trucks to be convenient and useful. The following are examples where the core team decided to capture explicit requirements in support the Beta quoting activity.

1. **Package Space:** In order to be functional for operations purposes, packaging of the add-on systems needs to be minimized in the usable tool storage compartments. As such, these requirements were included in the beta specifications related to the add-on systems:

   - Class 3 vehicles: No more than 10 percent of truck bed volume should be consumed with allowance to project vertically while remaining below cab roof profile.
   - Class 5 vehicles: To be integrated in aerial device body system with primary components and control panel embedded in passenger (curb) side, rear-of-cab compartment; consuming no more than 10 percent of typical cargo provisions.
   - Class 6 vehicles: To be enclosed in separate cabinet at front of flatbed (rear of cab). To occupy no more than 5 percent of volume defined by footprint of flatbed extended to top of cab

2. **Parking Brake System:** Removal of the OEM-provided transmission removed some of the positive parking brake mechanical locking features. During the Beta phase, auto-apply parking brake features were added to Class 3 and Class 5 vehicles. The Class 6 truck was equipped with

its standard compressed air parking brake system provided by the original equipment chassis manufacturer.

4.2.3 Beta Phase

4.2.3.1 Hardware Integration Testing (ATS & Field)

The Beta build phase was intended as the final build within the scope of the EPIC project, incorporating learnings to date and demonstrating a vehicle system in a near-commercial readiness state. The vehicles, shown in Figure 4-7, expanded to additional weight classes, body styles and peak export power capabilities to explore variations in use cases and expand awareness within PG&E and the industry.

Figure 4-7 Beta Phase Delivered Trucks; (clockwise from upper left): Class 3 Pickup (1 of 2), Class 5 Trouble truck with aerial bucket (1 of 3), Class 6 flatbed (1 of 2); Seven total.

4.2.3.2 Export Power Demonstration (ATS & Field)

<u>ATS Demonstration</u>

At least one sample from each beta truck type (class) was delivered first to PG&E’s Applied Technology Services (ATS) for an export power try-out prior to exposure to the electric operations crews. In addition to a general assessment of interconnectivity, power quality, etc., the rated power levels were assessed with supplier participation during development steps or reconfirmed for final delivery. At project conclusion, the rated power levels achieved are summarized in Table 4-3.

Table 4-3 Target and Demonstrated Export Power Levels

Truck Type and class	Target Peak Power Output	Demonstrated Peak Power Output
Class 3 Pickup	75kVA	75kVA
Class 5 Aerial Bucket	120kVA	120kVA
Class 6 Flatbed	160kVA	160kVA

The validation test data from these vehicles for continuous running of a minimum one hour each is included in Appendix C.

As indicated, ATS tests successfully demonstrated the capability of VOGSS to provide the targeted level of export power in a sustained manner. The ATS demonstration also noted a few findings as potential areas for continued improvement or testing, namely thermal management, anti-roll back functionality (now included on all trucks), vehicle weight considerations, use of stored energy and controls access and export cable security at the truck. These findings are further detailed below in section 4.2.3.3

<u>Field Demonstration</u>

The following field tryouts were conducted leveraging Beta-level VOGSS trucks.

<table>
<tr><th>Use Case</th><th>Crew Base Location or Service Location</th><th>Activity</th><th>Timing</th><th>Discussion</th></tr>
<tr><td>Use Case 1: Transformer Replacement</td><td>Oakland Service Center</td><td>Transformer work</td><td>Aug 2016</td><td>Successfully leveraged VOGSS technology for a transformer replacement.</td></tr>
<tr><td rowspan="2">Use Case 2: Electric Vehicle Charge Station (setup or operation)</td><td>Various</td><td>Employee EV ride/drive event support</td><td>Various Events</td><td rowspan="2">Successfully demonstrated VOGSS capability to conveniently and easily provide power to an EV charger.</td></tr>
<tr><td>Bishop Ranch</td><td>Electric Vehicle Service Equipment (EVSE) setup remote from power</td><td>April 2016</td></tr>
<tr><td>Use Case 3: Establish or Support Temporary Microgrid</td><td>Santa Clara</td><td>VERGE Conference sustainable microgrid</td><td>Sept 2016</td><td>Similar to supporting a normal residential distribution circuit, temporary usage was successful at a temporary site during a time of emergency disruption. Generator failures often leave critical needs unmet where VOGSS can be prioritized to most critical use for fast mobile power.</td></tr>
</table>

