California Solar Initiative

RD&D: Research, Development, Demonstration and Deployment Program

Final Project Report:

PV and Advanced Energy Storage for Demand Reduction

Grantee:

SunPower Corp.

January 26, 2015

www.CalSolarResearch.ca.gov

PREPARED BY

SUNPOWER

Corporate Headquarters
77 Rio Robles
San Jose, California 95134

Principal Investigator:

SunPower

Carl Lenox (carl.lenox @ sunpowercorp.com)
Matt Galland, Senior Program Manager
Xina Lyons, Construction Project Manager
Govind Mittal, Senior Electrical Engineer

DNV GL Energy

Rick Fioravanti, Head of Section, Distr. Energy Resources
Dennis Flinn, Senior Principal Consultant

Sandia National Labs

Dan Borneo, Energy Storage Specialist

Project Partners:

DNV GL
Sandia National Laboratories
Ice Energy
ZBB Energy
University of California, San Diego
Redding Electric Utility / Kohl's
Pacific Gas & Electric

PREPARED FOR

California Public Utilities Commission

California Solar Initiative: Research, Development, Demonstration, and Deployment Program

CSI RD&D PROGRAM MANAGER

Itron CSI RD&D Program Manager

Program Manager:

Ann Peterson
Ann.Peterson@itron.com

Project Manager:

Ann Peterson
Ann.Peterson@itron.com

Additional information and links to project related documents can be found at

http://www.calsolarresearch.ca.gov/Funded-Projects/

Preface

The goal of the California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment (RD&D) Program is to foster a sustainable and self-supporting customer-sited solar market. To achieve this, the California Legislature authorized the California Public Utilities Commission (CPUC) to allocate **$50 million** of the CSI budget to an RD&D program. Strategically, the RD&D program seeks to leverage cost-sharing funds from other state, federal and private research entities, and targets activities across these four stages:

- Grid integration, storage, and metering: 50-65%
- Production technologies: 10-25%
- Business development and deployment: 10-20%
- Integration of energy efficiency, demand response, and storage with photovoltaics (PV)

There are seven key principles that guide the CSI RD&D Program:

1. **Improve the economics of solar technologies** by reducing technology costs and increasing system performance;
2. **Focus on issues that directly benefit California**, and that may not be funded by others;
3. **Fill knowledge gaps** to enable successful, wide-scale deployment of solar distributed generation technologies;
4. **Overcome significant barriers** to technology adoption;
5. **Take advantage of California's wealth of data** from past, current, and future installations to fulfill the above;
6. **Provide bridge funding** to help promising solar technologies transition from a pre-commercial state to full commercial viability; and
7. **Support efforts to address the integration of distributed solar power into the grid** in order to maximize its value to California ratepayers.

For more information about the CSI RD&D Program, please visit the program web site at www.calsolarresearch.ca.gov.

Table of Contents

Report Objective

This final report encapsulates the combined experience of a nearly four year effort to study the economic merit of integrated PV and energy storage systems. The study's original goal was to site, design, install, operate and analyze the performance of three unique energy storage systems integrated with existing, similarly-sized, commercial PV installations. However, because of multiple siting and equipment issues, the project was substantially delayed and did not achieve the original objective for all three systems. In the case of one system, this report provides insight to the value proposition of combining energy storage with PV as originally planned. This report also highlights the key observations, challenges and lessons learned from the effort.

It is expected that the reader audience will include analysts, prospective customers, systems integrators, manufacturers (e.g. solar, energy storage, energy management software, etc.) and project developers.

Written in collaboration with the project partners listed above, the overall report objective is to facilitate the reader's own considerations about embarking on prospective PV + energy storage project.

Executive Summary

This project was developed in response to the California Solar Initiative Research, Development and Deployment Program, Solicitation #2 (CSI RD&D II) to study improved solar production technologies. More specifically, the project was to address the CSI program area of "Testing and demonstration of existing energy storage technologies […] that allow the end user or utility to capture higher value from the energy produced." The hypothesis was that the integration of PV and energy storage would be of higher value than either technology alone. The project was also designed to assess the reliability and performance of different energy storage technologies.

Of the several technologies originally pursued, only one was successfully commissioned and operated. For this technology, the economic analysis found that while the energy storage system could have a positive return for the customer, there was no particular synergy with solar generation. This was largely due to the high energy to power ratio of the particular technology.

The project encountered a number of challenges which resulted in valuable lessons learned for SunPower, our partners in the project, the storage and solar community and the State of California.

Additional project information can be found at: http://www.calsolarresearch.org/funded-projects/69-pv-and-advanced-energy-storage-for-demand-reduction

Background and Project Timeline

On September 2nd 2010, the California Public Utilities Commission (CPUC) approved SunPower's grant application entitled, "PV and Advanced Energy Storage for Demand Reduction," a demonstration[1] project to test if the integration of PV and energy storage could be of higher value than either technology alone.

This project falls under the rubric of the CPUC's California Solar Initiative (CSI) Research, Development, and Deployment (RD&D) program and is designed to help build a sustainable and self-supporting industry for customer-sited solar in California. To achieve this, the legislature authorized the CPUC to allocate $50 million of the California Solar Initiative budget to focus on:

- Reducing technology costs and increasing system performance
- Focusing on issues that directly benefit California
- Filling knowledge gaps to enable wide-scale deployment of distributed solar
- Supporting the integration of distributed power into the grid

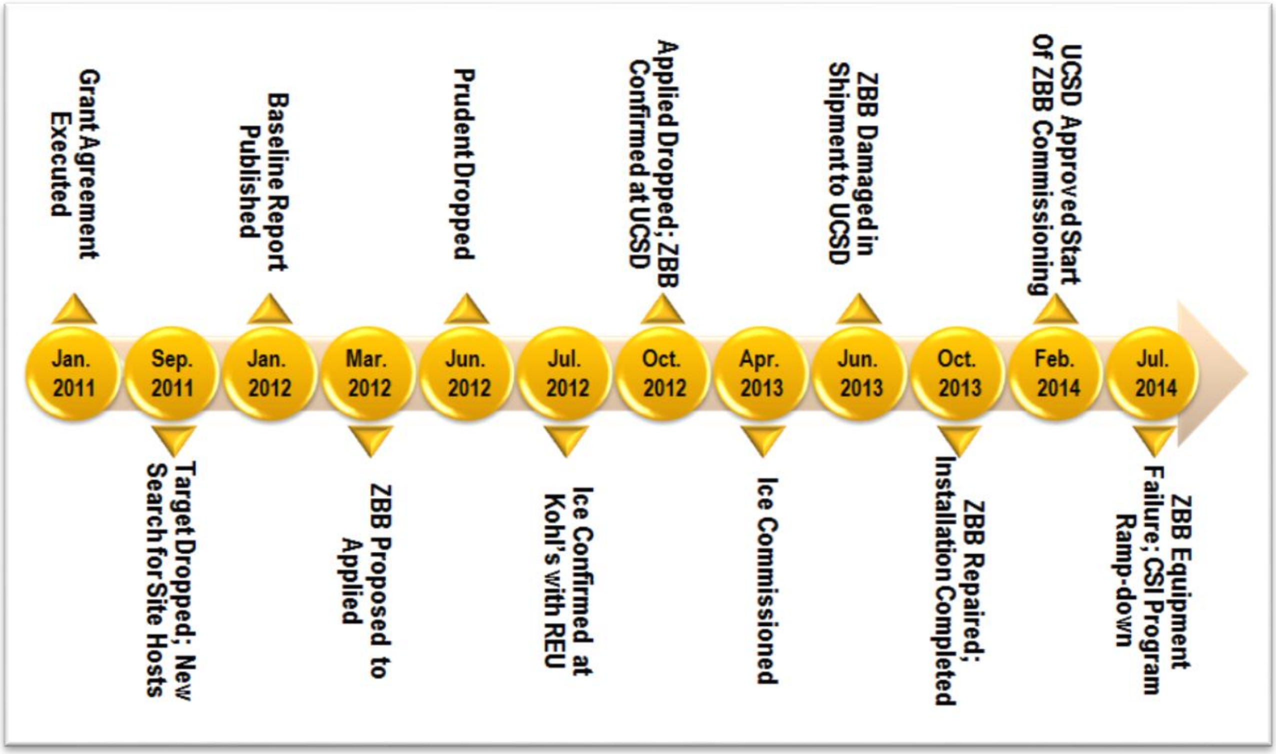
This CSI project included tasks to increase demand reduction and verify benefits of solar coupled with energy storage, and also to assess the reliability and performance of three different storage technologies. The storage options included an innovative thermal energy storage technology and two advanced electrochemical storage technologies.

The specific goals of this research project were to:

1. Determine if the combined value of PV and energy storage is of higher value to the commercial customer and utility than either one alone, and,
2. Assess storage capabilities, reliability and potential degradation of the technologies to assess lifetime characteristics.

With the grant, SunPower, its project partners and three energy storage vendors (Ice Energy, ZBB Energy and Prudent Energy) were to identify, site, design, install, operate and measure energy storage systems with existing commercial photovoltaic (PV) systems at Target Stores. Originally intended to be a two year study, the program was given two additional years in order to accommodate numerous siting, design and installation issues encountered along the way. The following timeline provides a birds-eye view of the way the plans actually unfolded.

[1] Activities which bring promising technologies closer to market by demonstrating their real-world feasibility to manufacturers.



1 Overall Project Timeline

The grant was awarded in late 2010 and, in January 2011, an agreement was signed with the expectation of a brief siting and installation period followed by eighteen months of monitoring and evaluation.

After considering multiple sites and with substantial design efforts under way, the project was not able to overcome a major contracting impasse with the site host and the proposed demonstration partnership with Target Stores was abandoned.

To find replacement site host(s), the CPUC granted the project a one-year, no-cost contract extension through January of 2014. Later, due to equipment delays and other technical issues, a second contract extension was granted through to January 2015.

The following is a brief description of where each vendor ended up and the status of their installations.

Prudent Energy

Over the course of the siting delays with Target, Prudent decided to pull out of the demonstration program in part because they had just won a large commercial project and desired to focus resources on that effort. In the fall of 2011, Prudent formally terminated their CSI grant agreement, leaving the project with the remaining two storage vendors.

Ice Energy

In late 2012 and in partnership with Redding Electric Utility (REU), Ice Energy (Ice) installed and commissioned six of their Ice Bear units at Kohl's in Redding, California. The Kohl's PV system had previously been installed by a 3rd party and the site required a new metering solution for the purposes of the CSI study. After several months of installation and data integration work, full access to PV production, net site load, and Ice Energy performance data was completed in the late spring of 2014.

The Ice-REU-Kohl's system and performance monitoring remain in operation as of the writing of this report.

ZBB Energy

In September of 2012, Itron introduced the partners for this project to staff from the University of California, San Diego (UCSD). With UCSD's advanced microgrid and experience with other grant-funded research and demonstration programs, all project partners quickly agreed to confirm the university as ZBB's site host. Plans were launched to have ZBB installed by early 2013. After considerable siting, engineering and permitting delays, installation and commissioning was rescheduled for the fall of 2013. When their equipment was damaged in transit to UCSD, ZBB was further delayed for repairs and installation wasn't completed until January 2014. In their repeated attempts to commission their system, ZBB was faced with additional delays from equipment failures, leaks and software configuration issues. At what was to be the final commissioning event, ZBB then suffered a substantial electrolyte leak. UCSD ordered ZBB to stop, remove all electrolyte fluid from the system, and wait for Sandia's 3rd-party leak incident report.

Sandia concluded, among other things, that ZBB's equipment should be removed, reengineered for better safety and spill containment and replaced. ZBB provided a root cause analysis and proposed to repairs *in situ*. (See Appendix B, Leak Incident and Root Cause report). Neither scenario was tenable with only a few months left on the CSI contract and, with Itron, SunPower, Sandia, DNV-GL and UCSD all in agreement, a decision was made to not to move forward with operating the ZBB system.

Ultimately, the ZBB equipment was removed from the site and returned to the manufacturer. UCSD has been left with a substantially improved site and the basic infrastructure (concrete slab, conduits to campus electrical switchgear, fence and bollards) for future energy research and demonstration programs.

Reporting and Analysis

The economic evaluation was intended to provide an analysis of the actual interaction of photovoltaic (PV) and energy storage (ES) systems relative to time-of-use (TOU) utility tariffs which include demand charges. This type of rate structure is the most common for commercial electricity customers in California.

