Advanced Grid-Interactive Storage: Task 2.1 Interim Report

Lead Acid Pilot Installations

Research, Development, Demonstration, and Deployment Program

Project Partners:

TESLA MOTORS

Pacific Gas and Electric Company®

Renewable & Appropriate Energy Laboratory

ENERGY AND RESOURCES GROUP

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2.1 Install a portfolio of Firm PV systems based on off-the-shelf, 48VDC hardware to begin immediate data collection to confirm product requirements

Introduction

Task 2.1 was designed to provide refined engineering feedback for the Tesla battery development in Task 3 and operational data for the refinement of business practices in Task 4. The first phase of the installation pilot, SolarCity needed to find pilot sites to install the initial lead acid systems for testing. Initial selection of pilot sites was delayed due to difficulty of defining the value proposition to the end customer. Although there is a considerable amount of value that energy storage can provide to both end customers and to the grid, the tariffs and markets needed to capture this value do not currently exist. For residential customers, the defining value is the ability to power their home in the event of a grid outage.

In order to make it possible to both have the grid interactivity and the backup capabilities, an AC-coupled system configuration was chosen using the SMA Sunny Boy/Sunny Island platform. The next step was putting together preliminary designs based on this configuration that could be vetted for installation requirements, cost, permitting, and interconnection requirements.

Three pilot sites were selected from existing solar PV installations under SolarCity management. They were selected because the customers had a strong interest in the development of battery technology and showed flexibility to pilot new technologies. They were all selected from areas near SolarCity's headquarters in San Mateo for ease of installation and data gathering. The value of the backup energy that these systems provide was the main feature that was presented to these residential customers.

Background

The goal of this phase was primarily to set a baseline for the performance with existing lead acid technology. This baseline included ease and cost of installing energy storage equipment, power electronics, and balance of system, the performance of equipment, and limitations of current technology. In order to adequately asses the viability of li-ion grid interactive storage, some assessment of commonly used energy storage technology (primarily for battery backup) was required. The assessment in this phase of the project helped shape the li-ion product specifications for both residential and commercial applications.

Initially, six lead-acid pilot installations were planned comprising three residential sites and three commercial sites. The scope was narrowed to encompass residential sites only at this stage. Due to the low throughput efficiency, limited life cycle capacity, and frequent need for maintenance, commercial pilots using lead-acid technology were deemed to offer too little benefit. Even with a limited scope, these initial installations revealed some valuable lessons about the installation, functionality, and long term viability of lead acid systems as well as providing the basis for the specifications for the storage equipment, power electronics, and communications systems of the forthcoming lithium ion systems.

Subtask 1 – Select Candidate Sites

San Carlos:

The first installation site was a home in San Carlos, CA. The home was located in Pacific Gas and Electric Territory and the City of San Carlos was the Authority Having Jurisdiction (AHJ). During a preliminary site audit the home was confirmed to be a suitable location for the pilot based on two key factors: the customer had an existing PV system that could be easily integrated with energy storage equipment, the garage had seven lateral feet of wall space, and the electrical system in the house was simple enough that transferring critical loads to the firm PV system.