Use Case	Crew Base Location or Service Location	Activity	Timing	Discussion
Use Case 4: Remote specialty equipment transport and powering	Various (ATS led)	Specialty truck-mounted gas pipeline service equipment	Sept 2016	This application is ideal for a VOGSS truck as it replaces a very costly (and much heavier) rental truck combined with large diesel generating unit mounted separately in the cargo area. This is an application where both transport of equipment and powering of it are combined very efficiently

4.2.3.3 Beta Phase Key Findings

Overall, PG&E successfully demonstrated the capability of the VOGSS technology to provide utility-grade power to island or grid-sync distribution loads. The test results described above demonstrate the technical feasibility and the value that this technology can bring to multiple use cases.

Additionally, several learnings have been documented from the Beta phase along with potential next steps that will be considered, listed below.

ATS Testing

Category of Export Power System	Results	Potential Next Step to Be Explored
120/240V Power Target	The export power system has constraints for power output in single/split phase 120/240V (below power target level). Target level achieved in 480V 3-phase mode.	Continue to validate use case need for full 120/240V single/split phase power levels and scale export power unit by setting future specifications accordingly.
Thermal management	While Beta builds were more robust in nominal ambient conditions than Alpha builds, (see 4.2.2.3) the export power load on the baseline vehicle engine system has not been validated at elevated ambient temperatures.	Controlled testing of total vehicle system including export power at elevated temperatures for production validation.
Vehicle Weight	The Class 6 VOGSS vehicles were overweight by 200 pounds in the front axle. A higher load-capacity front axle was exchanged into the vehicles prior to delivery to mitigate the condition short-term.	Choice of vehicle and application may result in overly constrained weight ratings for users or more expensive hardware for upgrades. Detailed mass/weight effects need to be comprehended and mitigated during planning stages of VOGSS vehicle production development.

Category of Export Power System	Results	Potential Next Step to Be Explored
Anti-Roll Back ("Hill Hold" Feature)	The hill hold feature was originally not included explicitly in specifications. It is an important safety feature to assist the driver to minimize roll-back when transitioning from holding the brake to initial acceleration in forward or reverse on a grade (hill). This was developed and updated on trucks in Beta phase in advance of deployment to service centers.	Inclusion in all future specifications.
Controls access and export cable security at truck	For Beta phase implementation on Class 5 and Class 6 a user interface and connection points on the curb (passenger) side of the truck are open and accessible. As currently constructed, a cabinet door must also remain open during operation subjecting inside of cabinet to elements.	It is envisioned that a more secure design solution would be implemented for any production execution of the concept.
Use of Stored Energy	The manual mode selections in Beta vehicles biased the use of stored energy to either driving or job site export use.	In order to maintain efficiency of stored energy use, explore the use of potential automatic mode selections with knowledge of intended job site or driving use.
Telematics for Prognostics	In all hardware phases, telematics were used for development diagnostics (such as after a malfunction). For example, state of battery charge and energy flows through parts of the system allowed supplier to confirm proper operation or help pinpoint software defects during development.	Once commercialized, telematics should be able to monitor system/ component health for preventive maintenance or other pro-active use.

Field Testing User Feedback

Overall, field testing successfully demonstrated the feasibility and value of VOGSS technology. Users found VOGSS to be convenient and easy to use, proven further by the fact that the vehicles are still in routine use by field operations post-project. From Beta testing, there were a few feedback items from users that are documented with potential next steps that will be considered in the table below. The users found the power cable handling to be logically challenging, and were in need of a single leg connect/disconnect option as well as a more sustainable battery packaging approach.