Because of technical and market issues, only the thermal energy storage technology from Ice Energy was deployed operationally for a sufficient period of time to draw conclusions about the combined value proposition with PV.

For the Ice Energy installation at Kohl's, a final performance and economics analysis has been performed and is included in this report as Appendix A.

The following pages are organized around the major project tasks: Siting, Design and Installation, Monitoring and Analysis. Each section includes a synopsis of what occurred during that phase of work with supporting details and project documentation by vendor. As appropriate, lessons learned and other key observations are noted.

Site-Host Negotiations and Planning

SunPower recruited Target Corporation to be the original site host team member, and Target representatives participated in the development of the project plan and proposal. At the outset of the project, the team worked closely with the Target corporate energy management team to identify sites that would be suitable for the program based on a number of key criteria including:

- SunPower PV system installed and monitored under O&M contract
- PG&E service territory
- E19 rate
- Late afternoon peaking load profile
- Availability of as-built drawings

This resulted in selection of five stores for site visits and further analysis.

First, an initial screen was performed using Google Earth to identify potential locations for equipment at each site. In person site walks were performed with the team, including representation from Sunpower, Sandia, DNV-KEMA, Target, and each storage vendor. These surveys were intended to identify if the site could reasonably accommodate each storage system and the relative cost of installation for the systems at each site.

The outcome of this process was selection of 3 final sites, one for each technology, and agreement on which technology would be hosted at each location.

Google Maps URL		Target Data by Site							PG&E	SPWR Data by Site				Vendor/Site		
ID	Location Name	kWp Load	PV kWSO	PV kWAC	Mech.	Struct.	Elec.	Civil	Rate	PV kWp	CDAS	MET	Other	Pru.	ZBB	Ice
T1851	Gilroy	438	336	319	Y	Y	Y	Y	E19S, NEMEXPM	381	Y	Y	Y	X		
T1862	Stockton North	509	325	310	Y	Y	Y	N	E19S, NEMEXPM	370	Y	Y	Y		X	
T2018	Clovis NW	618	338	299	Y	Y	Y	Y	E19S, NEMEXP	387	Y	Y	Y			X
T1428	San Leandro Bayfair	563	337	?	Y	Y	Y	N	E19S, NEMEXPM	392	Y	Y	Y	1	1	
T1472	Hayward	424	336	309	Y	Y	Y	N	E19S	387	Y	Y	Y	1	1	

However, it was ultimately not possible to come to agreement on certain terms of the Engineering, Procurement, and Construction (EPC) agreement between SunPower and Target legal. Neither ZBB nor Prudent had prior commercial qualifications and Target would not accept even an experimental project without some promise of commercial benefit or, at least, indemnification from potential service interruptions and lost revenue. SunPower could not assume liability for such indemnification risk and the project partners were forced to look for an alternate site host.

Following this event, SunPower and each energy storage partner reached out to additional potential site hosts to find locations that met the criteria outlined above. Based on existing relationships, the team engaged with Macy's, Applied Materials (AMAT), several California community college campuses, and Redding Electric Utility / Kohl's. Each was recruited to participate based on a presentation of potential economic and research benefits and dedicated time and resources to assist the team in the site evaluation process.

A similar site investigation process to that undertaken for Target was performed for all candidate sites, including analysis of load profiles and site visits to ascertain appropriate locations for equipment.

During this process two further events occurred. Prudent Energy exited the project in part because of their consummation of a large deal which required the focus of their team. In the same timeframe, AMAT decided not to move forward as a site host for ZBB. This occurred in part because of complex integration requirements, and associated high installation costs.

At this point, UC San Diego (UCSD) was offered as a potential site. The Macy's location that had been originally planned for siting the Prudent system was also considered. The team considered the options and determined that moving forward with UCSD was the best approach.

Intensive engagement with the UCSD team ensued, including representation from the facilities and Environmental Health and Safety (EH&S) teams as well as energy storage program management. The team quickly evaluated several potential on- and off-campus locations based on activities carried out at site, available physical space, load profiles, and a site walk, with the team ultimately settling on a physical plant location with appropriate chiller loads and two PV systems.

Lessons Learned:

- It is generally straightforward to make an initial screening determination of site suitability based on load profile, rate tariff, and a remote site assessment (e.g. Google Earth).

- For the type of equipment considered here, early site visits are critically important to verify that identified installation locations are suitable. In particular, the flow battery systems require a substantial footprint. In many cases, locations which appear suitable based on looking at imagery may not be acceptable to the customer due to plans for future use, traffic patterns, restrictions imposed by the site owner (e.g. within a shopping mall), alternate uses (e.g. sensitivity to losing parking spaces in a community college), and the relative locations of the appropriate electrical interconnection point, the available physical space for equipment, and the metering point(s) required for controls implementation.

- Securing and maintaining site host commitment to this type of project can be challenging. Even in the case of this pilot, with the system provided to the host at nominally zero cost, the site host must commit resources to assist in the planning and installation process. Relative to the value provided by one or a small number of storage system installations, corporate-level leadership in particular may be hesitant to incur the opportunity cost of assigning staff to resolve issues as they come up, given the need for the same personnel to resolve significantly higher impact core business issues. Additionally, in many cases the loss of alternative uses for the space may be an issue for the site host. Therefore, there must be broad motivation and buy-in across the host organization beyond project economics – to be viewed as a thought leader, to advance environmental stewardship, or to have these projects included as part of a bigger implementation effort (multi-site and/or multi-technology) to make more efficient use of resources.

Energy Storage Baseline Report

So that the team could better anticipate how each integrated PV and energy storage system would perform over the course of this study, SunPower compiled an initial baseline assessment of each of the storage manufacturers.

This assessment concluded at the time that given storage costs and tariff structures, the economics of combining PV and storage at the evaluated sites were challenged. The availability of incentives allowed for somewhat positive results for some systems.

In addition to providing an initial assessment of the storage value proposition, one key outcome of the baseline modeling was to provide comparison between modeled performance and actual performance of the storage devices at the same site. However, because no storage systems were implemented at the locations used for baseline modeling, this was not possible.

The report also highlighted that modeling of storage economics for demand charge reduction can be challenging and requires some form of discounting of demand reduction to account for numerous scenarios that may be difficult to mitigate.

Site & Design

Prudent

Prudent was originally slated for one of Target's stores in Gilroy. Prudent drafted installation plans, initiated interconnection paperwork filings with PG&E and met on several occasions with Target's planning engineers. The team also initiated an introductory meeting with the City of Gilroy planning division to discuss what requirements would be expected for a flow battery system, which this Authority Having Jurisdiction (AHJ) had not encountered previously.

Ice Energy

One of Target's Bay Area stores was identified as a suitable site to host Ices Energy's equipment. Ice worked with Target's planning department to develop a full set of installation plans and a local installer was contracted. With the exit of Target, Ice Energy had to scrap all of their nearly-complete plans.

In early 2012 and through its existing commercial relationship with Redding Electric Utility (REU), Ice Energy introduced the CSI program to their customer, Kohl's. A site hosting agreement was drawn up between Ice, Kohl's and REU and the team got back on track with their siting and installation planning.

Ice handled all design, engineering, permitting work in close coordination with REU and the local jurisdiction. SunPower had no direct involvement in Ice's design effort but for ensuring that the final plans include sufficient monitoring and data access for the CSI program.

ZBB

ZBB's original design intent was to install their containerized system in a spare parking area directly adjacent to Target's utility interconnection equipment. ZBB had plans and was not anticipating a complicated and expensive installation. Upon starting the search for new sites with the exit of Target, ZBB started voicing concerns about how it could manage potentially onerous, new siting requirements elsewhere.

In March 2012, ZBB leveraged a relationship with Applied Materials (AMAT) and secured their interest in participating in the project. Applied also has a SunPower PV system installed at the same AMAT Santa Clara campus.

Three alternate sites were identified within the AMAT Santa Clara campus. ZBB brought in Black & Veatch (B&V) as a part of their site assessment and planning. A Technical Services Agreement for engineering, design and installation was duly executed between ZBB and B&V and included a price for each site. The expectation was that ZBB and AMAT would share the responsibility for covering B&V's costs. However, with B&V's quotes coming in at $80,000, $90,000 and $130,000 respectively, negotiations between ZBB's and AMAT stalled. These costs were higher than expected in part due to the need to interconnect the storage equipment into the AMAT campus medium voltage distribution at specific physically available points, while system controls required metering at a distant point within AMAT's dedicated campus substation which interconnects with PG&E. Under these circumstances, the team decided to no longer pursue siting at the AMAT facility and began the search for an alternate host.

In the fall of 2012, and with the introduction of UCSD as a possible site, the team went back into action to find a suitable site somewhere on the UCSD campus. A rigorous siting analysis was conducted and, agreed upon by all the stakeholders. The team selected an area adjacent to one of UCSD's main utility sites on the East Campus.

2 UCSD East Campus - Selected ZBB Site

A full set of UCSD-approved plans can be found in See Appendix E (page 18).

It became apparent through the Applied Materials siting exercise that ZBB would not be able to provide a full turn-key installation solution at UCSD. In addition, the time and money spent on project development work on the prior sites introduced budget constraints. To address this, ZBB proposed a new modular (not containerized) ZBB product. This did require a pad mount solution and extensive site preparation work. With these circumstances, ZBB was forced to downsize their system and put a cap of $100K on their installation budget.

Itron, SunPower, DNV-GL and Sandia still had a keen interest to see this project through and the project team resolved to overcome the obstacles for this project demonstration

With the CPUC's approval, Itron extended the CSI grant to January 2014. DNV-GL stepped in to provide all civil, structural, electrical and mechanical engineering by taking-on more of the project scope. SunPower contracted with the installer and handled construction management. SunPower also arranged the site license with UCSD and provided a control system that would meet the needs of the project, as it was determined that ZBB's system did not have adequate control capability for the application.

UCSD is a self-permitting entity so no additional engagement with an Authority Having Jurisdiction (AHJ) was necessary, but UCSD personnel stringently evaluated the installation and certifications of the ZBB equipment. After resolving multiple concerns related to electrical permitting, the UCSD team allowed installation to move forward on a conditional basis. Conversely, the relatively novel chemical process and electromechanical subsystems of the ZBB equipment were not subjected to the same level of scrutiny, though standard requirements for chemical spill mitigation were employed.

The concerns related to electrical safety included: requirements for a specific fencing / lock scheme to prevent unauthorized personnel from entering the site area; lack of confidence in inverter Listing to UL Standard 1741 by a non-UL Nationally Recognized Testing Laboratory (NRTL); and requirements for demonstration of anti-islanding functionality in situ.

The concerns raised by UCSD regarding inverter certification for the ZBB system were not anticipated even with SunPower's long history and deep experience as an Engineering, Procurement and Construction (EPC) provider. Inverters used in storage are quite similar to photovoltaic system inverters, and listing by NRTL's other than UL is very common for PV system inverters. In most cases these Listings are accepted by AHJs and on the rare occasions they are not, generally it is possible to substitute a different inverter in the project that is listed by UL. UCSD made clear it had a policy of requiring Listing by UL for all inverters (including PV inverters) and in this case substitution was not possible as the inverter was integral to the storage device. With SunPower, ZBB and DNV/KEMA working together closely with UCSD technical personnel, concerns were resolved adequately such that permission to install the equipment on a temporary basis for research purposes was secured.

In parallel, Ice Energy moved forward with Kohl's / REU under an existing contractual relationship. This included all required site hosting agreements and the permitting process with the AHJ, which reportedly was uneventful.

Design work was started in January 2013 and by late May all plans were approved and ready for installation work to begin. SunPower issued a status update to the team with a revised project plan that expected to have ZBB commissioned in early July.

Lessons Learned:

- For battery systems, the process of working with the Authority Having Jurisdiction (AHJ) to obtain necessary permits can be extensive and may require significant engagement. AHJs generally have very limited or no experience with large battery systems. Any experience that they have is limited to lead-acid backup batteries for telecom and similar applications. The requirements are not well defined and are often determined in a somewhat ad-hoc manner by the involved personnel. The requirements AHJs propose based on their understanding of battery systems, may or may not be relevant to the technology deployed, and the immaturity or lack of certification standards can also be a barrier. AHJ's may be inclined to view flow battery systems as a small chemical process plant, especially when field-assembled, and other unanticipated requirements may be proposed. For example, once understood, the physical size of one of the systems raised an unexpected requirement from one AHJ to construct an enclosure building around the system so that it would blend in with adjacent structures; the size of this structure in turn required it meet significant additional permitting requirements.

