CSI RD&D
Research Briefs

CALIFORNIA SOLAR INITIATIVE RESEARCH, DEVELOPMENT, DEMONSTRATION & DEPLOYMENT PROGRAM

PROGRAM OVERSIGHT

California Public Utilities Commission
505 Van Ness Ave
San Francisco, CA 94102

PROGRAM MANAGER

Itron, Inc.
330 Madson Place
Davis, CA 95618

January 2017

CSI RD&D WEBSITE

CalSolarResearch.ca.gov

Research Briefs

The following research briefs summarize the research effort, describe methods, findings, outcomes, and public benefits for all funded CSI RD&D projects.

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CSI RD&D PROGRAM

Research Investment

Grantees:
Lawrence Berkeley National Laboratory and the University of California, Berkeley

CSI RD&D Funding:
$10,000,000

Project Timeframe:
2009-2013

Solar Energy Research Center

The first grant initiated through the CSI RD&D Program was for the Solar Energy Research Center (SERC), formerly known as the Helios Project, at Lawrence Berkeley National Laboratory (LBNL) and the University of California, Berkeley. The $10 million grant, along with $30 million in State Lease Revenue Bonds and $14 million in external financing provided the capital for design and construction of the research facility. The primary goal of the SERC is to develop methods to "store" solar energy in the form of renewable transportation fuel. Several approaches under investigation include the generation of biofuels from biomass, the generation of biofuels from algae, and the direct conversion of water and carbon dioxide to fuels using solar energy.

Senate Bill 1 (SB1), signed into law on August 21, 2006, directed the California Public Utilities Commission (CPUC) to allocate up to $50 million to research, development, and demonstration as part of the California Solar Initiative. The CPUC, through their adopted Plan (D.07-09-042), allocated the 20% research component of the CSI RD&D program to the SERC project.

The groundbreaking for the SERC was held on October 19, 2012. The three-story facility is nearly 40,000 square feet in size and houses approximately 75 research staff. On May 26, 2015, the SERC opened with a ribbon-cutting ceremony and named the facility Chu Hall in recognition of Steven Chu, the United States Energy Secretary who spearheaded President Obama's Sunshot Initiative and a former Director of LBNL.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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GRID INTEGRATION PROJECTS

Grantee	Project Title	Solar Resource/Forecasting	Utility Tools/Models	Interconnection/Rule 21	Grid Impact Studies	PV + Storage	Concentrated PV	Solar Thermal +	Financial Analysis	Balance of System Cost	Innovative Business Models	DER Tools	DER Projects	Demonstration
Clean Power Research	Advanced Modeling and Verification for High Penetration PV	■	■											
University of California, San Diego	Improving Economics of Solar Power Through Resource Analysis, Forecasting and Dynamic System Modeling	■												
University of California, Irvine	Development and Analysis of a Progressively Smarter Distribution System				■		■							
Southern California Edison	Analysis of High-Penetration Levels of PV into the Distribution Grid in CA		■		■									
Sacramento Municipal Utility District	High Penetration PV Initiative		■											
Clean Power Research	Integrating PV into Utility Planning and Operation Tools	■	■											
General Electric	Quantifying Unintended Islanding Risks and Interconnection Requirements for High Penetration Photovoltaics		■	■										
Electric Power Research Institute	Screening Distribution Feeders: Alternatives to the 15% Rule			■										
DNV KEMA	Tools Development for Grid Integration of High PV Penetration		■											
University of California, San Diego	High-Fidelity Solar Forecasting Demonstration for Grid Integration	■			■	■								

Primary Target Area:

- Grid Integration
- Production Technologies
- Business Development and Deployment
- Distributed Energy Resources Integration

GRID INTEGRATION PROJECTS (CONTINUED)

Grantee	Project Title	Solar Resource/Forecasting	Utility Tools/Models	Interconnection/Rule 21	Grid Impact Studies	PV + Storage	Concentrated PV	Solar Thermal +	Financial Analysis	Balance of System Cost	Innovative Business Models	DER Tools	DER Projects	Demonstration
Electric Power Research Institute	Standard Communication Interface and Certification Test Program			■	■									
Energy and Environmental Economics	PV Integrated Storage - Demonstrating Mutually Beneficial Utility-Customer Business Partnerships				■	■			■					■
Electric Power Research Institute	Analysis to Inform California Grid Integration Rules for PV			■										
Southern California Edison	Advanced Distribution Analytic Services Enabling High Penetration Solar PV		■	■	■									
University of California, San Diego	Comprehensive grid integration of solar power for SDG&E	■				■								
University of California, San Diego	Mitigation of Fast Solar Ramps through Sky Imager Solar Forecasting and Energy Storage Control	■				■								

Primary Target Area: Grid Integration | Production Technologies | Business Development and Deployment | Distributed Energy Resources Integration

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CSI RD&D PROGRAM

Grid Integration

Grantee:
Clean Power Research

Phase I Partners:
California Independent System Operator, Sacramento Municipal Utility District, National Renewable Energy Laboratory, State University of New York, New York State Energy Research and Development Authority, Solar Electric Power Association, Long Island Power Authority, Salt River Project, New York Power Authority

Phase II Partners:
California Independent System Operator, University of California San Diego, Electric Power Research Institute, State University of New York, and Solar Electric Power Association

CSI RD&D Funding:
Phase I $976,402
Phase II $852,620

Match Funding:
Phase I $295,370
Phase II $901,916

Project Timeframe:
Phase I 2010-2012
Phase II 2012-2014

RD&D Project Portal:
Phase I
calsolarresearch.ca.gov/csi/61
Phase II
calsolarresearch.ca.gov/csi/89

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Advanced Modeling and Verification for High Penetration PV and Incorporation into Utility Tools

OVERVIEW AND OBJECTIVES

Utility grid operations and planning models and tools lack the ability to account for the variability of distributed PV generation resources and technologies. Insolation data used in utility models is low resolution, providing only hourly resource values. Rapidly changing weather conditions over small areas can have significant impacts on aggregate PV system output, contributing to grid operators' concerns about integrating PV into the utility grid. To address these barriers, Clean Power Research (CPR) was funded to conducted research in two phases.

Phase I: The goal was to enhance and validate the spatial and temporal resolution of solar radiation data sets for select California locations and integrate these capabilities into distribution system engineering and analysis tools. Additionally, a tool was to be created to calculate the economic value of a specific PV fleet configuration.

Phase II: Building on the Phase I work, the goal was to extend the enhanced solar resolution database and create high resolution (one-kilometer, one-minute resolution) database and benchmark data accuracy. Additionally, the PV fleet simulation methods developed in Phase I would be validated using measured ground data from PV system fleets and these methodologies would be integrated into utility software tools for distribution planning and balancing area operations.

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PHASE I: METHODOLOGY

The CPR team obtained high resolution satellite imagery and set up a server to host the data. Irradiance measurement stations were installed in a PV system layout to model PV systems and account for variability. PV simulation software services were developed and integrated into existing distribution software and a web tool was built to analyze the economic value of the various PV fleet configurations based on a number of key factors.