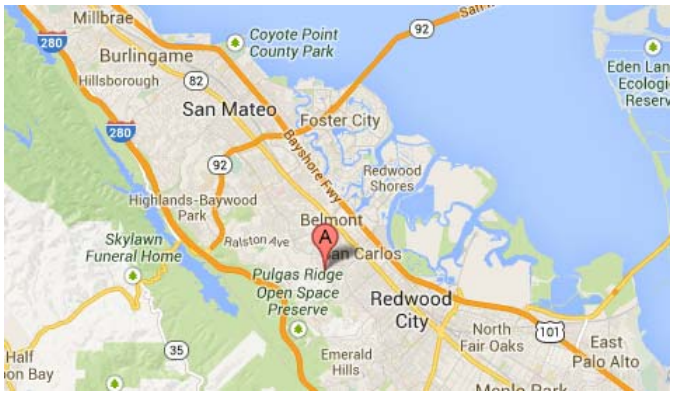

Figure 1 – Pilot 1 location

Figure 2 - Pilot 1 site

Figure 3 - Pilot 1 installation in process

Figure 4 - Pilot 1 battery enclosure

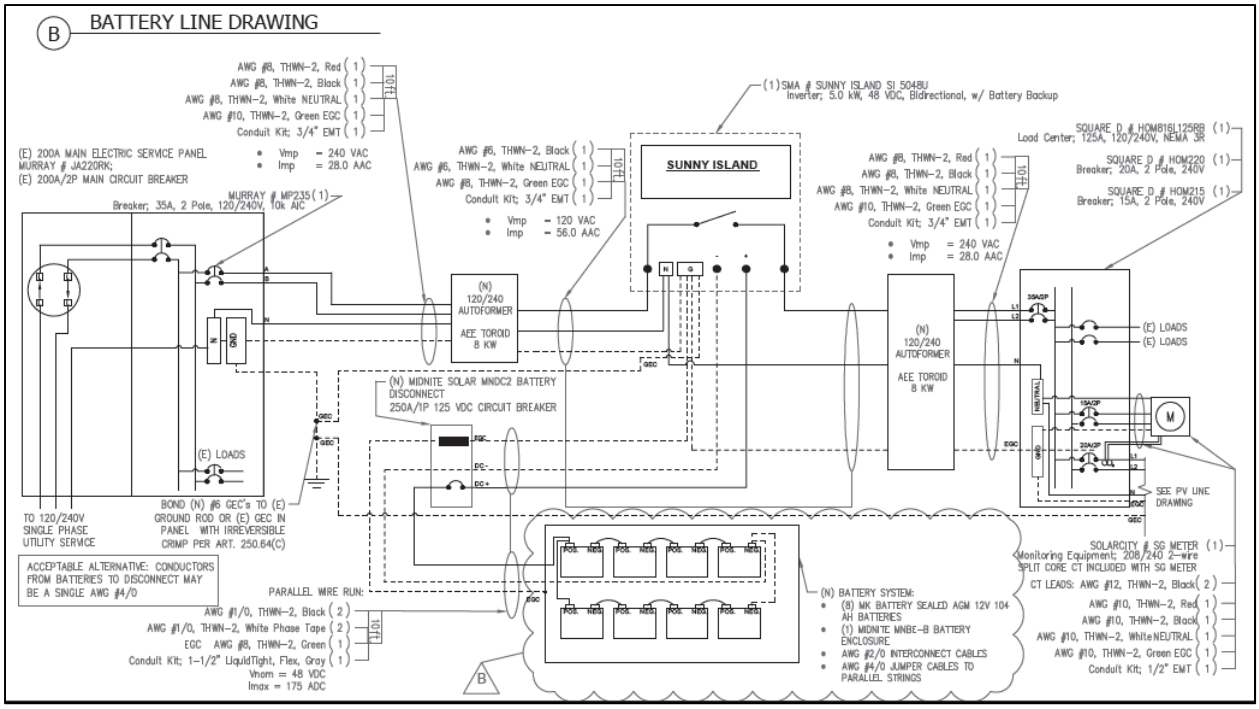

Figure 5 - Pilot 1 single line drawing

The installation process involved switching the existing Xantrex inverter with a Sunny Boy 3800 to enable optimum performance with the Sunny Island inverter/charger for the energy storage portion of the system. Due to the complexity of the system and mounting, the installation required several days.

Oakland:

The second installation was in Oakland at the home of a SolarCity customer. This site was also in Pacific Gas and Electric territory. The City of Oakland was the AHJ and its planning department that not had seen a battery job of this kind. They were very interested in taking a close look at the equipment and installation process. The initial site audit revealed that although a fairly long wire run would be needed from the mail panel to the energy storage location, it would make a good pilot site.