- Ice Energy demonstrated repeatedly that AHJs view Ice Bears as HVAC equipment, allowing the application to go through a well-defined permitting process.

- As seen at UCSD, the lack of acceptance of any component of a system by an AHJ may result in implementation barriers especially if component substitution is not possible. This is particularly likely to occur with novel equipment subject to additional scrutiny, even if some components are very similar to and meet the same certifications as equipment routinely permitted in other contexts without issue.

- Overall, the experiences in this phase of the project reinforced that project economics cannot be based on equipment costs alone. Site-specific installation and "soft" costs can be both significant, and difficult to predict.

Install

Ice Energy

Similar to their design and permitting work, Ice Energy handled all installation planning, installer subcontracting and construction management work. Installation appeared to be straightforward with no issues or delays.

ZBB

In June 2013, after a rigorous design/review/permitting process with UCSD, site preparation work was complete. ZBB's shipper, however, severely damaged their equipment in route rendering the entire system unusable. The equipment was promptly shipped back to ZBB for repairs but the project was, once again, delayed. Once the equipment was returned to site, physical installation was largely uneventful. However, control system integration proved to be challenging due to continuous changes in the ZBB controller mapping, resulting in the need for several rounds of modifications of the SunPower controller code that had to be performed and validated.

Lessons Learned:

- Installation of the Ice Energy systems appeared to be uneventful.

- Though shipping damage is not always avoidable, investment in robust packaging (e.g. crating) is advisable when transporting large, complex and expensive equipment. Also, the use of shock indicators on equipment is well advised. This will indicate the amount of shock a system was exposed to during the shipping process.

- It is important to have a stable environment for controls mapping, and that any planned changes are communicated clearly and well in advance so that necessary modifications and QA testing can take place. Also, an overall system integrator should be employed to insure that all systems communicate to one another.

Third Party Validation & Support

Factory Acceptance Testing

The original premise of Factory Acceptance Testing (FAT) was to establish that the equipment to be shipped to site met the vendor's performance specifications in advance of incurring shipping and installation costs. The intention of FAT was also to establish a detailed performance baseline to allow for assessment of any performance degradation over time.

No FAT was planned for the Ice Energy system because its performance is highly dependent on the specific HVAC equipment it is coupled with.

FAT was infeasible or the Prudent system since it is entirely field-assembled, however the team planned to perform similar field acceptance testing in lieu of FAT. Since the system was never installed, this was not carried out.

ZBB was unable to support FAT of the equipment it provided to UCSD, or similar hardware. Instead, the team was only able to validate interoperability of the SunPower supervisory controller with the ZBB battery controller on the test bench.

Lessons Learned:

- Vendors must be capable of supporting FAT if required by ?. FAT is an imperative part of a successful installation, especially for new technologies with a limited number of field installations. During the FAT process, equipment can be evaluated to insure that it supports the application that it will serve in the field. It can also be evaluated for any safety concerns as well as getting baseline data which to compare to during commissioning and operation.

Commissioning Verification and Reporting

Commissioning of the Ice Energy equipment was apparently uneventful.

Commissioning of the ZBB equipment was not completed since it experienced a serious failure during the commissioning process. Please see Appendix B for more details.

Closeout & Equipment Disposition

Ice Energy equipment remains installed and operational at the Kohl's Redding location.

The ZBB equipment and electrolyte was removed from the UCSD site and offsite storage location, and shipped back to ZBB.

Appendix A

PV+ES Final Economics Report

Executive Summary

This report summarizes the results of an analysis of the economic benefits to the customer by combining photovoltaic (PV) with energy storage to manage time-of-use, demand charge rates. Specifically, the impact on net facility demand at a Redding, California Kohl's retail store with PV and thermal energy storage from Ice Energy; and the two technologies in combination was evaluated.

These results were obtained by measuring and modeling the impact of the PV and energy storage systems on customer utility bills, using metered facility load, metered time-coincident PV output data, and metered Ice Bear operational data used to develop a model of avoided and time-shifted HVAC operation. Utility bill savings were modeled by calculating expected utility bills for each case using the most recent PG&E E19S tariff (published October, 2014).

The key finding of this report is that PV and Ice Energy storage at this site are complementary but do not have synergy in the sense that the two technologies together delivering more net value than the sum of each one alone. The Ice Energy system appears to be capable of delivering positive economics to a commercial customer on the PG&E E19S rate, with or without PV in place, assuming that 2015 CPUC Self-Generation Incentive Program (SGIP) incentive can be applied.

Methodology & Approach

Assumptions

For the analysis performed in this study, the following financial assumptions and system attributes were used:

Table 1: Financial Assumptions

Financial		
Hurdle Rate	9%	
Base Utility Rate	PG&E E19S - October 2014	
Utility Rate Escalator	2%	per year
Federal Tax Rate	30%	
State Tax Rate	8.80%	
Federal Tax Depreciation - Storage	Straight line over asset life	
State Tax Depreciation - Storage	12 year straight line	
Incentive - Storage	SGIP - 2015	

Table 2: Basic System Attributes

Vendor	Power (nominal)	Energy (nominal)	Average RT efficiency	Operational Life	Technology Type	Notes
Ice Energy	40 kW	240 kWh	> 100%	25 Years	Thermal	5 units

The thermal energy storage utilized in this study has unique characteristics compared to many other storage systems, requiring an additional assumption. Specifically, the Ice Bears (IB) from Ice Energy provides storage by running a refrigeration cycle at night to freeze a large vessel of water into ice. During the day, refrigerant from rooftop direct expansion (DX) air conditioning units is directed into condenser coils embedded in the ice. The implication of this is that the ensuing avoided compressor cycling of the DX units cannot be directly measured, it must be modeled. This is based primarily on the characteristics of the DX unit and rooftop ambient outside air temperature (OAT) measured by the Ice Bear units.

Ice Energy provided the modeled demand reduction utilized for this report, and one key assumption is that this model accurately represents actual avoided demand and energy usage.

Methodology

SunPower previously developed a technical-economic model for the evaluation of energy storage systems. It is based on a time-series analysis of 15-minute resolution load (demand) and PV production data. Any timespan can be handled, though at least one year of data is required to fully capture seasonal effects and gain a full understanding of the combined economics of PV and storage.

The model is capable of simulating detailed operational characteristics of different energy storage systems as well as different dispatch control strategies. However, for historical analysis this is unnecessary because actual metered data, along with Ice Energy's modeled avoided consumption data, was used.

Specifically, for this report SunPower had access to the following data sets starting in mid-July, 2013.

Metered data: Redding Electric Utility (REU) graciously allowed access to a meter data tool which allowed for browser-based access to easily download these data sets.

1) Metered 15-minute interval facility data. This net meter data measures import of energy from the utility and export of energy to the utility on two separate channels. PV production and Ice Bear operation are embedded in this net load data. Unfortunately, the net export channel was not enabled initially and this error was not rectified until mid-May 2014. As discussed below, this limits the ability to draw conclusions about some economic impacts prior to June, 2014.

2) Metered 15-minute interval PV production data.

3) Ice Bear 15-minute interval operational data. The Ice Bear units include a Cool Data controller which measures many parameters of the Ice Bear and the DX unit it is attached to, including energy usage during the ice make cycle and from auxiliaries.

Modeled Data: Ice Energy provided 15-minute interval avoided DX operational data. While these data sets were high quality, they were not error free. In the meter data, several months had duplicate or missing intervals (typically the first 4 of the day from midnight to 1 am) that were either deleted or filled with data from the previous interval. There were three missing days in the Ice Energy Modeled data (June 19th, July 19th, and October 31st) for which data from the previous day was substituted.

Using this data, the estimated facility load baseline without PV production or Ice Bear operation can be reconstructed via a simple calculation. This also allows estimate of the load shape with either PV or storage.

To estimate utility bill impacts, the model calculates the cost of utility service in each time step, based on the specific rate tariff. It calculates separate energy ($ per kWh) and demand ($ per peak monthly kW) charges across multiple time of use periods, including weekend and holiday exceptions to these periods. The components of the utility bill - energy, demand, and fixed charges - are calculated separately for a base case, a PV-only case, or a PV plus storage case. Different rate structures can be assigned to each case. If a year of data is available, this results in a “year 1” utility cost for each case.

These single-year results are passed to a cash flow model which is used to determine net present value (NPV) and internal rate of return (IRR) for each case given the expected operational life of the PV system and energy storage system. The cash flow model incorporates O&M costs for the PV and storage systems as well as changes over time in both systems, such as efficiency, output power, or energy capacity where these occur and data is available. The cash flow model can also incorporate federal and state tax considerations, including depreciation, and incentive structures that pay out over multiple years such as SGIP.

As noted above, the lack of PV export data over a full year constrains the analysis to a degree. The issue is that if there is any PV export, which is often the case; the baseline load cannot be estimated where net export data is not available. Figure 1 below illustrates that where the net demand measurement is artificially limited to zero due to the metering constraint, attempted reconstruction of baseline demands results in an apparent increase facility load during peak solar hours. While it may be possible to estimate actual baseline demand using other approaches, doing so would introduce additional uncertainty and inaccuracy and was not in the scope of this effort.

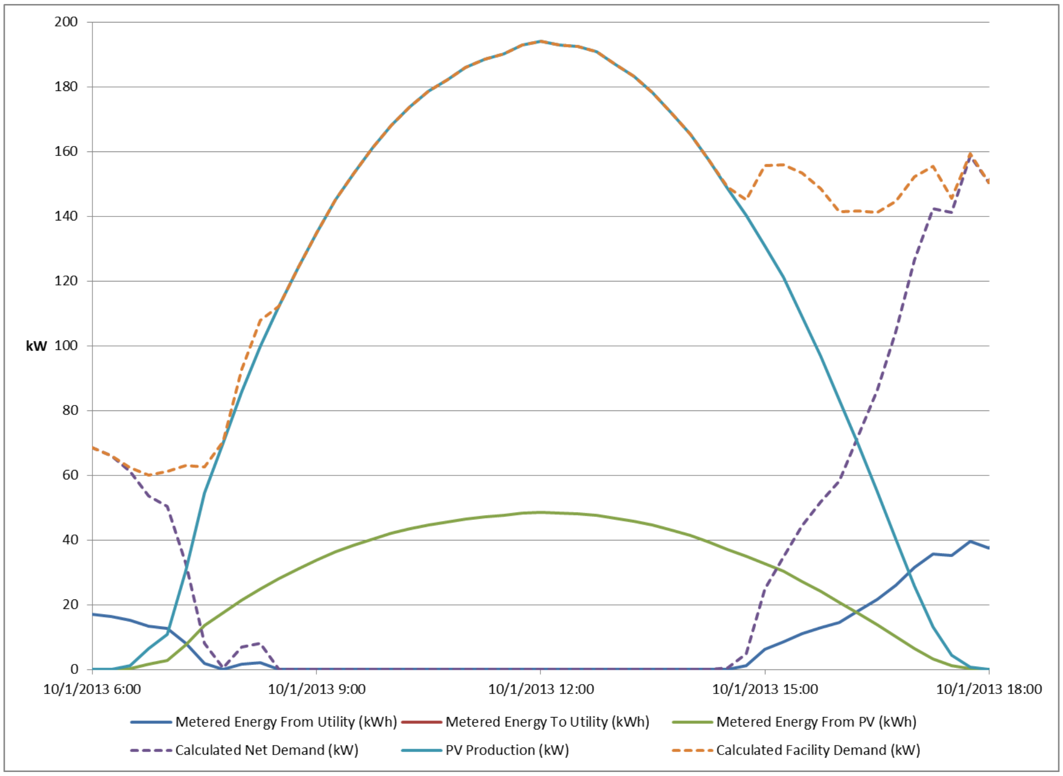


Figure 1 – Impact of missing net export data on calculated facility demand

In this case, lacking a full year of data, this analysis is necessarily somewhat limited. Assessment of the full economic value of PV alone, storage alone, and PV plus storage would require many assumptions that substantially reduce confidence in the results. Instead, for this analysis the focus is twofold.

First, an analysis is presented for the months where a full data set is available, June – October 2014. The focus of this analysis is to evaluate synergies or antagonisms associated with combining PV and Ice Energy storage in this use case. This requires that the site's original load shape be reconstructed so that the impact of PV alone and storage alone can be modeled.