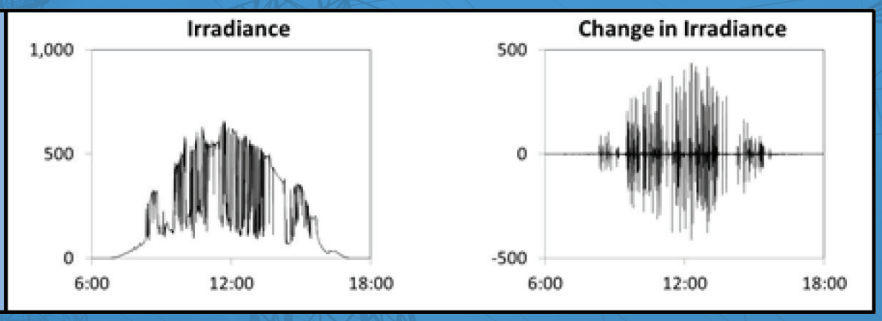
PHASE I: RESULTS AND OUTCOMES

CPR developed SolarAnywhere Enhanced Resolution (one-kilometer, 30-minute) database *ca.solaranywhere.com* for use in the forecasting and planning tools used by the California Independent System Operator (CAISO), utilities, and the research community. This data is available at no cost as part of this grant. The research team also developed an algorithm for PV output variability for various geographical locations and included it in PV modeling tools. Additionally, a tool was developed for calculating the economic value of distributed PV fleets and includes energy value, generation capacity value, environmental value, fuel price hedge value, transmission and distribution capacity value, and loss savings.

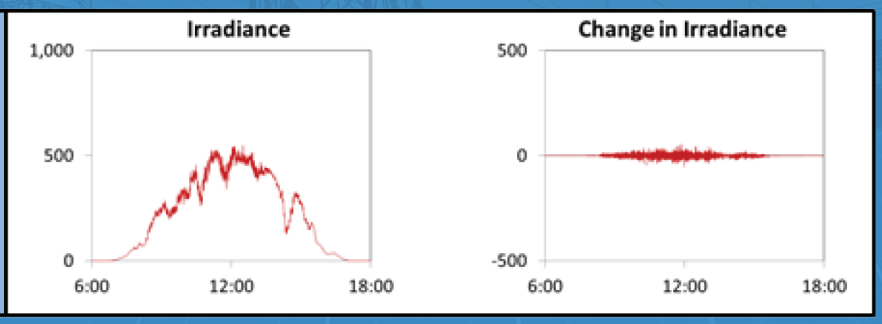
Evaluate the PV fleet, not individual PV systems: 4 km x 4 km grid in Napa, CA

Measured 10-second irradiance data from 4 km x 4 km grid in Napa on a highly variable weather day

1 LOCATION MEASURED

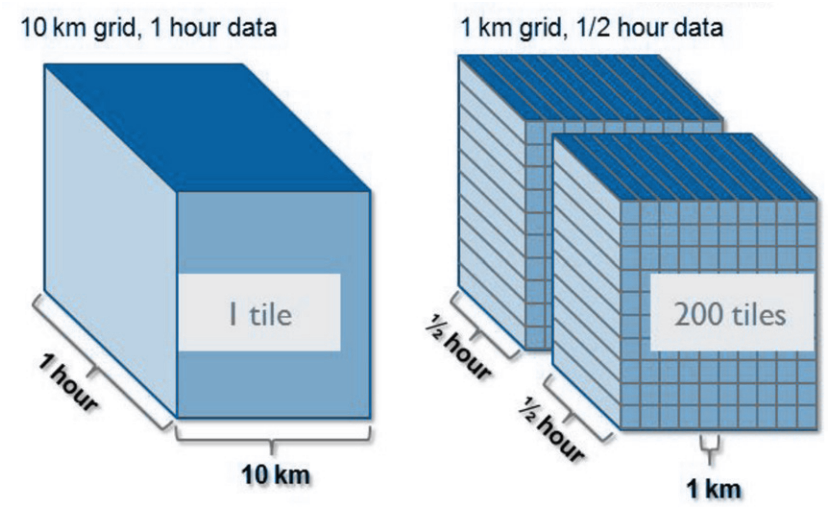


25 LOCATIONS MEASURED



PHASE II: METHODOLOGY

The SolarAnywhere Enhanced Resolution (one-kilometer, 30-minute) data was processed using the Cloud Motion Vector (CMV) approach to produce SolarAnywhere High Resolution (one-kilometer, one-minute) data. The CMV approach determines cloud movement by comparing consecutive enhanced resolution images. For validation of the PV fleet simulation, CAISO provided production data for 46 metered PV plants, and the Sacramento Municipal Utility District (SMUD) provided measured hourly production data and specifications for 2,206 distributed PV systems in their service territory. To integrate PV fleet simulation into software tools and to support CAISO's understanding of behind-the-meter PV fleet performance and production, CPR designed, tested, and implemented a PV fleet forecasting system. The fleet simulation incorporates high resolution solar resource data, PV system specifications, and a simulation model to convert this information into production.



Enhanced spatial and temporal resolution data set results in 200-fold increase in data.

PHASE II: RESULTS AND OUTCOMES

The CPR team developed, validated, and integrated PV fleet simulation tools that enable utilities and CAISO to cost-effectively integrate distributed PV resources into their planning, scheduling, and operating strategies. The research resulted in SolarAnywhere High Resolution (one-kilometer, one-minute) database. This database was used to validate previously developed PV fleet simulation methods using ground data from PV fleets connected to California's electricity grid. The validated fleet methodologies along with the high resolution solar resource database were integrated into utility software tools used for distribution planning and CAISO balancing area operations. CPR generated high resolution forecasts every 30 minutes for the entire state.

PUBLIC BENEFITS

SolarAnywhere High Resolution (one-kilometer, one-minute) database is state-of-the-art and provides the highest known resolution of any satellite-based irradiance dataset in the world, freely available at www.SolarAnywhere.com. This database is being used in PV penetration studies, variability studies, solar forecasting for the CAISO, and by project developers to obtain lower financing rates due to lower project risks.

The validated PV fleet simulation models using real-world data provide grid operators with confidence in the models prior to their use.

Prior to this research, CAISO did not have visibility into the performance of behind-the-meter PV systems and was concerned with the effect of power production from customer-owned PV on the balancing area. CPR began providing behind-the-meter PV fleet forecasts every 30 minutes to CAISO, giving them visibility into behind-the-meter PV performance. This has the additional benefit of being a valuable case study for California's IOUs as they consider using the same approach for their needs.

The tools and data streams developed through these two research projects are made available to utilities, ISOs, and others to help cost-effectively and reliably integrate distributed PV into the grid, supporting the transformation of the electric power grid into a clean energy marketplace.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
University of California, San Diego

Phase I Partners:
EnerNex, California Independent System Operator, San Diego Gas & Electric, Clean Power Research

Phase II Partners:
Green Power Labs, Clean Power Research, Sacramento Municipal Utility District, National Renewable Energy Lab, Power Analytics

CSI RD&D Funding:
Phase I $548,094
Phase II $1,261,828

Match Funding:
Phase I $146,254
Phase II $1,353,707

Project Timeframe:
Phase I 2011-2013
Phase II 2012-2015

RD&D Project Portal:
Phase I
calsolarresearch.ca.gov/csi/65
Phase II
calsolarresearch.ca.gov/csi/87

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Improving the Economics and Integration of Solar Power through Resource Analysis, Forecasting, and Modeling

OVERVIEW AND OBJECTIVES

Integration of large amounts of photovoltaics (PV) into the electricity grid poses technical challenges due to the variable nature of the solar resource. Solar distributed generation (DG) is often behind the meter and invisible to grid operators. The ability to understand the actual variability of solar DG will allow grid operators to better accommodate this resource in terms of planning, scheduling, and dispatching of electricity. From a system operator standpoint, it is especially important to understand when aggregate power output is subject to large ramp rates (increased or decreased output).

Phase I: The overall goal of the project was to accelerate the placement of higher levels of PV into distribution circuits. The University of California, San Diego (UCSD) research team studied:

- The accuracy and performance of solar resource models.
- Aggregated PV variability and ramp rates.
- PV performance and soiling analysis.
- PV impacts on distribution feeders.