Category of Export Power System	Results	Potential Next Step to Be Explored
Operator interface and connection convenience	Beta units included generator-style connectors and a programmable user interface. The Beta setup was easy to use for field operations.	While Beta units proved successful, user interface requirements are anticipated to continue to evolve with more experience / feedback.
Single leg connect/disconnect (for 3-phase output)	In three-phase circuits, disconnecting the grid one leg at a time (most practical for line workers) was not supported by the hardware.	Single-leg-at-a-time disconnect development is proceeding at PG&E direction outside this EPIC project.
Cable Handling	Export power cable handling (storage, lifting, etc.) is a significant operating constraint (bulky, heavy and difficult to find on-vehicle storage space without special accommodation).	Continued optimization through a designed-in cable storage/handling feature (like integrated in up-fit body system) is needed before widespread adoption is feasible.
Battery Packaging	Battery packaging as false floor in class 3 pickup bed is not a viable long-term solution. Pickup beds require maximum cubic volume for cargo, are subject to material handling "abuse" and create potential sealing problems with openings to water, snow, ice, etc. without high-cost sealing systems if batteries are integrated.	Production vehicle designs likely to require packaging of batteries under vehicle or (less optimal) contained immediately behind cab. Production supplier must balance end customer requirements to choose solution.

All seven Beta trucks continue in service at various PG&E locations beyond closure of this EPIC project. The plan is to continue to collect operating performance data and user experiences to make best use of the development and guide future specifications toward full commercialization.

4.3 Potential Next Steps for Additional Development

Overall, EPIC 1.16 demonstrated that VOGSS technology is both feasible and potentially beneficial for several use cases. However, there were limitations to scope of the demonstration in order to most efficiently achieve the objectives of the project. Table 4-4 lists the key demonstration limits and potential next steps that will be considered.

Table 4-4 Potential Next Steps for Additional Development

Category of Vehicle Development	Demonstration Limitations	Potential Next Steps
Thermal management testing	The project limited testing to a specific scope in order to efficiently achieve the objectives of the project to prove feasibility and value of the technology. As a result, the export power load on the baseline vehicle engine system has not been validated at elevated ambient temperatures in a controlled manner.	Controlled testing of total vehicle system including export power at elevated temperatures for production validation.
Battery sizing and modularity	For the sake of simplicity within the demonstration, and as is typical of vehicle product offerings, the project leveraged singular large battery configurations regardless of typical use (or variation in use).	Explore sizing and modularity to match battery capacity with duty cycle variations.
Power levels and voltages (potential simplification)	Beta vehicles had capabilities of single (Split) phase and 3-phase at multiple voltage levels (potential over-spec/cost driver rather than a limitation)	While some specialty trucks may need this flexibility, cost effective commercialization may drive simplification of the export power feature
Body/chassis choice	This project limited its demonstration to those applications/body types identified as key use cases by PG&E operations, as demonstrating all potential configurations would be infeasible from a cost and complexity standpoint. Not all applications or body types may be well suited for export power capabilities, but this is unknown without further analysis and/or testing.	Planning stages of future development projects to comprehend a clear mission of each vehicle type with user engagement.

Category of Vehicle Development	**Demonstration Limitations**	**Potential Next Steps**
Reconnecting to grid power	A means of re-syncing and reconnecting a supported islanded load to the grid is not developed as this is new technology outside this project's scope. At the current state of technology and equipment available, transitioning the load back to the grid (sometimes referred to as "go back") requires a short disruption, as maintaining grid sync or sensing and adjusting the now island load to the grid phasing is a more complex task not yet enabled. Creating a truly "blinkless" transition from and back to the utility grid is a potential frontier for future development work beyond the EPIC project.	Considered technically feasible, the process and special equipment to enable "go back" from island (truck-supported) loads to grid-supported needs to be developed
Power export "lite" use	Lower amperage outlets on the truck (120V/240V split single phase standard receptacles) were available but not exercised in the project. This is not in scope for VOGSS as it is not "grid support."	Future decision can be made to have a lower-rated export power capability (at conceivably much less cost per truck).
Delta versus Wye transformer configurations	As a very common industry 3-phase transformer configuration, only a balanced "wye" electrical source (star connected windings) was developed and demonstrated within the scope of the project. However, there are transformers in the PG&E system that are of a "Delta" configuration (triangular connected windings).	Delta with 120V "stinger" leg (e.g. for lighting loads in commercial applications) is under discussion for post-EPIC activity
Customer-side inverter effects	Circuits with multiple customer-side inverters (e.g. from solar) are also an emerging field condition. As this is still an emerging area of understanding, the team simplified the scope to a traditional utility-grid-dominant circuit. Thus these customer supply configurations were not considered to the point of distributed energy storage potentially exceeding the truck capability to absorb.	Additional treatment of distributed generation in planning scenarios is required prior to any large-scale deployments

Category of Vehicle Development	Demonstration Limitations	Potential Next Steps
Grid charge function	As a lower-priority capability, based on project resource constraints, demonstration uses in this project did not prioritize specific functionality for charging the high-voltage battery while grid-connected; Further an integration with the vehicle's 12-volt DC battery charge circuit would prove useful (i.e. allow high voltage battery to keep 12 volt battery in a good charge condition).	Include specific requirements for grid-supplied charging to the high-voltage battery. Include requirements for 12-volt battery charge support in a production system.