Second, a full analysis of the value of Ice Energy storage incremental to the PV-only case is presented. This incremental value analysis is feasible given available data because PV net export conditions do not impact the incremental demand reduction, or energy efficiency value of energy storage to a net-PV load shape base case. The results of the first analysis are that in this case, the value of PV and the value of storage are simply additive, so these results are valid. This analysis is based on subtracting the energy storage dispatch from the measured site load (net of PV and storage) to create a net-PV only baseline, and then calculating the difference in the cost of this baseline load shape verses the measured load shape. Results are presented both for the single year evaluated, and on an NPV basis. The calculation on NPV solves for the installed storage cost which results in an NPV of zero; that is the investment which just meets the buyer's assumed hurdle rate. Since net export is not available for many of these months, the value of the PV system cannot be similarly evaluated.

Site

The site evaluated is Kohl's retail store in Redding, CA. This location had a previously installed, non-SunPower PV system in place. Ice Energy installed 5 Ice Bear units on this location as part of a program with Redding Electric Utility (REU). In this report, we model the benefits of deploying the Ice Bear units in the context of a commercial customer's utility bill savings assuming a PG&E E19S tariff. However, this particular location is on a REU rate without significant demand charges. In actuality, the benefits are split between Kohl's and REU, with Kohl's agreeing to host the units and REU paying for the units for the system-level capacity benefits provided. For this reason, comparison of the modeled bill to actual bills for verification purposes was not possible.

Outcomes & Observations

PV System and Ice Bear Operation

The basic premise that combining PV and energy storage can have a greater combined value than the sum of each technology individually is that the PV system reduces demand across much of the peak period, but energy output is significantly reduced towards the end of the period so the actual impact on the demand charge is limited. In addition, reductions in PV output (for instance, from passing clouds) could reduce output at any time in the day, impacting demand charges.

Analysis of several sites, as discussed in the baseline report[2], showed that PV systems do provide meaningful demand charge reduction, and the primary value of pairing storage with solar is to further reduce demand during the last hour of the summer peak demand period and into the afternoon part-peak period as solar generation declines. Conversely, output variability due to clouds is far less of a factor in setting demand charges. This analysis of actual field results further corroborates these findings. The following plots show the maximum peak demand day of each summer month with valid data. Note that even on days which obviously have cloud cover resulting in variability in the PV system output, maximum peak (and all hour) demand is consistently set in the last hour of the peak period, as solar generation approaches zero. It is also notable that for this site, load variability or "spikes" in demand are in general more significant than PV variability.

---

2 http://www.calsolarresearch.org/images/stories/documents/sol2_funded_projects/SunPower/sunpower%20pves%20baseline%20report%20revised%2002-06-12.pdf

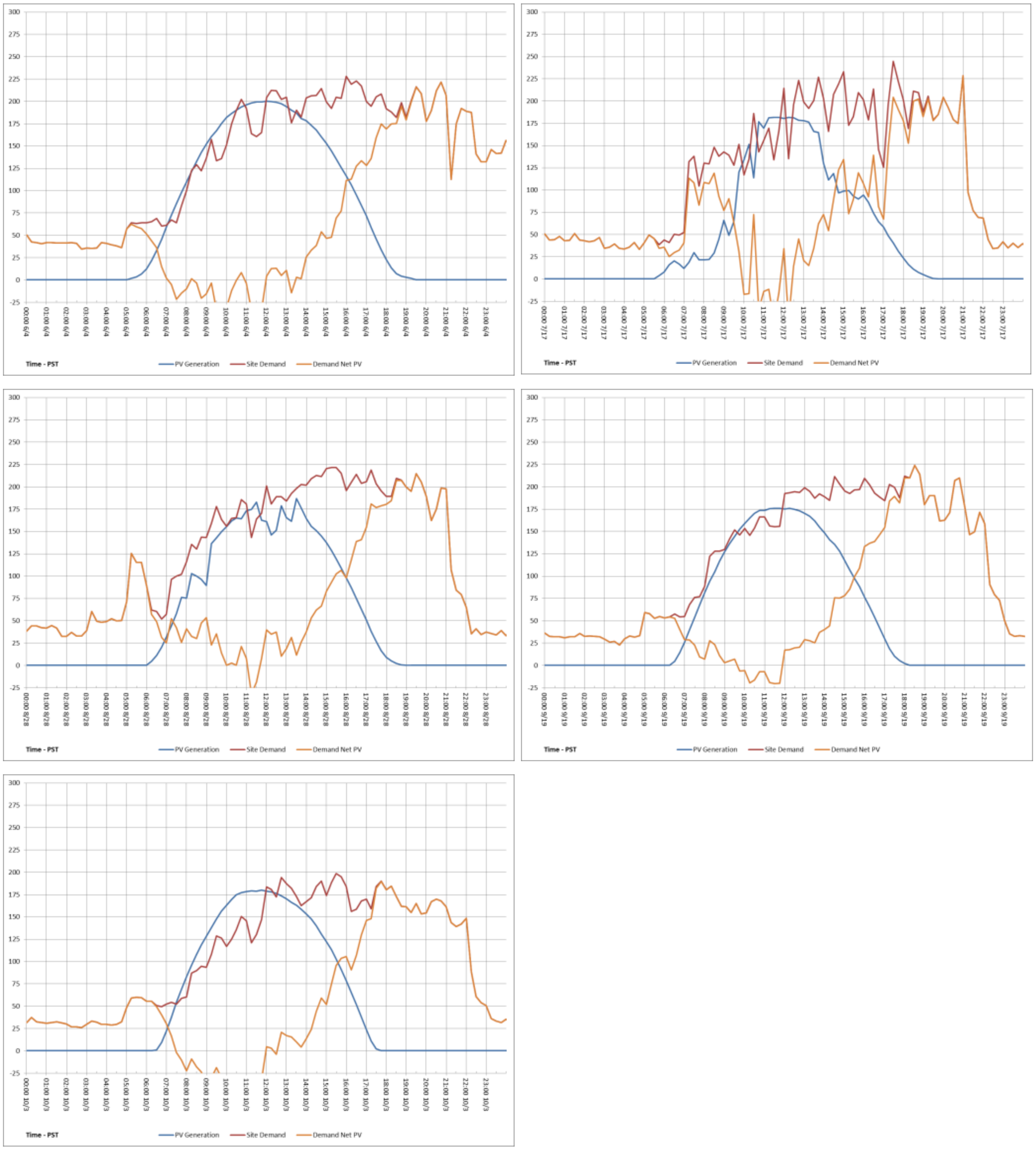


Figure 2 – PV generation, load, and net load on the peak demand day (post-PV) June – October 2014

The value of combining PV and storage thus derives from the fact that a give unit of demand reduction (kW) can be achieved with far less energy (kWh) with a PV system in place than without, and as a result PV makes storage for demand management significantly more cost effective.

The Ice Bear system has characteristics that differ significantly from most other forms of energy storage. The Ice Bears are designed with a ratio of energy to power of 6:1 which is inherent to the product, and the cost structure of this type of storage is such that a significant reduction of this ratio would have a limited impact on installed cost. Additionally, the operation of the Ice Bear system is such that shifting of energy use from mid-day cooling to night ice making results in significant energy efficiency savings, because of the relatively large amount of energy use shifted.

On an annual basis, the model provided by Ice Energy indicates that 35,969 kWh of DX usage was avoided with 25,501 kWh of energy usage for the ice make cycle and auxiliaries, for an equivalent efficiency of 141%.

This is in sharp contrast to other forms of storage, which exhibit an increase in energy use due to round-trip efficiency losses which can result in limited or even negative energy arbitrage value.

The effective >100% efficiency of Ice Bear units is attributed to the increased efficiency of making ice at night when outdoor air temperatures are cool, as compared to the efficiency of the DX units operating at high outdoor air temperatures mid-day.

The Ice Bears on this site were programmed to run starting at noon and offset demand through the peak and into the part-peak period. This meant that the operation of the units for most of the peak period had no impact on demand charges, as the PV system already reduced demand significantly. For most storage technologies, this dispatch would be "wasted" indicating that the system was significantly oversized when combined with PV. However, because the Ice Bears deliver significant efficiency savings by avoiding HVAC compressor operation during the hottest hours of the day, operation in this manner does contribute value.

PV and Ice Energy Storage – Synergy or Antagonism?

One of the questions that this project was intended to answer was whether significant synergy exists between PV and storage in real-world deployments. In the baseline analysis report, this synergy was not expected for the combination of PV and Ice Energy. In fact, the modeling performed at that time indicated that the opposite was true. Across two of the sites modeled, the incremental demand reduction benefit provided by Ice Bears in combination with PV was reduced by 24% and 7% respectively, compared to the modeled benefit provided by Ice Bears alone. It was also noted that the latter, relatively high value was due to the PV system inverter(s) tripping offline for a significant portion of several summer days; the extended duration of Ice Bear dispatch mitigated the resulting net demand increase. Thus, this analysis indicated antagonism (the whole less than the sum of the parts) between the technologies. The observed dynamic was that in some cases the peak demand with PV in place was set on partly cloudy days, when PV output was consistently depressed. These conditions are associated with cooler ambient temperature, leading to reduced demand reduction from the thermal storage system compared what would have been achieved on a hot, sunny day with no PV in place. The net effect was that in this previous analysis, the Ice Energy system achieved a lower value with the PV system in place than if no PV system had been in place.

The results from the analysis of the Kohl's site showed a more muted effect. To assess this, the combined actual impact, on energy and demand charges, of PV and Ice Bear operation was compared to summing the modeled impact of each technology operating by individually[3] on facility load. For the months with valid data, the total reduction of demand charges was 4.2% less for the combined PV and Ice Bear units than the sum of demand charge reduction achieved by each technology in isolation. The energy cost reduction is identical is both cases, as expected. Overall, energy cost savings (predominantly from PV) dominate the value stack for this site. Thus the total

[3] This assumes no change in storage operational strategy across these cases. For Ice Bear units, this is an accurate assumption but it would not be for many energy storage systems, particularly with lower energy to power ratios.

savings achieved by PV+ES in combination is within 1% of the sum of savings from each technology alone. Note the delivered value shown below is only for June – October.

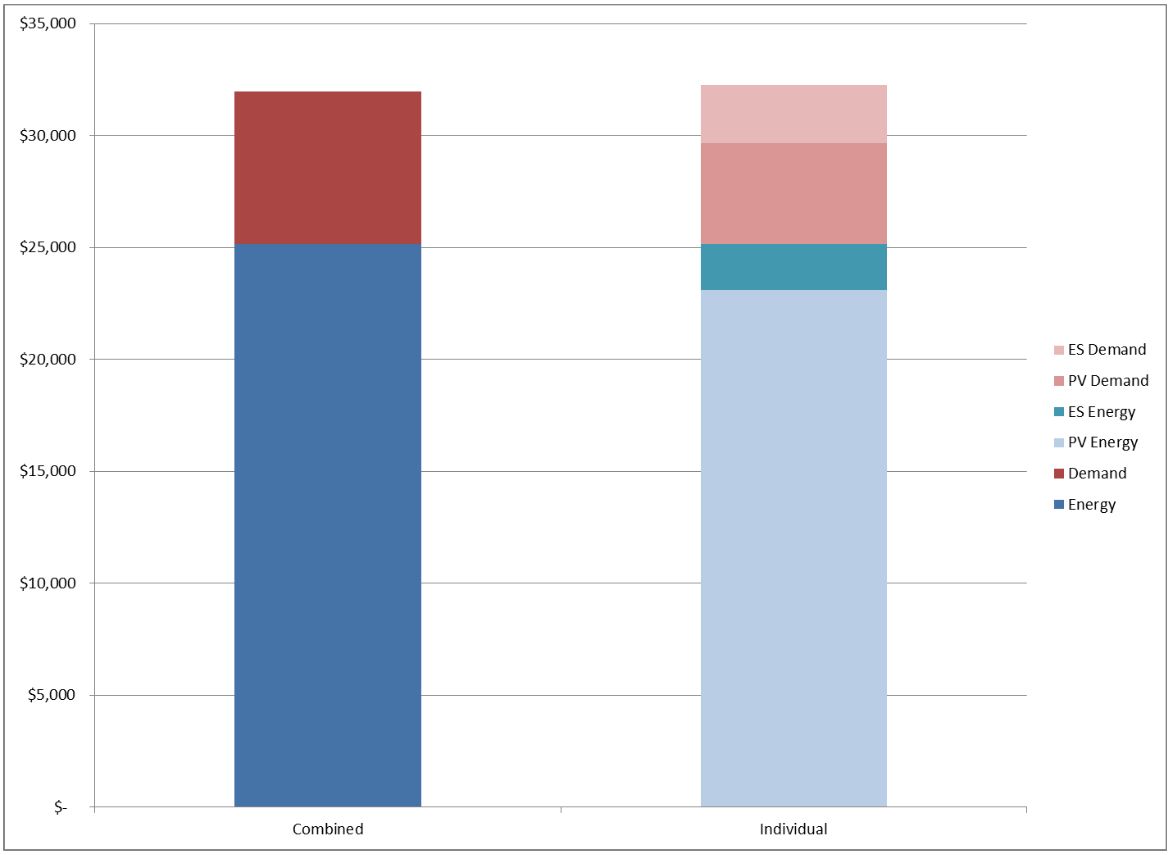


Figure 3 – Combined value of PV and Ice Energy storage versus the sum of modeled value

It is worth noting that in the previous analysis, the ratios between the PV system kW, storage system kW, and load were significantly different than this case, as outlined below:

	Stockton (2010)	Gilroy (2010)	Gilroy (2008)	Kohl's (2014)
Maximum peak period load (kW)	497	446	464	279
PV maximum output (kW, AC)	309	327	314	212
Ice Bear maximum output (kW)	107	107	107	37
Ratio Ice Bear : PV	0.35	0.33	0.34	0.17
Ratio Ice Bear : Peak Load	0.22	0.24	0.23	0.13

Table 3 – Relative PV and ES system sizes across studied sites

The smaller relative size of the storage system to the load and PV system are clearly one component of this result.