Phase II: The goals of this project were to:

- Reduce solar integration costs through more accurate solar forecasting.
- Demonstrate distributed generation solar forecasting in aggregation at the system level and the distribution level.
- Demonstrate forecast applications to net load forecasting, feeder control, and fast demand response. Specifically, the UCSD team demonstrated forecast performance during meteorological conditions with the greatest impact on San Diego Gas & Electric (SDG&E) operations, developed day-ahead solar forecast models for marine layer clouds, produced localized solar forecasting and distribution feeder models, and integrated solar forecasts with utility models for resource adequacy.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

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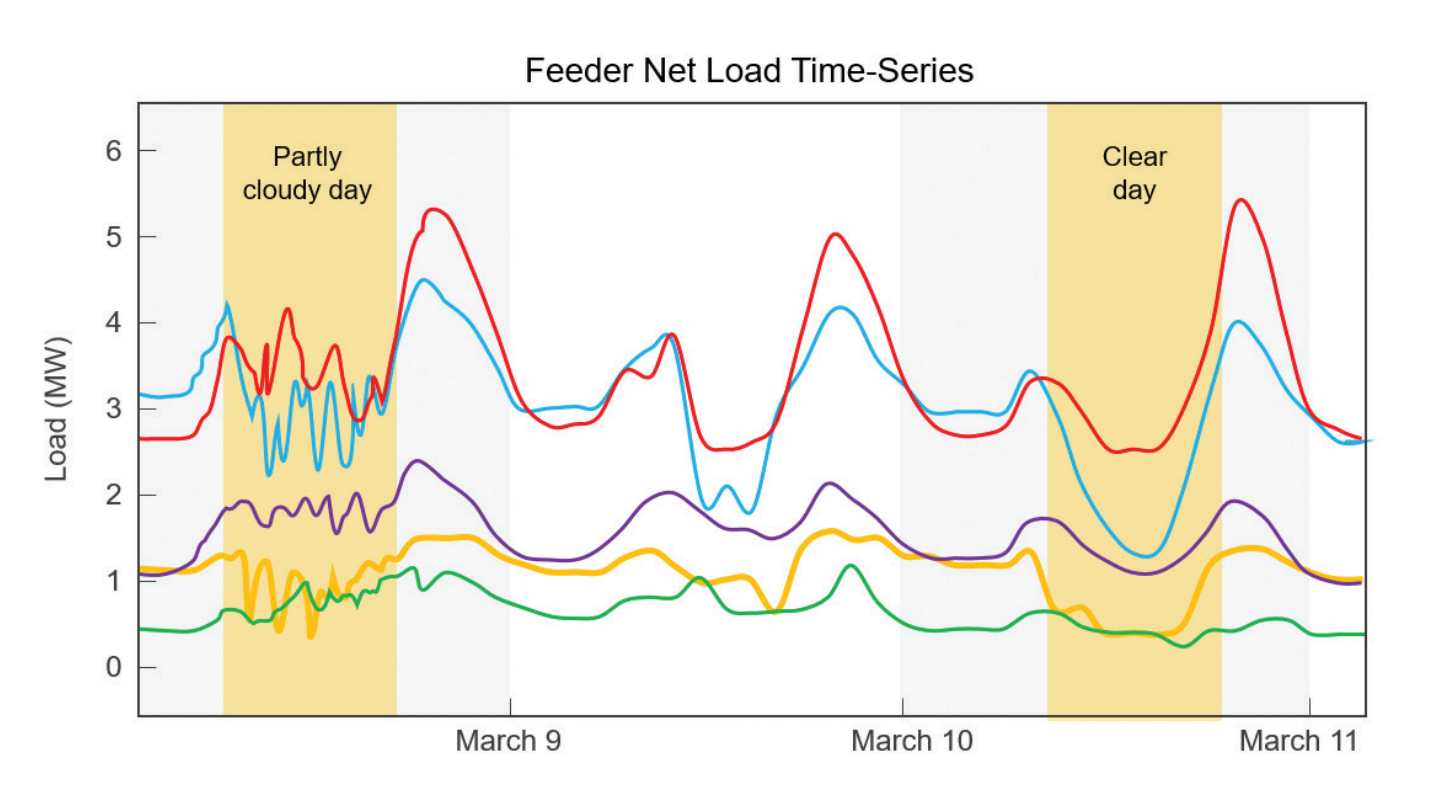
PHASE I: METHODOLOGY

The UCSD team validated SolarAnywhere, the high-resolution solar resource model, against ground measurements and developed additional modeling capabilities to account for the effects of topography shading and PV soiling on PV output and spatial solar resource data. A PV performance model was developed that can be applied to satellite solar resource data to simulate PV power output taking local weather conditions into account. Lastly, satellite forecast models were compared against numerical weather prediction to examine how to best integrate the different models into seamless solar forecast products.

PHASE I: RESULTS AND OUTCOMES

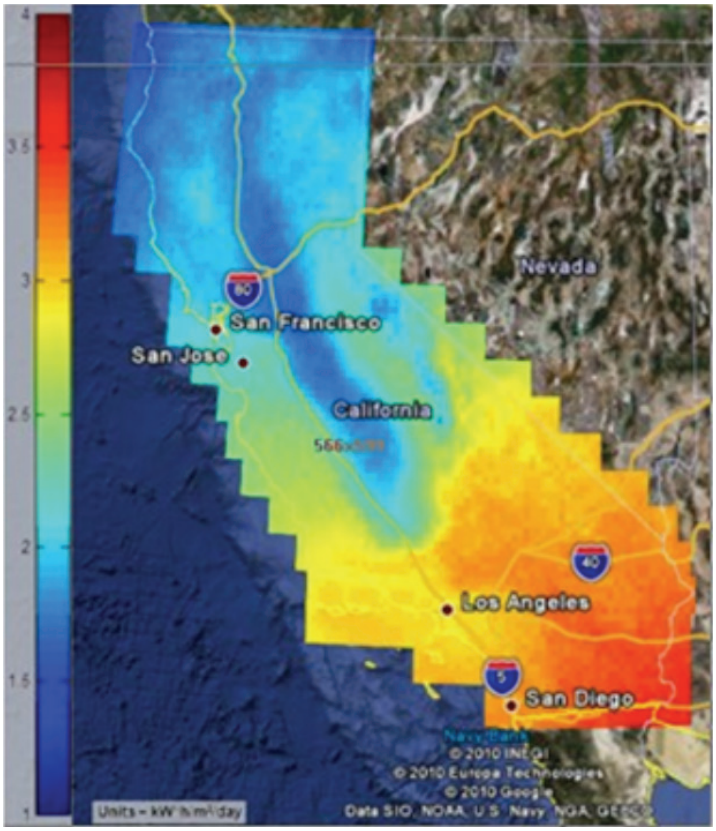
The SolarAnywhere model validation against ground measurements was found to be slightly biased high, but generally of high accuracy. The effects of topographic shading and PV soiling were found to be small. A high resolution PV output dataset for over 115 PV sites across the state was developed to facilitate integration studies. Ramping was found to be most significant during sunrise and sunset periods. Weather-induced ramps were small at the California Independent System Operator (CAISO) level but can be significant for smaller utilities. Generally, these findings show that for load balancing over large areas, the impact of distributed PV generation is smaller than previously thought and often highly predictable. For very short-term forecasting, cloud speed sensors and algorithms were developed to predict and mitigate short-term fluctuations in solar power output caused by weather variability.



Net load time-series of multiple residential feeders. Net load is higher and more variable on cloudy days than on clear days, illustrating the daytime impact of solar PV.