Figure 6 - Pilot 2 location

Figure 7 - Pilot 2 installation in progress

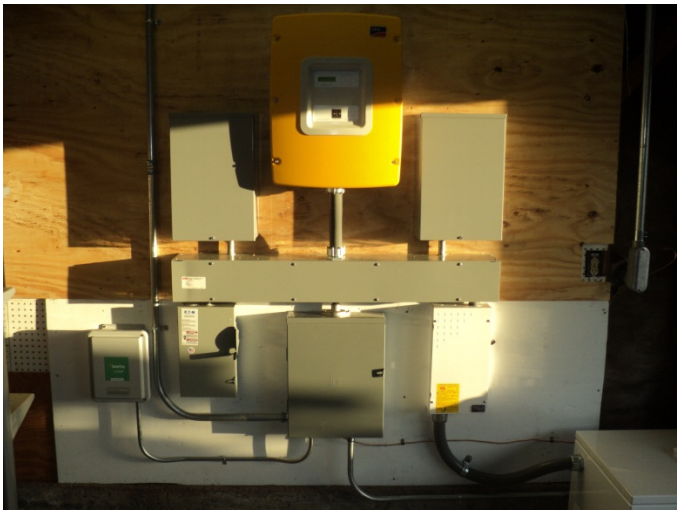

Figure 8 - Completed installation of pilot 2

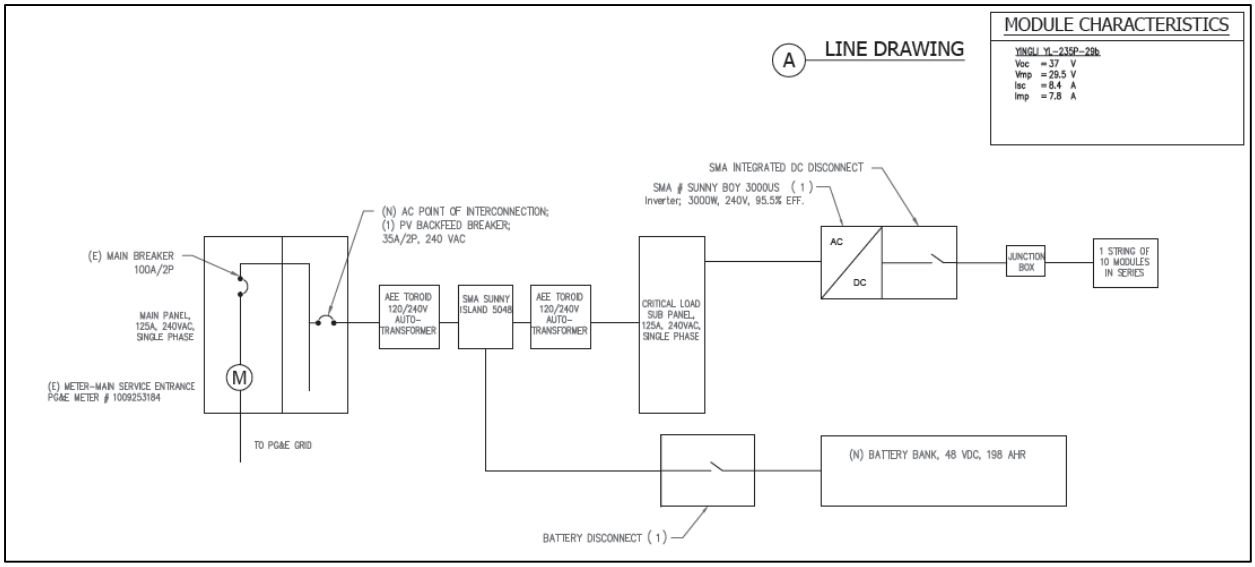

Figure 9 - Pilot 2 single line drawing

The installation process was simpler than pilot 1 because there was no need to replace the existing PV inverter. There was also ample wall space at this location which improved the ease of installation. There had been electrical upgrades when the PV system was installed.

San Francisco

The third pilot site was located in San Francisco. This site was also located in Pacific Gas and Electric territory. The AHJ was the City of San Francisco which had a fairly easy process for dealing with permits for similar PV-paired energy storage systems. At the inspection stage two of the Senior Building Inspectors came out to the final inspection out of interest in the configuration and operation of the system. The audit at this site revealed a very easy installation with both the main electrical panel and the existing PV inverters in the garage where the energy storage system was to be located.