5.0 Special or Unique Technology Implementation Issues

5.1 Vehicle System-Based Implementation Issues

The highly integrated nature of the export power technology created unique demands on the base vehicle system. The most demanding of these issues observed was thermal management. While the optimal approach would be a total vehicle optimized solution, disturbing the "stock" vehicle/power train cooling systems created its own downsides related to a system design already optimized without knowledge of the intended downstream system demands; and potential reliability and warranty issues of "spliced" connections. Removal of the OEM-provided transmission also removed some of the positive parking brake mechanical locking features. Future PHEV driveline designs could restore these integrated features; or, a version of the current add-on solutions may be maintained.

The system weight increases can also encroach on (or worst-case exceed) the weight rating of the vehicle without sufficient payload provisions for vocational tools, materials, cables, etc. Reducing weight of up-fit drive lines, batteries and export power units must be a continued emphasis. The same is true of physical space consumption of cargo areas by auxiliary systems (such as heat exchangers, batteries, etc.) that are at present borderline acceptable.

5.2 Export Power System-Based Implementation Issues

Perhaps the most significant implementation issue for exporting power was related to cable storage and handling. The upside of power availability from a truck is partly offset with the inconvenience of the space, weight and handling of cables to connect the truck to the distribution circuit or island load. A strategy for handling of cables is a necessary part of future usage planning.

At present, a "go back" or re-synch and transitioning a distribution load back to the utility grid is not enabled without a short power disruption (described in Table 4-4 above (in row: "Reconnecting to Grid Power"). This issue is technically solvable, likely through the development of additional equipment or connections with both the vehicle and utility.

Additional work would also be required to determine the tradeoff of hook-up time (setup) and tear-down as additional on-site crew time required for the incremental benefit of minimizing a planned outage duration. The planning and conclusions of these special analyses may have considerable variation in the industry at the risk of lower adoption rates.

Lastly, similar to the general vehicle system issues, the export power unit electronics, package size, heat generation and connection/controls provisions have unintended compromises to the efficient use of space and payload on vehicles.

6.0 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

7.0 Value Proposition

This project advances several EPIC principles by potentially reducing the customer minutes of outage during planned and unplanned maintenance and repairs, improving public and employee safety, reducing costs and reducing Green House Gas emissions. Table 7-1 and the discussion that follows summarize the specific primary and secondary EPIC Guiding Principles advanced by this technology demonstration project.

Table 7-1 EPIC Primary and Secondary Guiding Principles

Primary EPIC Guiding Principles			Secondary EPIC Guiding Principles				
Greater Reliability	**Affordability**	**Increased Safety and/or Enhanced Environmental Sustainability**	**Loading Order**	**Low –Emission Vehicles/ Transportation**	**Societal Benefits**	**Economic Development**	**Efficient Use of Ratepayer Monies**
✓	✓	✓		✓	✓	✓	✓

7.1 Primary Principles

- **Greater Reliability**: This project was executed to explicitly enable more resilient and reliable power through the substitution of truck exported power for the utility grid when a planned shut-down is needed. When the grid is down from unplanned events, VOGSS enables localized re-energizing prior to a future permanent repair.
- **Affordability:** VOGSS leverages a multi-function tool used in lieu of either greater outage exposure or increased investment in dedicated generator sets (less capital efficient to buy another stand-alone equipment asset). Additionally, EPIC 1.16 supports the case for leveraging electric vehicles in utility fleets. Cost savings are primarily accounted from the operating savings from a plug-in hybrid electric drive system. The drive system exploits the use of lower-cost stored grid electricity as an offset to more expensive exclusively fossil-fuel-based mobility. Other benefits in lower maintenance of engines and brakes is inherent to hybrid drives.