In addition, the original modeling assumed the Ice Bear system was 100% efficient, that is, there were no energy efficiency savings. In these results, energy efficiency savings are significant, comprising 44% of the savings delivered by the Ice Bear units overall.

Of the seven months not evaluated here, six are winter months. The Ice Energy system provides some energy savings and very little demand savings in these months, further reducing the overall gap on an annual basis.

Overall, the result is the value of PV and Ice Energy storage is for all practical purposes additive for this site, and neither synergistic or antagonistic. The results do indicate that this may not be the case for all sites, particularly where a higher capacity of Ice Bear units are installed relative to the peak load and PV generation.

Incremental Value of Storage

Since the incremental, individual value of Ice Energy storage was shown to not differ materially from the combined value with PV, the full year data can be directly utilized to determine the value of the storage system at this site. The incremental value for the year studied is shown in the below table:

Month	kWh - P	kWh - PP	kWh - OP	kW - P	kW - PP	kW - AH	Total	Energy Net	Demand Net
1	$ -	$ (26)	$ 20	$ -	$ 0	$ 0	$ (6)	$ (6)	$ 0
2	$ -	$ (5)	$ 7	$ -	$ 0	$ 40	$ 42	$ 2	$ 40
3	$ -	$ (22)	$ 12	$ -	$ 0	$ 0	$ (10)	$ (10)	$ 0
4	$ -	$ (224)	$ 115	$ -	$ (2)	$ (140)	$ (251)	$ (109)	$ (142)
5	$ (395)	$ (90)	$ 132	$ (327)	$ (44)	$ (70)	$ (795)	$ (353)	$ (442)
6	$ (423)	$ (106)	$ 165	$ (386)	$ (105)	$ 63	$ (791)	$ (364)	$ (428)
7	$ (587)	$ (144)	$ 216	$ (622)	$ (111)	$ (211)	$ (1,457)	$ (514)	$ (943)
8	$ (546)	$ (128)	$ 175	$ (554)	$ (127)	$ (419)	$ (1,599)	$ (498)	$ (1,101)
9	$ (480)	$ (112)	$ 170	$ (466)	$ (112)	$ (269)	$ (1,270)	$ (422)	$ (848)
10	$ (250)	$ (38)	$ 92	$ (414)	$ (41)	$ (283)	$ (933)	$ (196)	$ (738)
11	$ -	$ (44)	$ 22	$ -	$ (1)	$ (87)	$ (110)	$ (22)	$ (88)
12	$ -	$ (21)	$ 17	$ -	$ 0	$ 0	$ (4)	$ (4)	$ 0
Total / Max	$ (2,681)	$ (959)	$ 1,143	$ (2,769)	$ (543)	$ (1,376)	$ (7,186)	$ (2,498)	$ (4,688)

Table 4 – Energy, demand, and cost savings of the Ice Energy system on PG&E E-19S tariff

Note that savings here are shown as negative values. The Ice Bears units at this site provided a savings of $7,168 annually (on a PG&E E-19S tariff), with 65% of the value delivered by demand reduction and the balance by energy efficiency.

The break-even NPV, given assumptions outlined above, is $114,082 for this system or $475 / kWh nameplate. This compares favorably to the benchmark installed costs provided by Ice Energy previously for the baseline report.

Technology	Benchmark Power	Benchmark Hours	$/kW	$/kWh
Ice Energy[4]	8 kW	6	$2500 - $3000	$417 - $500
Ice Energy[5]	50MW	6	$1500 - $2200	$250 - 367

Table 5 – Benchmark installed costs for the Ice Bear technology

Conclusions & Recommendations

The key finding of this report is that PV and Ice Energy storage at this site are complementary but do not have synergy in the sense of the two technologies together delivering more net value than the sum of each one alone. The Ice Energy system would appear to be capable of delivering positive economics to a commercial customer on the PG&E E19S rate, with or without PV in place, assuming that the 2015 SGIP incentive can be applied.

At the present time, SunPower has no further recommendations to the CPUC but commends the CPUC for its significant contributions towards incredible progress made in the area of distributed storage deployment.

[4] Cost benchmark representative of installed costs for a single site (typically comprising ten or more units).
[5] Cost benchmark is representative of its utility scale projects where the capacity is purchased by the utility as a deferred or avoided cost alternative for generation, distribution, and reserve margin resource planning requirements.

Appendix B

Leak Incident Report and Root Cause Analysis

Sunpower/ZBB Energy Storage System AT UCSD – Unit #3 LEAK Report

July 18, 2014

Benjamin Schenkman, Daniel Borneo

Sandia National Labs

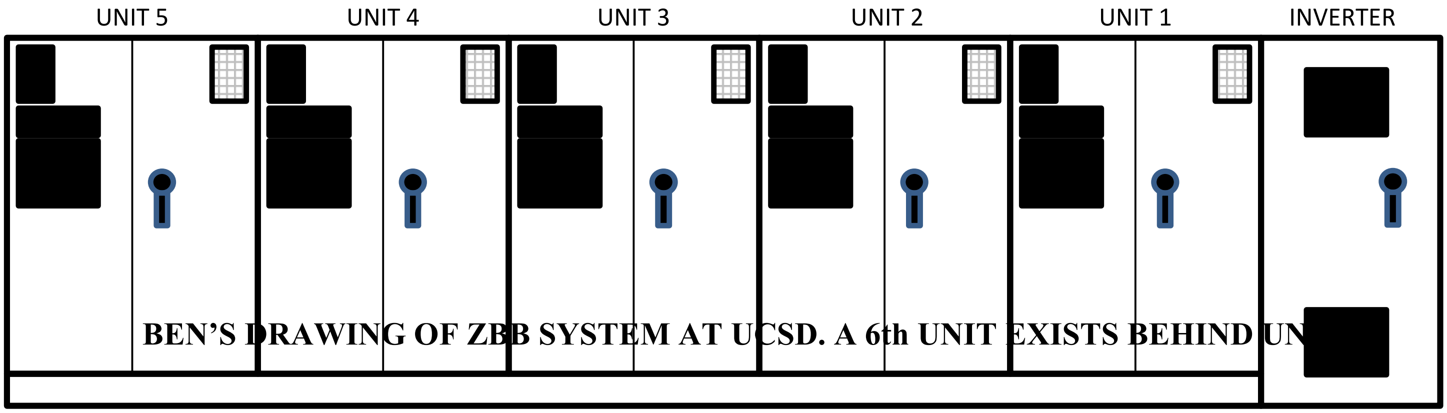
PROJECT BACKGROUND

California Public Utility Commission (CPUC) funded Sun Power and ZBB to demonstrate the economic benefit of combing PV and electrical energy storage in a commercial building application. ZBB technology is a Zinc Bromide flow battery which is controlled by a Sun Power controller as a peak shaving service. Space was leased at the University of California San Diego to connect the ZBB energy storage system to a commercial grid that had PV on the same AC bus. DNV was contracted by Sun Power to provide a third party evaluation of the commissioning of the ZBB system. Sandia National Labs (Sandia) joined the project as a technical consultant to DNV to help with the commissioning test development and operational data analysis. The construction of the UCSD site and ZBB energy storage system was completed in the year 2013.

ZBB Energy storage system specs:

- Technology: Zinc Bromide Flow Battery
- Inverter: 208V, 3-phase, 125kVA
- Energy rating: 300kWh (6 Enerstor units each rated at 50kWh)

In the spring of 2014, during the initial ZBB system commissioning leaks developed in units 1-5 of the system, which shut the system down. The leaks were due to a pressure build up in the electrolyte tanks, causing the pump gaskets to fail and leak electrolyte in the enclosure. The pressure build up was determined to be the result of insects clogging up the pressure release vent tubes that are externally exposed through the unit doors. The pumps and the vent tubes were replaced in the affected units and upgrades to the vent piping were made to mitigate the insect nesting problem. The units were cleaned of any residual electrolyte. In addition, the plumbing of the system was changed out to match a newer more efficient stack design. It should be noted that after the repairs the leak sensors were tested on all units and were also connected to a relay that would send the leak detection alarm to the UCSD emergency response team.



BEN'S DRAWING OF ZBB SYSTEM AT UCSD. A 6th UNIT EXISTS BEHIND UN

SANDIA ON-SITE COMMISSIONING NOTES

DATE: 07/16/2014

- The test performed on the 16th was to verify that the Sun Power controller could send and receive information from the ZBB controller. Controller test was successful for sending and receiving data between the ZBB controller and the Sun Power controller. However, testing was not completed since there was discrepancy between the data that was shared with the Sun Power controller and the ZBB Human Machine Interface (HMI). This step in the test was unsuccessful.
- 0800 Site Visit and Physical Inspection notes:
  - ZBB technicians performed verification of the voltage and currents that the ZBB inverter was recording by using a multi-meter at the 150kVA system transformer.
  - Moisture was present on the concrete and on the ZBB pad in front of Unit 4 on the side of the ZBB system that is closest to the road. It was due to ZBB technician changing a hose within this unit the day before.
  - Most connections and other metal parts within the ZBB system had discoloration. The discoloration was the color of rust which is very similar to the ZBB electrolyte so it is uncertain if the parts were rusted or just residuals of the earlier leakage in the year. It was noted that the top cover of the 150kva pad mounted transformer for the ZBB system was replaced because of salt air caused rust.
- Because of the previous pump gasket failure and leak in the spring of 2014, an absorbent sock was placed on the concrete pad around the ZBB unit.

DATE: 07/17/2014

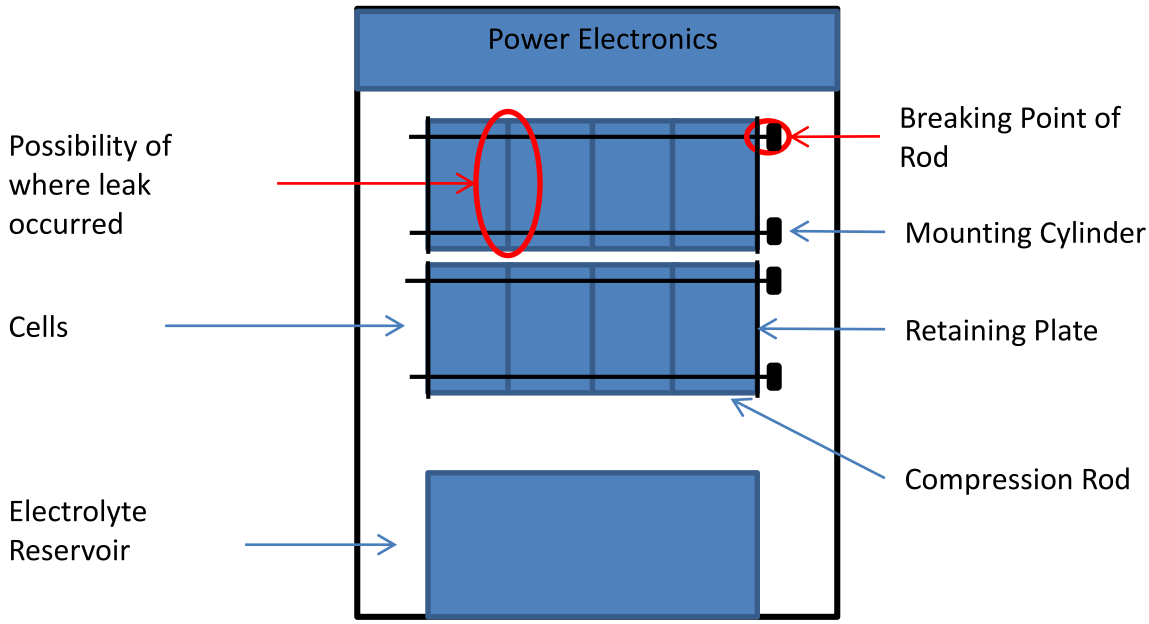
- A full cycle efficiency test was planned. In order to perform this test the ZBB system has to fully charge and discharge to complete the full cycle. For this test UCSD required that at least one person be on site in the event of a problem. Due to the length of time required for the test and a late start due to the repair of the controller problem, the testing team (ZBB-Phil Gull, Kevin; Sun Power- Matt Galland, Govind Mittal; UCSD- Bob Caldwell; DNV – Dennis Flinn; and Sandia- Ben Schenkman) decided to take shifts through the night to allow for the completion of this test.