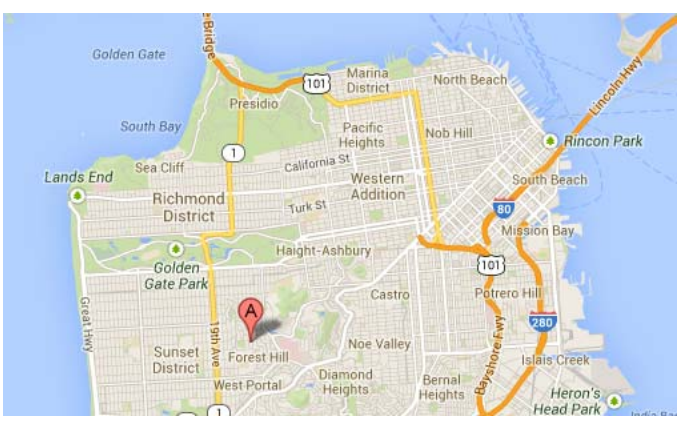

Figure 10 – Pilot 3 location

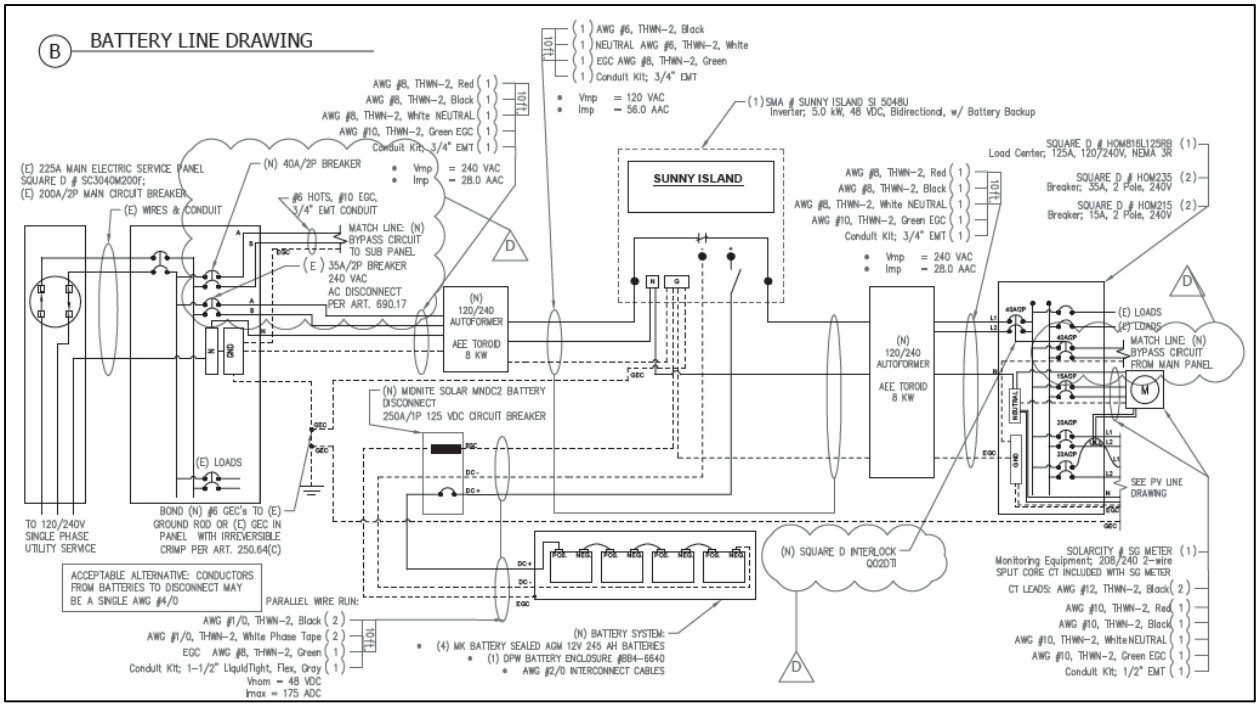

Figure 11 - Pilot 3 single line drawing

Figure 12 - Completed installation of pilot 3

The installation of pilot 3 was also complicated by the need to replace the existing Fronius inverter with an SMA Sunny Boy. There was also limited wall space and floor space to accommodate the installation so the placement of equipment and wiring was much more complex on this site than on the other two.

Subtask 2 – Selection of Power Electronics

The selection of power electronics was a fairly straightforward process given the limited options currently on the market. The following vendors and models were considered:

Vendor	Model
SMA	5048U
Schneider	XW6048
OutBack	GVFX3648

The Schneider option was eliminated at the time due to a bug in the inverter firmware (that has since been fixed) that was causing voltage overshoot on the DC battery bus. The OutBack option was eliminated due to lack of support at the time for grid interactive programmable control.