PHASE II: METHODOLOGY

The project team developed forecasting tools through a combination of very high resolution numerical weather prediction, statistical modeling, and dense measurement infrastructure installed by SDG&E. Distribution feeder power quality analysis was conducted with total sky imager forecasts feeding into power flow modeling to identify voltage control needs. The modeling was conducted on five representative feeders with variations in PV penetration, location, meteorology, and voltage regulation equipment. For these same feeders, net load forecast models were also developed and validated.



The forecasting tools developed in this phase support more accurate solar resource assessments.

PHASE II: RESULTS AND OUTCOMES

The model outputs were integrated into utility forecasting tools and transmission and distribution models based upon the needs of the CAISO and the utilities in the state. SDG&E was supplied with forecasting data for distributed PV facilities in their territory. Net load forecasting was provided to CAISO on the meter- and feeder-levels. High penetration PV impacts on distribution circuit loads were quantified and used to produce power demand forecasts to CAISO. Solar forecasting and power flow models were validated against PV system performance. Finally, data management and visualization software was used to provide more detailed access of microgrid data to CAISO.

PUBLIC BENEFITS

Variability and forecasting models and datasets are available to other researchers for validation. The PV performance model is posted at http://www.calsolarresearch.ca.gov/ and the horizon database and PV output data are available upon request from jkleissl@ucsd.edu.

SDG&E is implementing hours-ahead and day-ahead solar forecast strategies which has been considered the largest source of uncertainty to utility resource adequacy operations.

Solar power integration provides better foresight for power system operation, better understanding of distribution system operation and maintenance costs and mitigation options, and smarter investment in monitoring infrastructure.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
University of California, Irvine Advance Power and Energy Program

Partners:
Pacific Gas & Electric

CSI RD&D Funding:
$297,564

Match Funding:
$100,845

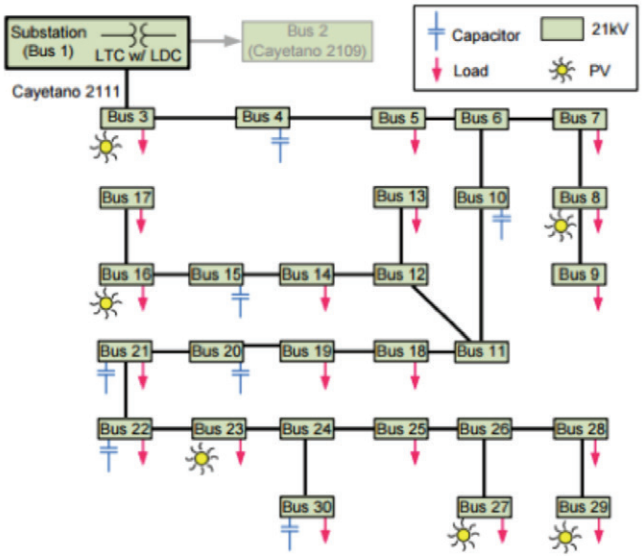
Project Timeframe:
2011-2013

RD&D Project Portal:
calsolarresearch.ca.gov/csi/63

Development and Analysis of a Progressively Smarter Distribution System

OVERVIEW AND OBJECTIVES

The limitations of high-penetration photovoltaics (PV) on the utility distribution system are not well known, and utility personnel have concerns that the current distribution system cannot support high levels of solar distributed generation penetration. To address these barriers, the University of California Irvine (UCI) developed modeling tools to simulate distribution circuits, collaborated with Pacific Gas & Electric (PG&E) to acquire, analyze, and evaluate circuit performance data from circuits with high penetration PV, and evaluated the control and integration of existing major components on both the primary and secondary distribution system. The research sought to identify PV integration limitations of standard operating procedures and develop a progressively smarter distribution system to mitigate distribution circuit limitations that might otherwise delay the goals of the California Solar Initiative (CSI) program.



Commercial Circuit Balanced Three Phase Model

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METHODOLOGY

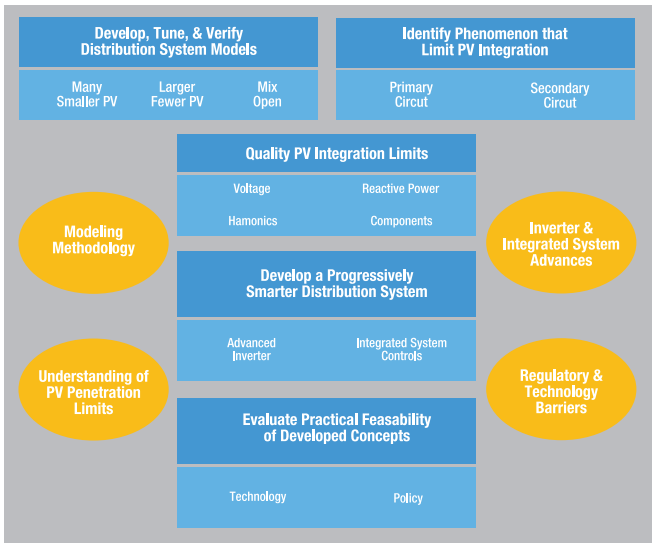
The UCI team developed, evaluated, and verified a model for comparison to grid monitored data. Two specific distribution system configuration scenarios were evaluated— the first scenario included many small PV systems, and the second scenario consisted of fewer but larger PV systems. The team next determined the limits for PV penetration within existing circuit architectures with current technology. The risks and benefits of advanced inverter control were assessed along with the development and evaluation of integrated control strategies to support the increased penetration of PV in the distribution system. Lastly, the research team evaluated the practical feasibility of the relevant standards, hardware, and communications needed to enable progressively smarter distribution systems.

RESULTS AND OUTCOMES

This research provided the needed information and understanding regarding:

- Modeling methodology to evaluate PV installation on distribution circuits.
- PV penetration limitations and tradeoffs.
- Control strategies and communication advances that may be required to achieve different levels of PV penetration.
- Regulatory and technology barriers.

The project evaluated the control and integration of existing major components on both the primary and secondary distribution system. Two specific distribution system configuration scenarios were evaluated, one with many smaller PV installations and a second with fewer larger PV installations. The project identified PV integration limitations of standard operating procedure and developed a progressively smarter distribution system to mitigate distribution circuit limitations that might delay the CSI goal of installing 3,000 MW of new solar generation by 2017.



Project approach and projected major insights

PUBLIC BENEFITS

Contributes to the understanding of PV integration limits and the development of a progressively smarter distribution system required to enable flexible integration of PV installations in California.

Provides insights into modeling methodologies, and limits to PV penetration, as well as progressive actions that can be taken to enable wide-scale deployment of solar distributed generation technologies.

Improves the economics of solar by reducing the need for costly ad hoc load flow studies and custom engineering analysis to determine whether the PV installation creates unacceptable circuit conditions.

Increases the value of PV installations by enabling ancillary services such as active power filtering and controlled reactive power support.

Demonstrates how advanced inverters and communication along monitored points on distribution circuits can be used to increase PV interconnection limits progressively.