- During this test, ZBB technicians were also working in unit 4 replacing hardware and completed the work a few hours before the Unit 3 failure. Also Unit 2 was only partly working as there were DC to DC converter failure issues.

- **UNIT 3 FAILURE**
  - Around 0100 PST, a Sun Power employee noticed that the incoming data from the ZBB system was sending corrupt values. The values that were in error were the SOC of the modules which were changing from 0% to 95%. Values settled back to the 95% after approximately 5 minutes. This data was not logged by ZBB controller and not captured by the UCSD PI server.
  - At 0324 PST, a ZBB technician heard a loud noise at the ZBB system and went into the electrical room across the street from the ZBB system and informed the ZBB project manager and Sun Power employee about the noise that he heard.
  - All 3 workers went outside to the ZBB system to assess the situation. Units 1, 2, 5 and 6 were in the discharge mode while unit 4 was charging. The units were still operating based on the ZBB design. Each unit is in a separate cabinet and able to continue to run as one unit can be brought down for maintenance issues or during a fault.
  - Low-level leak detection was triggered for unit 3 and the Sun Power employee immediately hit the ESTOP for Unit 3 which shut the unit down while the remaining units remained online. Time was approximately 0327 PST.
  - The system started to de-energize the stack and perform a stripping cycle on unit 3. Note – The Emergency Stop (ESTOP) is only automatically engaged when the high-level leak detection is triggered. The leak detection alarm was not sent to the fire alarm because the relay to send the signal was disabled from the Sun Power controller during testing. The relay was disabled during testing in order to avoid nuisance trip alarms to the emergency response teams at UCSD.
  - ZBB contained the spillage immediately after Unit 3 was shut down and started to neutralize the spilled Zinc Bromide around the outside of the Unit 3 cabinet along with wiping down the sprayed Zinc Bromide within the Unit 3 cabinet.
  - Approximately at 0400 PST, Sun Power and ZBB decided to shut down the remaining 5 units to prevent any further leak incidents from occurring. The entire system was shutdown using the ZBB controller.
  - AT 0642 PST Sun Power sent an email to EH&S and other stakeholders regarding the Unit 3 incident.
  - 0900 – 1000 PST, a meeting was held between all stakeholders to assess the incident at which time the HAZMAT team from UCSD met with ZBB to go over the neutralization process and determine if any other steps were needed. EH&S was satisfied with the methods and procedure ZBB was implementing.
  - ZBB system was left offline when all parties left the site with the ZBB perimeter gate locked

- Upon initial investigation the noise, and subsequent failure of unit 3, was due to the failure of the weld on the threaded rod connected to the mounting cylinder that compressed the battery cell stack together. The leak was at the endplate of the stack, as the threaded rod no longer compressed the seal.

Single Unit from ZBB ESS inner depiction



- Byron Washom required that the electrolyte should be drained and stored off site to insure that no more leaks could occur. ZBB requested the electrolyte be left in the containers within each unit but was denied by Byron. The fire marshal concurred with Byron's decision.
- It was determined that when Unit 3 incident occurred, one of the testing team members at the site should have called 911 in order to properly contain the incident. Reasoning behind this is because the ZBB system is on UCSD property and they are ultimately responsible for all installed systems
- UCSD has taken pictures of the incident for documentation

POSSIBLE REASONS FOR THREADED ROD WELD FAILURE:

- Threaded Rod weld to cylinder mount is not rated for pressure of the cell stacks
- Threaded Rod had hair line fracture at the weld from when the unit was dropped and damaged during shipping earlier in the project
- Threaded Rod was rusted due to the caustic environment which weaken the strength below the pressure it was designed to hold
- Cold Weld of the threaded rod head. Note: This is the cause that has been put forth by ZBB.
- Pressure relief system did not operate as designed, increasing pressure beyond that of the threaded rod weld. It was believed that the earlier leakage in the project where the pump gaskets failed was due to the pressure relief tubes being clogged by insects. Is there a relationship?
- The system creates more heat within the cells during discharge than during charge. The additional heat may have caused further expansion of the stack, compared to the expansion during charging, that developed a force above the strength of the threaded rod weld. This would explain why the threaded rod weld did not break while the system was charging and did when it was discharging.

RECOMMENDATION SECTION BASED ON INCIDENT AND TESTING

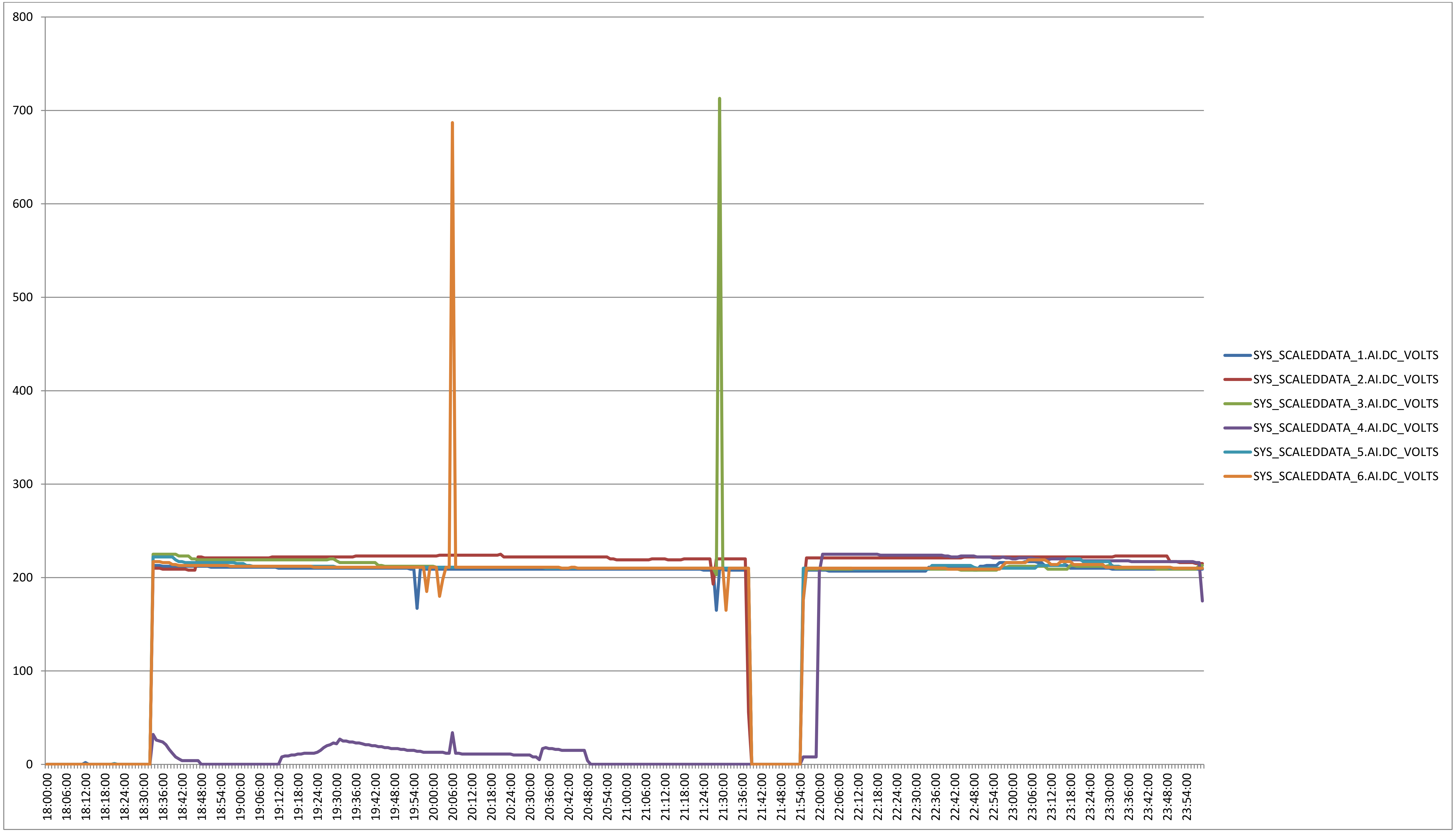
- The system should be removed and a thorough engineering analysis of the entire system should be conducted. Analysis should include safety engineering and failure analysis to determine all possible failure modes, risks and mitigation. Some thoughts for the analysis include but should not be limited to:
    - There have been two over pressure related incidents. While on the surface the problems seem unrelated, further investigation should be done to understand the failures. A pressure profile should be developed and analyzed.
    - Install flow and pressure meters throughout the ZBB units. Flow and pressure meters should be incorporated to shut down the system in the event of over (or under if appropriate) pressurization.
    - Have containment for the spraying of the electrolyte within the unit. Containment for the sprayed liquid should allow it to be put into the secondary containment where the leak alarms reside.
    - ZBB controller software or hardware needs to be revisited to fix the values that were witness by the testing team at 0100 PST on 07/17/2014. Try and mimic the condition at which the system was reporting bogus values.
    - The graphical data from DNV shows that there are spikes in the data which occur in multiple units at various times. These spikes need to be evaluated as to why they are happening and what the ZBB controller calculates during this time. Note: These spikes do not seem to be linked to the failure of Unit 3.