- **Increased Safety and/or Enhanced Environmental Sustainability:** Improved safety is achieved by providing on-site generation to maintain or restore customer service while maintenance or repairs are being completed. This improves public safety by minimizing the public's exposure to the elements such as heat and cold. In extraordinary conditions where customers are actually evacuated from their domicile, VOGSS-equipped vehicles have already proven to support shelter sites with reliable, temporary electric power (e.g. Red Cross at Valley Fire; (see section 4.2.2.2)). In addition, reduced noise from short-term battery-supported electric vehicle export as opposed to standard generators improves the work environment for employees and enhances the ability to safely communicate in the field. Environmental sustainability is a further benefit of a hybrid electric drive system reducing both criteria pollutants and greenhouse gas emissions.

7.2 Secondary Principles

- **Low-Emission Vehicles/Transportation:** At its core, the project is advancing vehicle electrification through the plug-in hybrid driveline that becomes the hardware enabler for the export power generation. This reduces the need for an external generation source normally run by fossil fuels.

- **Societal Benefits:** VOGSS improves safety and reliability for the public by supporting emergency events and reduced downtime for planned outages. Additionally, the public experiences reduced noise pollution, given the alternative for powering a building during an outage would leverage standard generators.

- **Economic Development:** The system was primarily designed, engineered and developed by multiple suppliers in California including the plug-In hybrid electric drive system, vehicle modifications and installation and the core export power conversion unit.

- **Efficient Use of Ratepayer Monies:** Ratepayers support the fleet infrastructure and maintenance activities and benefit from reduced operating costs of fuel and maintenance as well as the capital efficiency of having a multi-function tool used in lieu of either greater outage exposure or increased investment in dedicated generator sets (less capital efficient to buy another stand-alone equipment asset).

8.0 Technology Transfer Plan

8.1 PG&E's Technology Transfer Plans

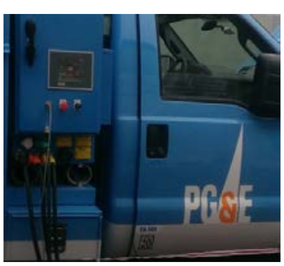
From the outset of the demonstration, PG&E has been actively networking within the electric utility industry supporting advanced electrification technology on fleet vehicles. At one level this transfers technology for electric-driven mobility to improve efficiency and reduce emissions. More direct to VOGSS this outreach has generated wider industry interest in export power from trucks. For example, the following engagements were initiated:

Engagement	Description	Dates
US DOE	Dialog with U.S. Department of Energy resulting in export power highlighted in recent funding opportunity announcement (FOA) of medium truck electrification through the DOE's Vehicle Technologies Office.	Ongoing 2015-2016; FOA issued: June 6, 2016
EEI	Edison Electric Institute CEO meeting review in Palm Beach, FL	January 2015
VERGE	Clean Economy Conferences (2015 & 2016) where a VOGSS-equipped vehicle contributed to the renewable microgrid exposition	October 26-29, 2015 September 9-22, 2016
EUFMC	Electric Utility Fleet Management Conference (EUFMC) in Williamsburg, VA presentations and demonstrations	June 6-8, 2016
Battery Show	Presentation to The Battery Show 2016 Conference and panel discussion (Novi, Michigan)	September 13-15, 2016

In the comings months, PG&E will continue exploring industry outreach in order to share project learnings and discuss future potential opportunities.

Additional public statements or responses are found in these web links:

- PG&E CURRENTS links to related articles:
http://www.pgecurrents.com/2014/11/20/pg-vehicles-can-provide-exportable-power/
http://www.pgecurrents.com/2014/09/17/solano-county-pge-edi-unveil-utility-trucks-capable-of-shortening-or-eliminating-electric-outages/
- White House blog with John Podesta, White House Senior Advisor
https://www.whitehouse.gov/blog/2014/11/19/electric-vehicles-help-drive-climate-action
- External press with PG&E quotes:
http://www.fleetsandfuels.com/fuels/evs/2014/09/pge-shows-edi-altec-hybrids/
- Photos of Washington DC event hosted by TheHill and sponsored by PG&E:
https://www.flickr.com/photos/thehillevents/sets/72157647056735683/
- In committee work led substantially by PG&E Transportation Services, Edison Electric Institute issued this white paper as industry guidance on electrification, particularly on work trucks:
http://www.eei.org/issuesandpolicy/electrictransportation/FleetVehicles/Documents/EEI_UtilityFleetsLeadingTheCharge.pdf