Focuses on a staged implementation with progressive benefits to minimize the early cost while maximizing future circuit performance.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
National Renewable Energy Laboratory

Partners:
Southern California Edison, Clean Power Research, Electrical Distribution Design, Satcon, Quanta Technology

CSI RD&D Funding:
$991,100

Match Funding:
$1,538,727

Project Timeframe:
2010-2013

RD&D Project Portal:
calsolarresearch.ca.gov/csi/67

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Analysis of High-Penetration Photovoltaics into California's Distribution Grid

OVERVIEW AND OBJECTIVES

Distribution utilities have limited experience with high-penetration photovoltaic (PV) integration particularly in terms of methods to mitigate impacts. Sustaining high growth rates in the PV industry requires being able to successfully integrate PV into the electric power system while maintaining reliability. This National Renewable Energy Laboratory (NREL) research project addresses the integration of high levels of PV into the electrical distribution system by fully examining the issues, developing solutions, and transitioning those solutions to the field for large-scale deployment. This project was designed specifically to benefit from the experience that Southern California Edison (SCE) and the project team gained during the installation of 500 megawatts (MW) of utility-scale PV systems (with 1–5 MW typical ratings) from 2010 to 2015 within the SCE service territory. At that time, this installation represented the highest level of distributed PV in any utility service territory in the United States and included several distribution circuits with high penetrations of PV.

PV system on Fontana warehouse

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

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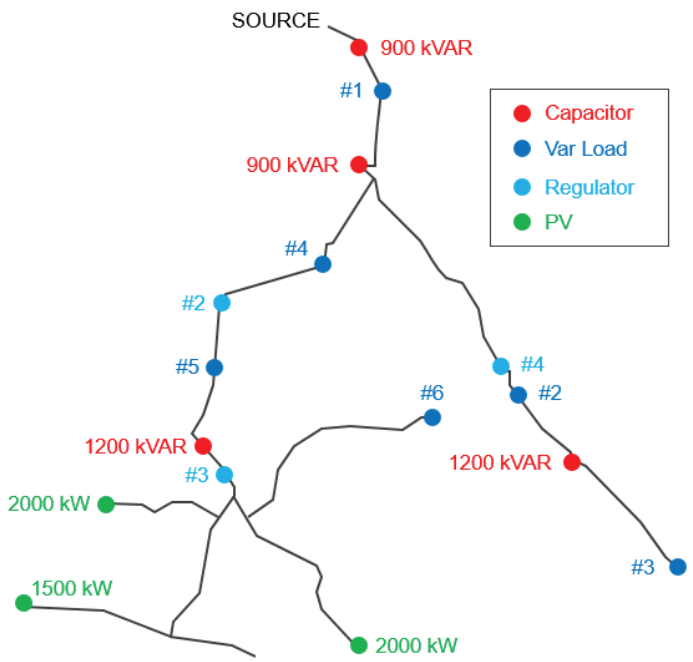
METHODOLOGY

To understand the impact of these new PV installations on the distribution grid, the project team conducted modeling and simulation, laboratory testing, and field demonstrations of the effect of high penetrations of PV on electrical distribution systems. The project team first defined a number of factors and impacts related to introducing high-penetration PV systems into the system and defined hardware and software solutions. NREL conducted laboratory testing on advanced inverters and control systems. These advanced systems were installed on projects in the SCE service territory to help eliminate issues that arise due to high penetration levels of PV, such as voltage regulation or unintentional islanding. The NREL testing consisted of developing the functional requirements and then implementing them in hardware and testing them in the field.



Reduced version of the test feeder used for simulated time-series studies

RESULTS AND OUTCOMES

The final results from this project are summarized into technical reports on best practices, designed to instruct utilities on how to integrate high levels of distributed PV systems into the electrical distribution grid. This will accelerate the placement of high levels of PV into existing distribution circuits and identify new circuit configurations that will help increase PV penetration levels. Various visualization tools were developed for measuring the extent and frequency of potential problems as well as comparing mitigation measures. The research team found that inverter control with the following capabilities can be implemented with little additional equipment cost: reactive power control, real power control, steady-state voltage control, and fast automatic voltage control (flicker reduction). The research and testing results collected during the entire project will be compiled into a *High Penetration PV Integration Handbook* for use by distribution utility engineers facing the challenges of high penetration PV interconnections.

PUBLIC BENEFITS

Improved PV impact modeling capabilities using experience and data gained with the demonstration project.

Modeled impacts of high-penetration PV integration on real distribution circuits and validated PV impacts using field data and mitigation strategies to reduce PV related impacts.

Demonstrated (via field deployment) the ability of PV inverters to implement advanced functionality to mitigate the impacts of high-penetration PV integration.

Advanced PV inverter control requiring minimal equipment upgrade costs. Inverter control was tested at the 500 kW level to provide verified mitigation of PV impacts.

New knowledge and experience for high- penetration PV integration on the SCE system. These findings are shared and disseminated to the wider distribution engineering community to accelerate the rate of PV interconnection in a safe, reliable and cost-effective manner.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
Sacramento Municipal Utility District

Partners:
Hawaiian Electric Company, BEW Engineering, National Renewable Energy Laboratory, New Energy Options, Areva, Irradiance, Solar Consulting Services, Augustyn & Company, SynerGEE

CSI RD&D Funding:
$2,000,089

Match Funding:
$1,940,793

Project Timeframe:
2010-2013

RD&D Project Portal:
calsolarresearch.ca.gov/csi/66

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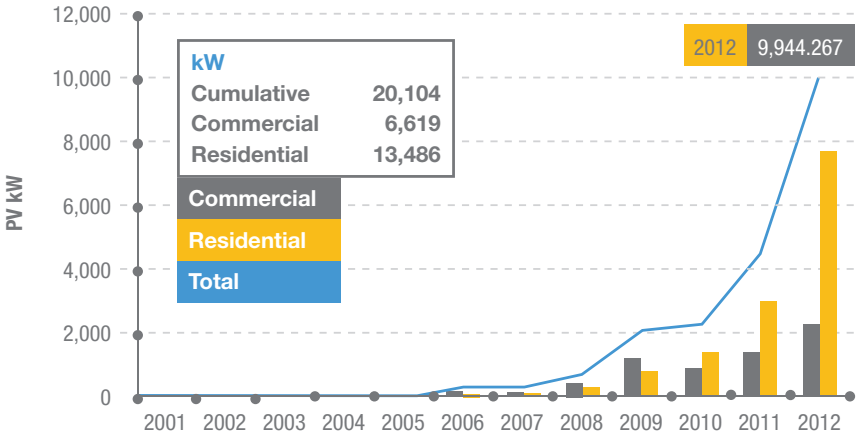
High Penetration Photovoltaic Initiative

OVERVIEW AND OBJECTIVES

Utilities facing exponential growth in distributed solar lack the capabilities, tools and data to effectively plan and account for photovoltaic (PV) impacts on the electricity grid. The level of PV penetration often exceeds the 15% integration threshold and standards used in traditional utility practices for planning & operations. To address these barriers, the Sacramento Municipal Utility District (SMUD) in partnership with the Hawaiian Electric Company (HECO) conducted research to inform and pilot the development of visual tracking tools for understanding and communicating the bi-directional flow management of PV throughout the utility grid. A key research focus for this project was the development of a software visualization tool to identify high value locations for distributed PV in the distribution system, and to identify problem areas to enable high penetration PV. A key project objective included collaboration with other utilities and the transfer of lessons learned from this research.