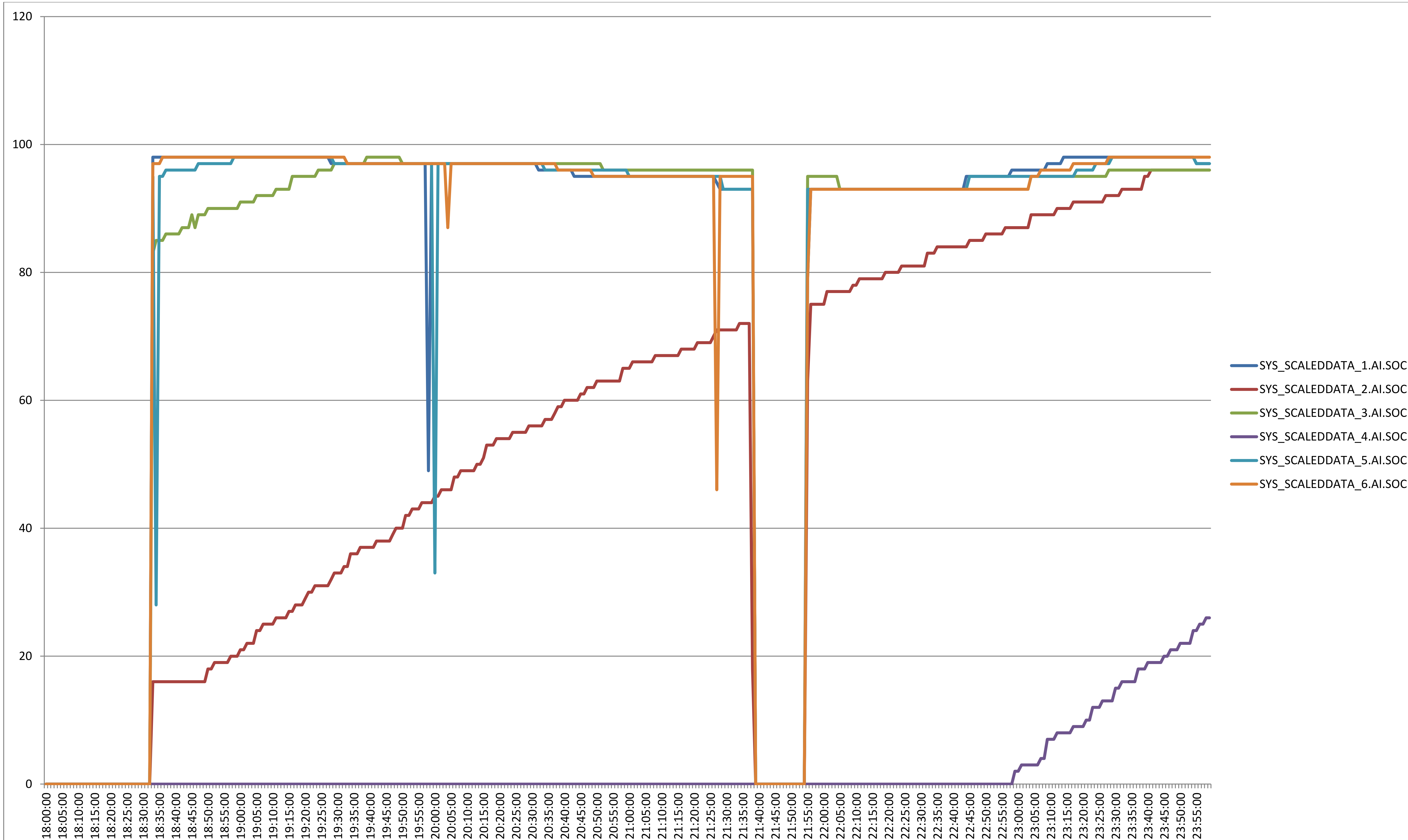
- Determine if the threaded rods welded at the cylinders that were holding the cells together are correctly rated and designed to hold that much pressure. Determine if present design is adequate.
- Materials used in ZBB system need to be replaced with materials that are resilient to the caustic environment of La Jolla, CA
- Provide door sensors on the doors of the ZBB units such that it will ESTOP that unit when it is opened while operating. Allow this sensor to be disabled by a qualified ZBB technician when performing diagnostics or permitted energized work
- Develop on site plans and procedures for any technicians working at the site. Keep the developed safety plan in a readily accessible location at the site
- ZBB to work with Sun Power in developing the communication between controllers to work properly.
- ZBB and Sun Power should develop a change procedure to insure proper notification between the companies when updating software.
- Manufacturing quality assurance processes should be revisited for all manufacturing.
- Further investigation is needed to determine to what extent rust is impacting the system.

GRAPHS CREATED BY DNV USING UCSD PI SERVER DATA

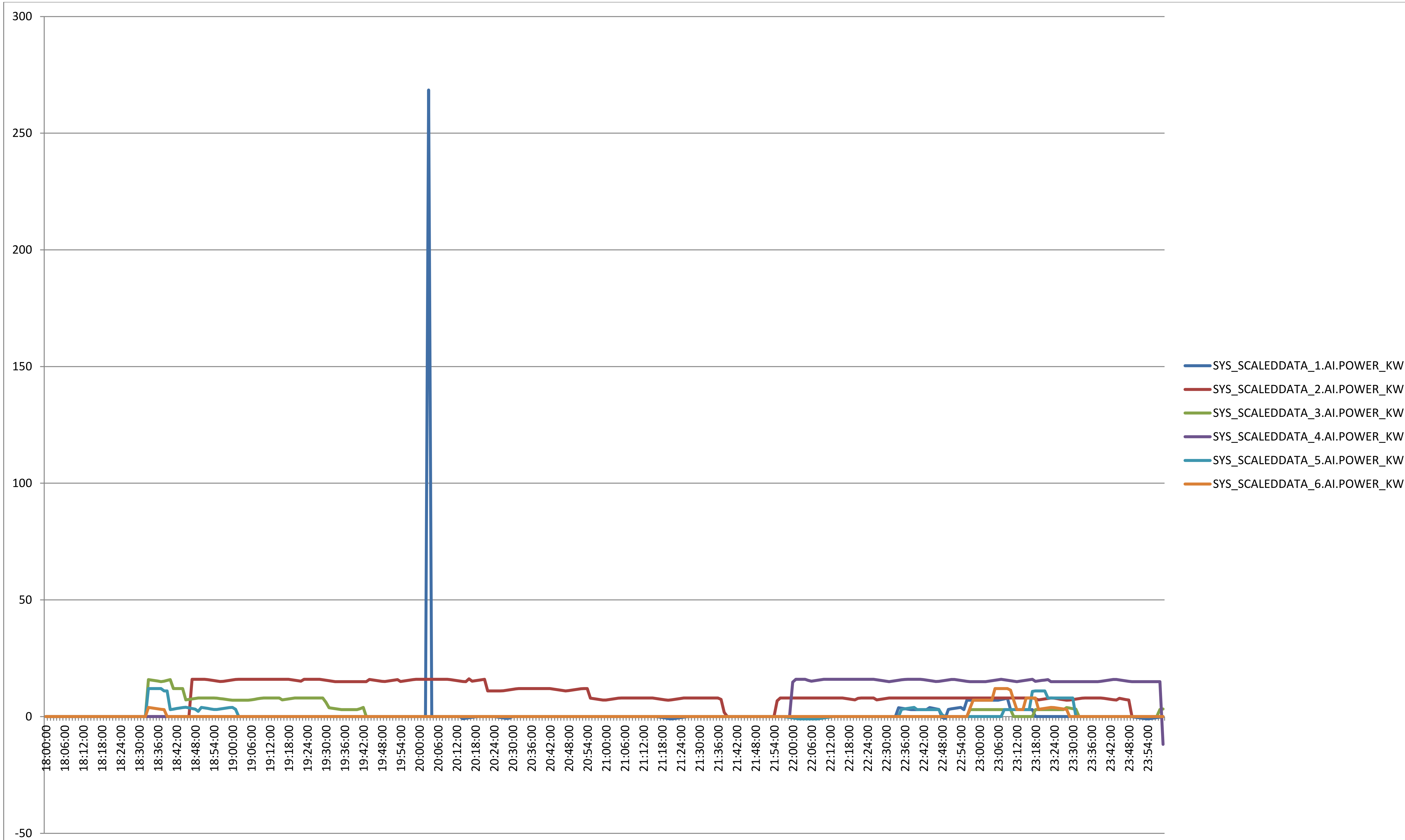
1) Data collection started around 18:30
2) There was a gap in the data collection between 21:39 and 21:54
3) Before Midnight - the following spikes occurred close to each other (but not at the same time):
    a. Unit 1 – SOC 19:58
    b. Unit 5 – SOC 20:00
    c. Unit 6 – DC Volts 20:06
4) Another set of spikes:
    a. Unit 6 – SOC 21:27
    b. Unit 3 – DC Volts 21:29
5) After Midnight – the following spikes occurred:
    a. Unit 6 – DC Volts 00:55
    b. Unit 3 – SOC 00:57
    c. Unit 2 – kW 00:58
    d. Unit 5 – DC Volts 00:58 (same time as c.)
6) Based on the High speed data collected, Unit 3 failed at 03:24:22