The SMA Sunny Island 5048U was selected as the inverter/charger for the lead acid pilot systems based on scalability, efficiency, cost, availability technical support, and communications capability. Key concerns about the SMA product were:

1. 120 VAC Native Output – A 120 VAC output required the use of costly, bulky autotransformers to interface the Sunny Island with a 240 VAC PV inverter and native 120/240 VAC split-phase loads.
2. Indoor rated – The inverter is rated for indoor installation only, restricting options for pilot site installation
3. Heavy weight – The product weighs 139 lbs versus 121 lbs for the Schneider product and 62 lbs for the OutBack product. Excessive weight complicates transport and installation.
4. Limited integrated wire management and BOS – Unlike the Schneider and Outback options, the SMA product did not have off-the-shelf accessories for wiring and over current protection requirements.

Subtask 3 – Battery Cells and Balance of System

Flooded lead acid and Valve-Regulated Lead Acid (VRLA) battery cells were considered for deployment. Flooded cells typically offer high energy capacity and cycle life per unit cost compared to VRLA cells[4]. A VRLA cell does not require watering, emits less hydrogen gas and is not at risk of spills. VRLA, Absorbed Glass Mat (AGM) type cells were chosen based on a lower expected lifetime cost, less mandatory maintenance, and design flexibility.

Additional Balance of System components included a utility AC disconnect, a battery DC disconnect, autoformers, and an enclosure for the batteries.

Subtask 4 – Audit, Design, and Permitting

The systems were designed using a combination of information from existing photographs and information from the PV system installations and new information gathered at on-site audits. They key pieces of information needed to design these systems were: specifications of all existing PV system equipment, measurements and locations of desired mounting surface, electrical system specifications (main panel rating, brand, and location), and desired critical loads.

[4] Valve-Regulated Lead-Acid (VRLA): Gelled Electrolyte (Gel) and Absorbed Glass Mat(AGM) Batteries, http://www.dekabatteries.com/assets/base/1927.pdf

Once these data points were gathered, a designer created plan sets for each site showing a site plan, the PV system electrical diagram, the battery system electrical diagram, cutsheets showing specifications of all equipment being installed.

These drawings were delivered to the local AHJ and when possible, an electrician walked through the drawings with the plan checker or inspector. Acquiring permits was relatively straightforward for these installations and the permitting fees were between $100 and $300 with a wait time of 1-4 weeks.

Subtask 5 – System Installation and Inspection

All three of the pilot sites were relatively similar in scope and complexity of installation. All three sites were in garages with existing PV systems to tie into. They were all designed to operate in both grid-interactive and back-up modes.

The steps of the installation included replacement of existing PV power electronics (when applicable, for compatibility with battery power electronics), the mounting and wiring of battery inverter/charger, mounting and wiring of autotransformers, installation of battery enclosure and batteries, and wiring of customer critical loads. The most time consuming element in all installations was the process of wiring the critical loads into the battery system. However, the additional cost of whole house backup is significant enough that it outweighs the added installation cost of rewiring critical loads circuits.

The interconnection applications to PG&E for these pilot installations were submitted as revisions to the existing PV systems. The applications were submitted with plans that detailed the systems being installed. These applications were all approved for interconnection and all sites received their official notice of “Permission to Operate” or PTO within approximately one month from the date of final inspection.

Lessons Learned

These first pilot installations provided valuable information for the design of a lithium ion energy storage product including which features of a battery are most important and useful for a customer, and what is needed to integrate and operate with existing power electronics equipment.

Space constraints proved to be a significant concern with the initial pilot installations. Not only was the floor space required for the battery packs and enclosure an issue in many homes, but the wall space needed to install the power electronics and balance of system was a challenge for design and installation. Floor space was an issue for batteries on the floor of a garage, which is often the most suitable space for an energy storage system, not only because most residential customers have limited garage space, but because even when the systems could fit, there was a vehicle collision concern. Although there is typically ample room to mount this type of equipment outdoors, the cost and selection of outdoor rated equipment or enclosures is prohibitive.

For lithium ion systems, a system that can be wall mounted inside a garage as well as outdoors is necessary to make a storage product accessible to the majority of homes. It is also important that the system not require additional wall-mounted components such as discrete disconnects, wiring boxes and

autotransformers. Based on SolarCity's experience with typical customer wall space, the complete PV and battery system should be able to fit within a space of no more than four to five horizontal feet.

Another important lesson from the pilot installations was in the selection of power electronics. A native 120/240 VAC split-phase power output product would have simplified the interconnection process greatly. The power electronics with partial 120 VAC support required significant additional cost and installation space.