Distributed Generation Growth in Hawaii

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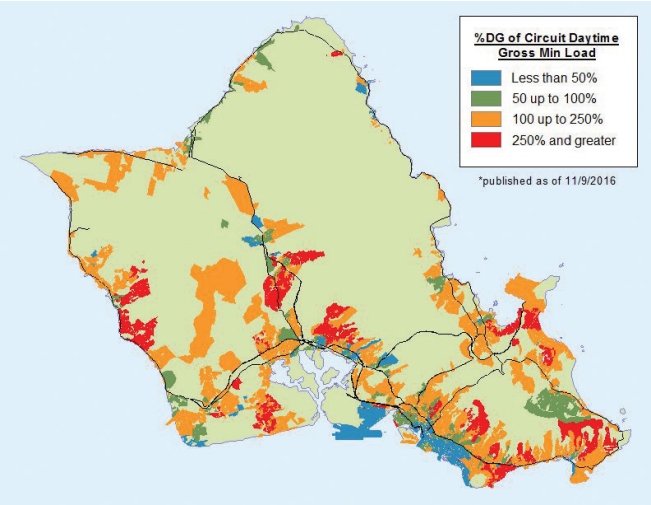
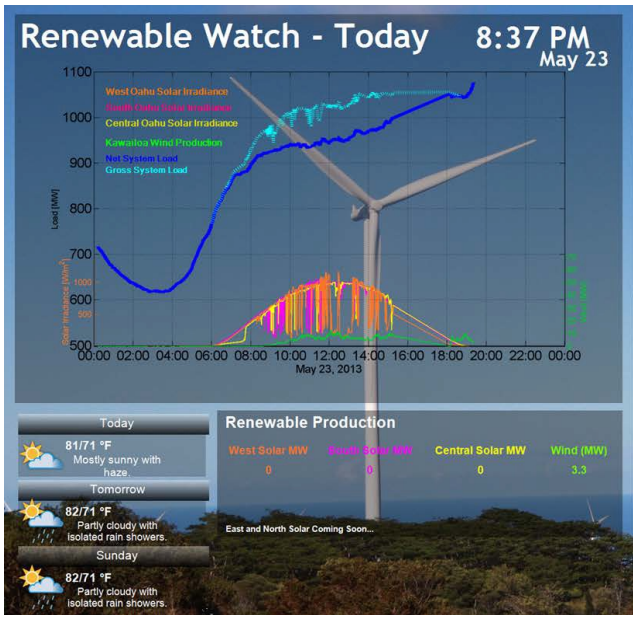
METHODOLOGY

The SMUD and HECO team conducted baseline feeder and system modeling as well as field monitoring and analysis on identified case studies that included sites and feeders within the SMUD and HECO utility service territories.

A software visualization tool was developed to enable identification of high value locations for distributed PV on the distribution system and to identify areas of constraint for high PV penetrations. The research team deployed an irradiance monitoring sensor network and coordinated advance communication for controls (i.e., dedicated cellular, advanced metering infrastructure (AMI) network, supervisory control and data acquisition (SCADA) system-enabled condition monitoring, and distribution remote terminal units (RTUs). Inverter monitoring via AMI communication from smart meter to inverter was also demonstrated. The tools were tested at residential, commercial and utility-scale deployments in California and Hawaii.



Oahu Locational Value Map showing installed PV compared to daytime minimum load



Renewable Watch: Seeing the Value of Renewables in Real-Time

RESULTS AND OUTCOMES

The outcome of this research was a software visualization tool which enables identification of high value locations for distributed PV on the distribution system and to identify problem areas requiring reinforcement or modification to enable high PV penetrations. Smart siting of renewable distributed generation involves fully understanding the solar resource, its potential deployment, and interaction with the existing distribution infrastructure. Case studies include residential, commercial, and undeveloped lots overlaid throughout the electrical system in order to assess interconnection benefits (cost and locational value) to the system. An additional outcome was a renewable generation operational tool that allows utilities to see how the renewable generation is functioning on their systems. This tool enables full use of distributed PV in displacing the need for distribution upgrades and natural gas peaking plants and allows validation of forecasting software, providing three hour-ahead and day-ahead PV output forecasts.

PUBLIC BENEFITS

- Provides advanced knowledge on addressing high penetration PV by two small yet progressive utilities that are currently seeing significant growth of distributed PV in their service territories.
- Makes available the software visualization tool and methodology developed by this project to other utilities coping with high penetration PV. The framework to optimize the location of PV systems within their service territories is a valuable outcome of this research.
- Jumpstarted lasting initiatives that are being adopted into SMUD and HECO processes and regulatory recommendations (interconnection standards, Reliability Standards Working Group).
- Resulted in numerous technical presentations and papers throughout the research project period to inform market product development and industry standards development.

GO solar CALIFORNIA

CSI RD&D PROGRAM

Grid Integration

Grantee:
General Electric International-Energy Consulting

Partners:
Pacific Gas & Electric

CSI RD&D Funding:
$629,102

Match Funding:
$1,393,646

Project Timeframe:
2012-2015

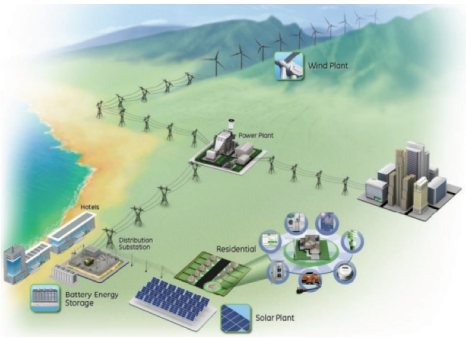
RD&D Project Portal:
calsolarresearch.ca.gov/csi/86

Itron | CSI RD&D PROGRAM MANAGER

Quantifying Unintended Islanding Risks and Interconnection Requirements for High Penetration Photovoltaics

OVERVIEW AND OBJECTIVES

Pacific Gas and Electric (PG&E) leads the nation in quantity and capacity of distributed generation interconnections and receives at least 2,000 interconnection applications per month. All utilities review these interconnection requirements to ensure that proper grid operations are maintained. One area of concern to utilities is islanding, a condition where distributed generation is on and connected to the load, while electrical grid power from the utility is no longer present, such as in a blackout. This condition is a safety risk to the public and utility crews. General Electric (GE), in collaboration with PG&E, conducted research to quantify the risks of unintended islanding in distribution circuits with high penetration of customer-sited distributed PV generation. The GE and PG&E team used full-scale laboratory testing to determine the risks to both utility and customer equipment that may result from an unintended islanding situation. The main goal of the project was to better understand the behavior of PV inverters and connected loads during an islanding event. Additionally, the team reviewed PG&E's islanding-specific interconnection requirements and provided specific recommendations on potential changes based on the findings from this project. The results of this research informed PG&E's interconnection requirements and have been valuable to other investor-and-customer-owned utilities. This research has also been useful to the CPUC in making decisions regarding interconnection requirements for anti-islanding operations of PV inverters (Rule 21).



This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

METHODOLOGY

The GE team quantified field conditions including spatial correlations and temporal matching of load types and PV. An experiment was designed and conducted to quantify the probability of islanding if a feeder or portion of a feeder is tripped. Comprehensive full-scale laboratory testing was used to determine how long an island will persist in an energized state and the risks to utility and customer equipment that may result from an unintended islanding situation. The team reviewed and suggested changes to PG&E's islanding interconnection requirements. The GE team worked with both PG&E internal technical staff and other interested stakeholders to disseminate the research findings.

10 MW-scale electronic load at PG&E Applied Technology Services Center in San Ramon, CA.

Residential PV inverters installed at PG&E Applied Technology Services Center in San Ramon, CA.

RESULTS AND OUTCOMES

The recommendations to PG&E on changes to their interconnection requirements for high penetration customer-sited PV were the most significant outcome of this research. All of the recommendations from this research were shared with the utility industry, but most importantly have been implemented by PG&E.

This research project also resulted in numerous technical achievements that include:

- Building the most sophisticated MW-scale load model in the utility industry.
- Developing a highly-streamlined testing procedure that enabled capture of a large number of islanding experiments.
- Capturing and publishing an exhaustive library of islanding experiments with consistently-recorded results in high resolution.
- Developing a set of computationally efficient analysis tools and placing them in public domain.