8.2 Adaptability to Other Utilities / Industry

VOGSS technology is directly applicable to any electric utility seeking to minimize impacts of planned outages and improve unplanned outage resiliency. Outside the electric utility industry strong potential exists for integrated PHEV work truck systems including an export power feature. An example is telecom companies where service trucks have similar needs for repairing infrastructure and maintaining services powered by electricity. Another is municipalities with strong interests in resiliency of their communities and fleets of vehicles that have daily work tasks that may be reprioritized to generate power in times of emergency. Federal emergency management, state agencies and military applications (e.g. non-tactical base support) could be additional customer markets as well.

9.0 Metrics

The following metrics as identified in CPUC Decision 12-05-037 were addressed in this project:

3a. Economic Benefits: Maintain / Reduce Operations and Maintenance Costs: The enabling plug-in hybrid electric vehicle system is designed to substantially reduce the cost of fuel by substituting grid electricity for petroleum in all-electric drive mode. Beyond this electric range, the vehicle operates as a hybrid electric system also capturing energy through regenerative braking. The latter feature is a major contributor to reducing brake change frequency and thus lifecycle costs. In addition, idle reduction technology puts less strain on the truck's engine and thus less maintenance.

4a. Environmental Benefits: GHG Emissions Reductions (MMTCO2e): GHG reductions are a direct result of reductions in engine operations with vehicle electrification

5a. Outage Number, Frequency And Duration Reductions: VOGSS is designed to directly reduce number of planned outages by using temporary truck-generated power. Potential reduction in outage duration and resiliency from unplanned outages are benefits of power availability when portions of the grid at a local distribution level are not functional and a VOGSS unit is connected.

5e. Utility Worker Safety Improvement and Hazard Exposure Reduction: With diesel idling reduction using the vehicle's high-voltage energy storage, PG&E crews benefit from a quieter job site improving the basic communication ability and thus safety.

10.0 Conclusion

EPIC 1.16 successfully achieved its primary objective of developing and demonstrating utility-grade power export from fleet trucks to a distribution circuit or independent ("island") load. Comprehensive lab and field tests with multiple hardware builds / refinements illustrate that VOGSS is both technically feasible and provides potential value for several operational use cases. VOGSS provided reliable and convenient power for transformer replacements, EV chargers and emergency relief.

The use of the VOGSS technology for temporary power at emergency relief areas during the 2015 wildfire especially highlighted the tangible safety and reliability value of this technology. During the Valley Fire in Lake, Napa and Sonoma counties, the kitchen at an American Red Cross evacuation shelter in Calistoga needed to be moved. One of these exportable-power vehicles was quickly mobilized to provide power so that meals could be served to hundreds of evacuees during the evening hours. Additionally, in September 2015, a church was being used as a relief shelter for several hundred Calaveras County residents. The only generator failed, leaving the evacuees with no power. VOGSS trucks stepped in and provided power for two full days until the replacement generator arrived.

While the project was successful in its objective and demonstrated value of the technology, there are still improvements that PG&E will potentially explore in moving towards full production, such as mitigating vehicle weight concerns and further testing of thermal management under elevated ambient conditions. Additionally, the project has identified promising areas for future potential enhancements to the technology, such as enabling a “blinkless” transition back to grid power from an island state, and investigating the potential use of multi-unit connections (multiple vehicles linked) in parallel for larger circuit coverage. Overall, VOGSS is a technically feasible and value-add technology that PG&E will continue to leverage for the use cases demonstrated in this project and beyond with continued field use and refinement.

11.0 Appendices: Exhibits A through I

Exhibit A. **VOGSS Use Case Descriptions**

Exhibit B. **EPIC VOGSS Project Tangible Asset List**

Exhibit C. **Peak Power Performance Validation Data**

Exhibit D. **PG&E Applied Technology Services (ATS): Mule-level Testing (August 2014)**

Exhibit E. **VOGSS Beta program vehicle specifications (March 2015)**

Exhibit F. **PG&E Export Power Job Aid Example 1**

Exhibit G. **PG&E Driver Reference Job Aid Example 2**

Exhibit H. **Beta Phase Vehicle Supplier's Technology and Operating Narrative**

Exhibit I. **NREL Alpha Test Results**