The final insight for the lead-acid pilot sites was the importance of compliance with the National Electric Code and importance of UL Listed equipment. Because so many energy storage systems have been off-grid in the past, many of the technologies that were part of these installations have not been up to code standards. As an example, the autotransformers that were required to convert 120 VAC to 240 VAC were UL Recognized but not UL Listed components. A field UL Listing was required to meet the requirements of a permitting authority. Field listings are time consuming and carry a heavy cost, severely impacting the economics of a project. To be commercially viable, a lithium ion system must incorporate both a battery and power electronics that have received a factory UL Listing. In SolarCity's experience, UL 1741[5] is the appropriate listing standard for battery inverters and UL 1973[6] is the appropriate listing for battery modules.

Lead-Acid Battery Technology for Commercial and Industrial Applications

The project scope originally included deployment of three commercial and industrial pilot sites using lead acid technology. The pilots were not deemed beneficial and thus not deployed due to the following characteristics of lead-acid batteries.

Limited Cycle Life - A primary reason is the limited cycles over the system lifetime that lead acid products tend to be capable of achieving. Commercial sites are generally incentivized to operate batteries in a much more intensive way than residential sites. Demand reduction can cycle a battery multiple times per day and can require a deep discharge. The limited cycle life – 600 to 800 lifetime cycles at 80% depth-of-discharge – of lead acid systems makes the technology very limited in providing value to commercial sites. In order for a storage system to be commercially viable in this use case, a storage technology with lower cost per cycle is needed.

Limited Warranty - A typical lead acid storage product is warranted for between one and five years. A warranty of this term significantly limits the ability to finance the equipment which is a component of making energy storage economically feasible for commercial sites. Finance partners typically require a 10 year or longer warranty.

Frequent Maintenance - Another concern with lead acid storage at both residential and commercial locations is the maintenance required to keep the systems safe and functioning. Lead acid systems require servicing every six months to one year depending on whether the system is a flooded or sealed

[5] "Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources", http://ulstandardsinfonet.ul.com/scopes/1741.html
[6] "Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications", http://ulstandardsinfonet.ul.com/scopes/1973.html

configuration[7]. Commercial customers tend to be very resistant to adding new technologies that require significant maintenance and the frequency of maintenance required makes a third party maintenance method financially unfeasible.

Peak Power Limitations - The primary use case for energy storage in the commercial market is demand reduction. Commercial utility rates are structured to incentivize reduction of peak demand. This means commercial storage systems need to be able discharge their energy fairly quickly (high power) in order to effectively shave these demand peaks. Due to high internal resistance, lead acid systems tend to have very low throughput efficiency at high power (loss of 25% or more at two hour, C/2 discharges)[8]. This significantly reduces the effective energy capacity of the system.

Low Voltage Limitations - Because individual cell maintenance is required, the National Electrical Code requires that these systems to operate at a nominal 48 VDC maximum[9]. This results in high amperage to output the same power. The high energy loss as well as increased equipment costs in high amperage, low voltage systems is damaging to the economics of demand reduction at current utility rates.

Large Physical Size - The final limitation of lead acid systems for commercial use is the large indoor physical space or costly enclosures required for these systems. A lead acid battery can only deliver 60 – 75 Wh/L versus an advanced lithium ion system's 250-730 Wh/L. The significant bulk of lead acid requires dedicated "battery rooms" at commercial scale or if indoor space is not available, requires complex outdoor rated enclosures for which the options are limited and the costs are extremely high.

Conclusion

Lead-acid technology has been around for many years and is the technology of choice for backup systems for solar PV. However, there are many constraints with this technology that can be remedied by leveraging the huge improvements that both the automotive and consumer electronics markets have created in lithium ion technology, and in other novel battery chemistries. The pilot installations discussed in this section were integral to giving both Tesla and SolarCity the insights needed to develop a lithium ion battery pack and select system components that would create a cost effective and space constrained energy storage solution.

[7] LEAD-ANTIMONY, LEAD-CALCIUM, LEAD-SELENIUM, VRLA, NI-CD. WHAT'S IN A NAME?, http://www.battcon.com/PapersFinal2009/ClarkPaper2009FINAL_12.pdf
[8] Effects of variability and rate on battery charge storage and lifespan, http://dataspace.princeton.edu/jspui/bitstream/88435/dsp01x633f110k/1/Krieger_princeton_0181D_10531.pdf
[9] National Electric Code,2011, Article 690.71