Before Midnight

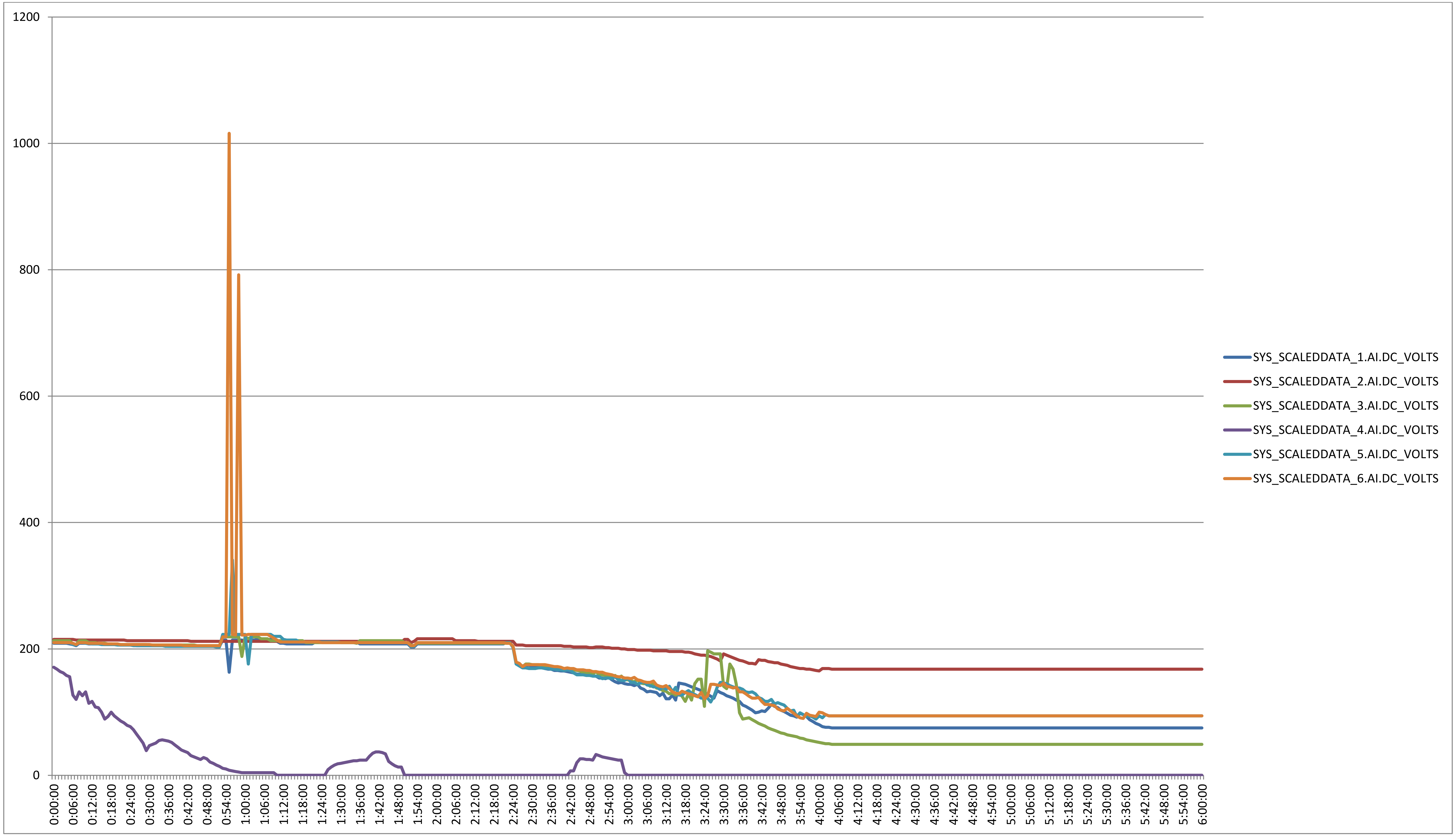


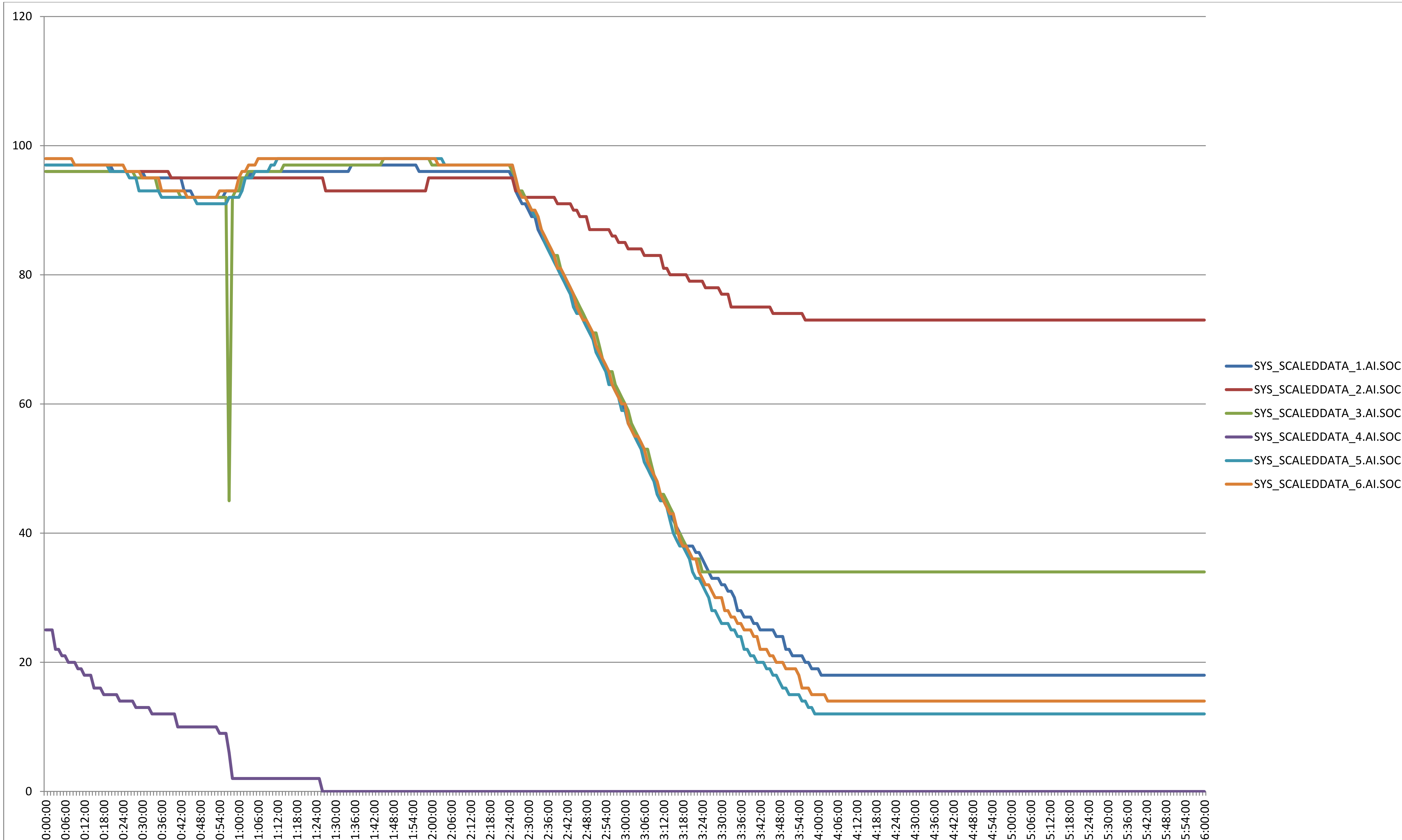


120
100
80
60
40
20
0
SYS_SCALEDDATA_1.AI.SOC
SYS_SCALEDDATA_2.AI.SOC
SYS_SCALEDDATA_3.AI.SOC
SYS_SCALEDDATA_4.AI.SOC
SYS_SCALEDDATA_5.AI.SOC
SYS_SCALEDDATA_6.AI.SOC
18:00:00
18:05:00
18:10:00
18:15:00
18:20:00
18:25:00
18:30:00
18:35:00
18:40:00
18:45:00
18:50:00
18:55:00
19:00:00
19:05:00
19:10:00
19:15:00
19:20:00
19:25:00
19:30:00
19:35:00
19:40:00
19:45:00
19:50:00
19:55:00
20:00:00
20:05:00
20:10:00
20:15:00
20:20:00
20:25:00
20:30:00
20:35:00
20:40:00
20:45:00
20:50:00
20:55:00
21:00:00
21:05:00
21:10:00
21:15:00
21:20:00
21:25:00
21:30:00
21:35:00
21:40:00
21:45:00
21:50:00
21:55:00
22:00:00
22:05:00
22:10:00
22:15:00
22:20:00
22:25:00
22:30:00
22:35:00
22:40:00
22:45:00
22:50:00
22:55:00
23:00:00
23:05:00
23:10:00
23:15:00
23:20:00
23:25:00
23:30:00
23:35:00
23:40:00
23:45:00
23:50:00
23:55:00

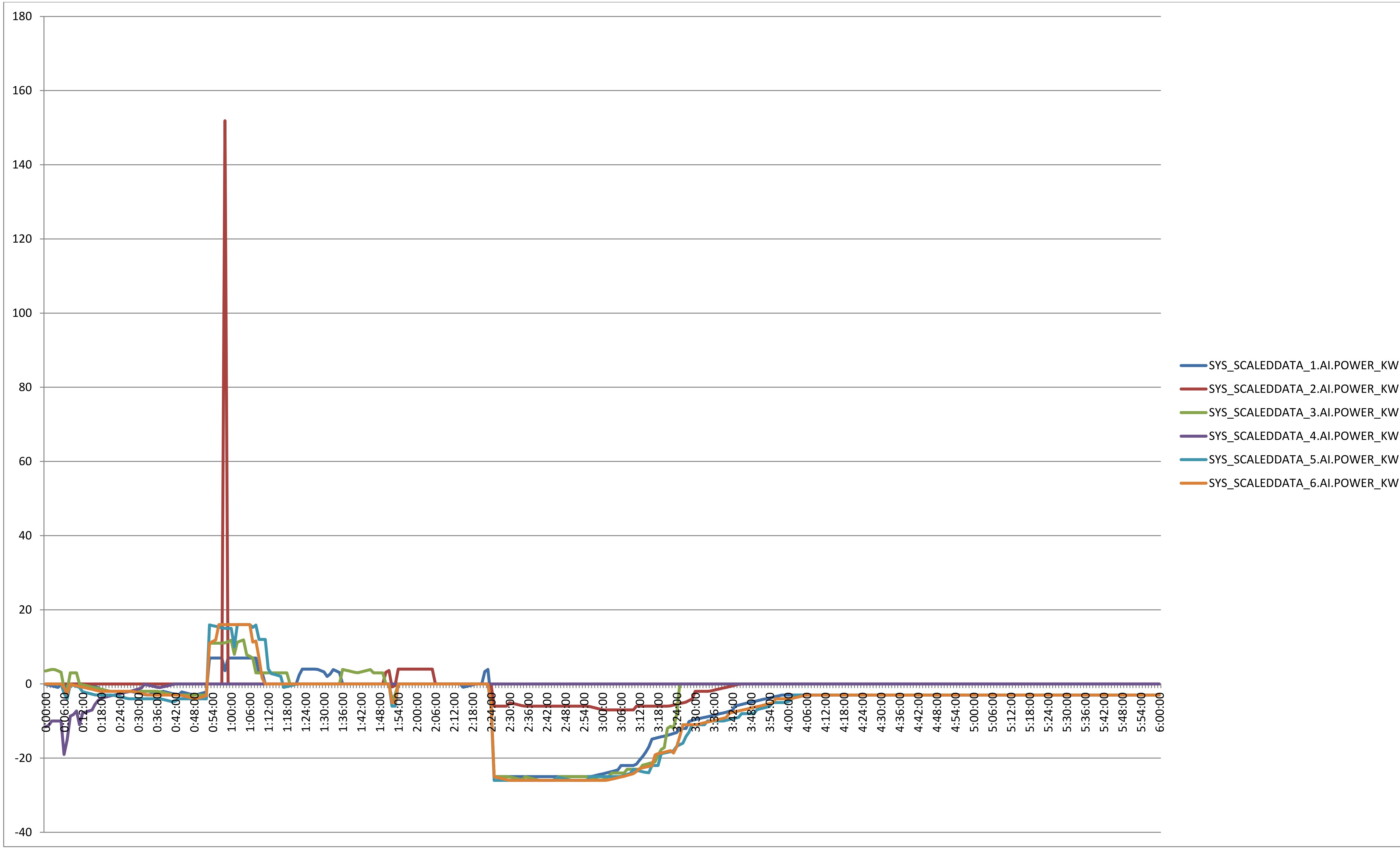

300
250
200
150
100
50
0
-50
18:00:00
18:06:00
18:12:00
18:18:00
18:24:00
18:30:00
18:36:00
18:42:00
18:48:00
18:54:00
19:00:00
19:06:00
19:12:00
19:18:00
19:24:00
19:30:00
19:36:00
19:42:00
19:48:00
19:54:00
20:00:00
20:06:00
20:12:00
20:18:00
20:24:00
20:30:00
20:36:00
20:42:00
20:48:00
20:54:00
21:00:00
21:06:00
21:12:00
21:18:00
21:24:00
21:30:00
21:36:00
21:42:00
21:48:00
21:54:00
22:00:00
22:06:00
22:12:00
22:18:00
22:24:00
22:30:00
22:36:00
22:42:00
22:48:00
22:54:00
23:00:00
23:06:00
23:12:00
23:18:00
23:24:00
23:30:00
23:36:00
23:42:00
23:48:00
23:54:00
SYS_SCALEDDATA_1.AI.POWER_KW
SYS_SCALEDDATA_2.AI.POWER_KW
SYS_SCALEDDATA_3.AI.POWER_KW
SYS_SCALEDDATA_4.AI.POWER_KW
SYS_SCALEDDATA_5.AI.POWER_KW
SYS_SCALEDDATA_6.AI.POWER_KW

After Midnight





120
100
80
60
40
20
0
0:00:00
0:06:00
0:12:00
0:18:00
0:24:00
0:30:00
0:36:00
0:42:00
0:48:00
0:54:00
1:00:00
1:06:00
1:12:00
1:18:00
1:24:00
1:30:00
1:36:00
1:42:00
1:48:00
1:54:00
2:00:00
2:06:00
2:12:00
2:18:00
2:24:00
2:30:00
2:36:00
2:42:00
2:48:00
2:54:00
3:00:00
3:06:00
3:12:00
3:18:00
3:24:00
3:30:00
3:36:00
3:42:00
3:48:00
3:54:00
4:00:00
4:06:00
4:12:00
4:18:00
4:24:00
4:30:00
4:36:00
4:42:00
4:48:00
4:54:00
5:00:00
5:06:00
5:12:00
5:18:00
5:24:00
5:30:00
5:36:00
5:42:00
5:48:00
5:54:00
6:00:00
SYS_SCALEDDATA_1.AI.SOC
SYS_SCALEDDATA_2.AI.SOC
SYS_SCALEDDATA_3.AI.SOC
SYS_SCALEDDATA_4.AI.SOC
SYS_SCALEDDATA_5.AI.SOC
SYS_SCALEDDATA_6.AI.SOC


180
160
140
120
100
80
60
40
20
0
-20
-40
0:00:00
0:06:00
0:12:00
0:18:00
0:24:00
0:30:00
0:36:00
0:42:00
0:48:00
0:54:00
1:00:00
1:06:00
1:12:00
1:18:00
1:24:00
1:30:00
1:36:00
1:42:00
1:48:00
1:54:00
2:00:00
2:06:00
2:12:00
2:18:00
2:24:00
2:30:00
2:36:00
2:42:00
2:48:00
2:54:00
3:00:00
3:06:00
3:12:00
3:18:00
3:24:00
3:30:00
3:36:00
3:42:00
3:48:00
3:54:00
4:00:00
4:06:00
4:12:00
4:18:00
4:24:00
4:30:00
4:36:00
4:42:00
4:48:00
4:54:00
5:00:00
5:06:00
5:12:00
5:18:00
5:24:00
5:30:00
5:36:00
5:42:00
5:48:00
5:54:00
6:00:00
SYS_SCALEDDATA_1.AI.POWER_KW
SYS_SCALEDDATA_2.AI.POWER_KW
SYS_SCALEDDATA_3.AI.POWER_KW
SYS_SCALEDDATA_4.AI.POWER_KW
SYS_SCALEDDATA_5.AI.POWER_KW
SYS_SCALEDDATA_6.AI.POWER_KW

NOTE: The graphical data from DNV shows that there are spikes in the data which occur in multiple units at various times. These spikes need to be evaluated why they are happening and what the ZBB controller calculates during this time. Even with the spikes, it is inconclusive to link the data to the failure of Unit 3.

THE FOLLOWING ARE PICTURES TAKEN BY SANDIA AND UCSD

3 - Unit 3 broken threaded rod still within system

4 - Unit 3 Electrolyte external spill

5 - Electrolyte residue on ground

6 - Unit 3 electrolyte residue on electrolyte reservoir

7 - Unit 3 closer look at residue of electrolyte reservoir

8 - Unit 3 broken threaded rod with residue electrolyte

9 - Electrolyte leak location on top left cells of Unit 3

10 - Back side of Unit 3 where electrolyte was spilled outside the cabinets

11 - Components after spill with damage

12 - Back side of Unit 3 top cells where leak occurred

13 - Electrolyte residue along on top part of container