PUBLIC BENEFITS

Provides a research foundation and a comprehensive understanding of the conditions necessary for unintentional islanding to occur, along with the associated risk and magnitude of the problem.

Project results aid all three phases of the interconnection review process and enable more informed, circuit-specific interconnection review and study with minimal additions to the timeline.

Utilities in California can integrate higher levels of behind-the-meter PV, resulting in lower electricity demand across the system and lower energy prices for all rate-payers.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
Electric Power Research Institute

Phase I Partners:
National Renewable Energy Laboratory, Sandia National Laboratory, Southern California Edison, Pacific Gas and Electric, San Diego Gas and Electric

Phase II Partners:
National Renewable Energy Laboratory, Sandia National Laboratory

CSI RD&D Funding:
Phase I $1,669,222
Phase II $267,801

Match Funding:
Phase I $1,669,343
Phase II $514,398

Project Timeframe:
Phase I 2012-2015
Phase II 2014-2016

RD&D Project Portal:
Phase I
calsolarresearch.ca.gov/csi/88
Phase II
calsolarresearch.ca.gov/csi/110

Itron | CSI RD&D PROGRAM MANAGER

Screening Distribution Feeders: Analysis to Inform California Grid Integration Rules for Photovoltaics

OVERVIEW AND OBJECTIVES

Utility incentive programs have significantly increased the number of installed photovoltaic (PV) systems, requiring utilities to evaluate these interconnection requests to ensure proper grid operations. To assist utilities in quickly evaluating these systems, screens have been developed that help identify when issues may arise. The most common screening approach looks at the ratio of solar PV to peak load (15%); however, this method does not account for the locational impact of PV or the characteristics of specific feeders. Some of the factors known to be important to feeder hosting capacity include steady state voltage regulation limits, tap changer cycling issues, reverse power flow issues, unintentional islanding risks, fault current contribution issues, ground-fault relaying desensitization issues, neutral grounding compatibility, ground fault overvoltage issues, and harmonics.

Phase I: For the first phase of the project, the Electric Power Research Institute (EPRI) team developed an interconnection screening methodology that takes into account individual distribution feeder characteristics. Distribution modeling and simulation techniques were used to determine the level of PV that can be accommodated on individual feeders without impacting distribution system operations. This measure of hosting capacity is expected to become more critical as PV deployment increases. Major California utilities participated in the project and helped to detail which tools and penetration screens have most commonly been used and which procedures have been most effective for evaluating PV interconnection requests in California. The utilities also helped review distribution feeder classification methods to identify and map areas with additional capacity for hosting PV.

Phase II: For the second phase of the project, the EPRI team examined the impacts of using advanced inverters to perform different functions at different complexity levels, with a focus on expanding hosting capacity. This research addressed both simple and advanced methods for determining the most effective and beneficial smart inverter settings based upon feeder characteristics, PV penetration levels, and distribution. Locations where advanced inverter controls are most effective were also identified.

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PHASE I: METHODOLOGY

The EPRI team began by documenting current practices for screening PV interconnections both inside and outside of California and determining the range of feeder configurations for utilities in the state. A database of feeder characteristics was developed and sample feeders were selected from each utility and placed into two groups — one group of 16 feeders for detailed analysis and another group of six feeders for screening validation.

A detailed feeder model was developed for each of the selected feeders and EPRI's Distributed PV (DPV) Feeder Analysis Method was used to simulate a wide range of PV deployment scenarios and penetration levels on each feeder to determine hosting capacity. The hosting capacity analysis determined the amount of PV that can be accommodated on a distribution feeder without exceeding utility-guided thresholds. The hosting capacity for each feeder is unique for voltage and protection issues. A formal validation process was conducted to determine the accuracy of the screening methodology.

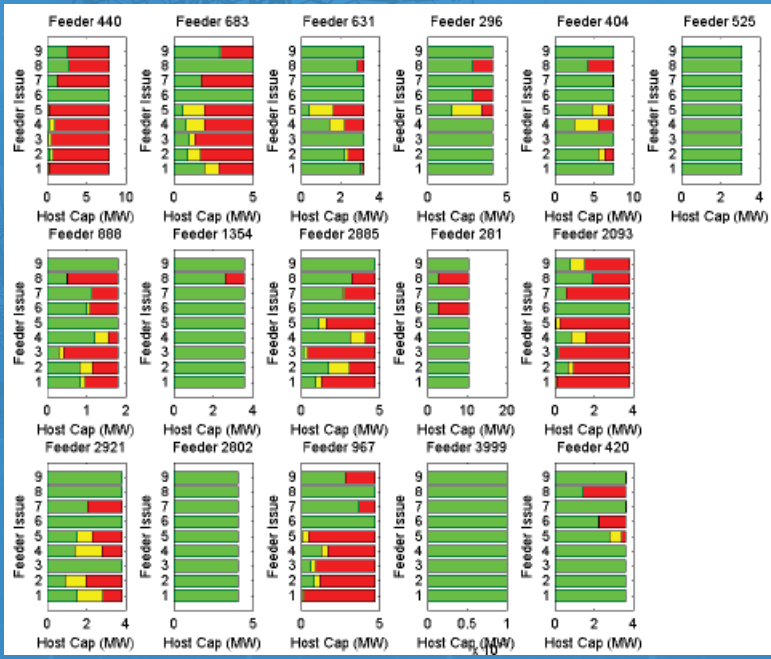
PHASE I: RESULTS AND OUTCOMES

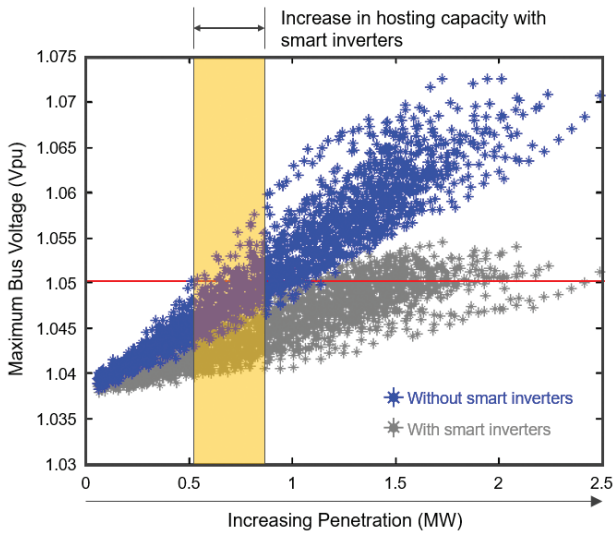
The detailed feeder impact analysis identified when potential issues from aggregate distributed generation were not properly identified and also when a feeder was capable of accommodating considerably higher levels of distributed generation. The *Alternatives to the 15% Rule* found in this project more properly address the impacts from distributed generation and were not solely dependent on load level. These improvements can be used to provide a more detailed screening mechanism while the utilities are developing the distribution resource plans.

The improvements suggested to Rule 21 included:

- Add an Initial Review screen that addresses if the feeder has line regulators.
- Modify the Initial Review to always address aggregate generation.
- Add Supplemental Review equations to be used as a guideline to address the voltage and protection impacts from aggregate generation.

Issue-Specific Residential and Commercial Rooftop PV Hosting Capacity





Smart inverters can improve the integration of solar PV. The above orange highlights the increase in hosting capacity with smart inverters.

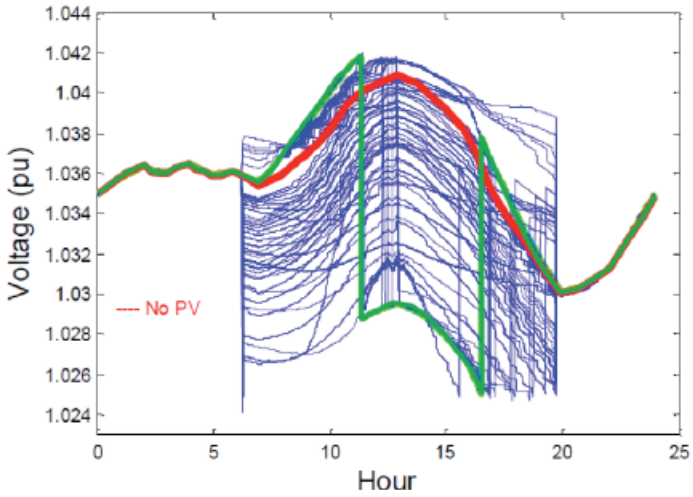
PHASE II: METHODOLOGY

Seven feeders were selected for their diversity in size, location, and overall representation of those present in California. For each feeder, thousands of simulations were run by selecting locations of PV systems and applying advanced inverter logic to typical generation and demand profiles. Each simulation investigated one of three main advanced inverter functions designed to reduce voltage issues: power factor control, volt-var control, and volt-watt control. For the first two methods, three complexity levels were developed:

- Level 1: incorporated basic inverter settings.
- Level 2: added feeder size and location-specific information along with other more advanced settings.
- Level 3 leveraged system-specific load flow information to perform customized calculations.

PHASE II: RESULTS AND OUTCOMES

Based on the findings of this work, the suggested advanced inverter settings and methods to determine settings can be used to improve the accommodation of higher levels of PV on the grid. All three levels for each function of smart inverters resulted in net improvements in hosting capacity for each feeder and had similar benefit to impact ratios, but did so at various rates and efficiencies. The voltage impact from PV can be mitigated using power factor, volt-var, or volt-watt control, while the bulk system impact can be improved with frequency/voltage ride-through. As demonstrated in this research, appropriate inverter control settings are feeder-dependent. Several methods for each control function have been created such that the utility can make use of the data and tools available to make the determination of control settings.



There are multiple inverter settings. The blue lines indicate voltage response using different volt-var settings.

PUBLIC BENEFITS

Provide utilities insight into how to proactively develop cost-effective mitigation strategies incorporating non-traditional technologies and better plan for the high PV penetration future.

Inform on-going grid modernization efforts and Distribution Resources Plan demonstrations, which target increased penetration of distributed energy resources and understanding the value of these resources.

Increase understanding of the issues associated with high solar PV penetration and improve quality of interconnection applications.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
DNV GL

Partners:
Sacramento Municipal Utility District, Hawaii Electric Companies (HECO, MECO, HELCO), Pacific Gas & Electric, and City of Roseville

CSI RD&D Funding:
$943,555

Match Funding:
$901,345

Project Timeframe:
2012-2015

RD&D Project Portal:
calsolarresearch.ca.gov/csi/85

Tools Development for Grid Integration of High Photovoltaic Penetration

OVERVIEW AND OBJECTIVES

This project addresses the lack of high quality, high resolution, field-measured photovoltaic (PV) data to inform adequate modeling of high-penetration PV on the utility system. This research targets the development of methodologies and software for evaluating high-penetration PV on the distribution grid and builds on work conducted under the prior CSI RD&D Solicitation #1 project with the Sacramento Municipal Utility District (SMUD) and their partners.

Transmission simulation tools define both congestion zones and optimal locations for new generation through map overlays of renewable resource potentials across the transmission grid. The objective of this DNV GL research was to integrate the distribution grid with a visual mapping tool (i.e. GIS-compatible platform specified by the utility) into an expanded locational value methodology. The approach assessed impacts across the system from a strategic development and grid enhancement perspective. California Rule 21 and Hawaii Rule 14H sets guidelines for analyzing PV installations. The methodology and process was used by utilities to facilitate distributed renewable resource expansion without negatively impacting system performance.

The second objective of this research was to develop a validation approach for evaluation of PV integration. Studies were carried out on potential impacts to individual feeders, substations, utility regions, and utility grids from high penetrations of PV. The participating utilities select different feeder configurations to demonstrate, evaluate, and validate high PV penetrations under steady-state, contingency, and dynamic scenarios. This objective was to document the ability of the software tools to study PV integration.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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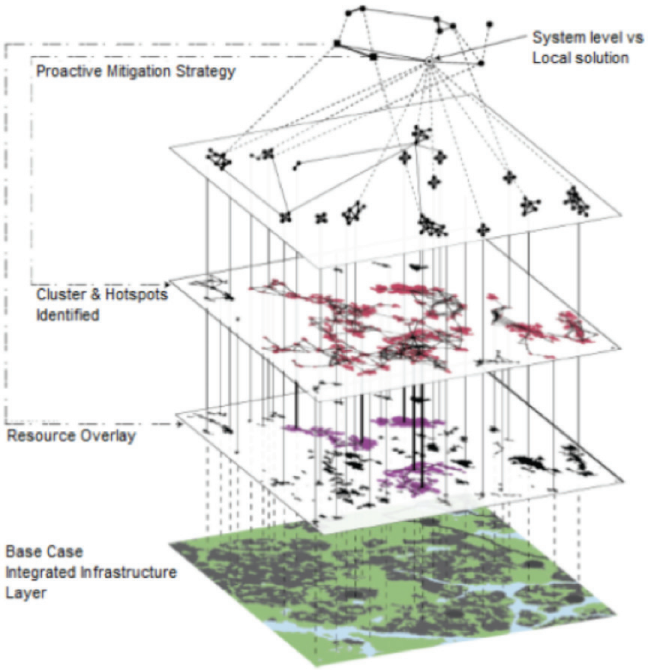


Graphical representation of the proactive modeling approach

METHODOLOGY

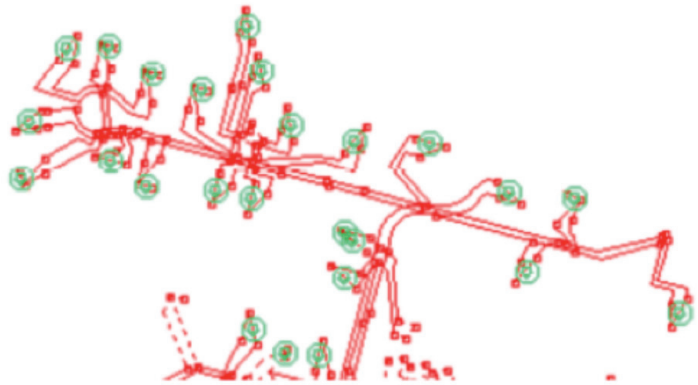
The DNV GL team explored a nodal approach for locating PV strategically, by integrating the distribution grid and a global visual mapping tool into an expanded locational value analysis. The visual map located potential PV development sites such as roof space and vacant lots. The nodal approach aggregated and assessed impacts across the system from a strategic development and grid enhancement perspective. The methodology and process were used by the participating utilities to facilitate expansion of PV into the grid without negatively impacting system performance. The four utility partners (Pacific Gas and Electric, Hawaiian Electric Company, SMUD, and Roseville Electric) selected different feeder configurations to demonstrate, evaluate, and validate high PV penetrations under steady-state, contingency, and dynamic scenarios. The project also conducted case studies for evaluating PV penetrations on the distribution grid.

RESULTS AND OUTCOMES

The final project report includes the results from the studies conducted by each of the four electric utilities with selected feeders of different line lengths, line characteristics, customer, mix and customer load/PV locations that potentially limited the amount of solar that could be installed on the feeders. Each utility had specific study objectives, informed by its territory's geography, customer demographics, and historic PV penetration. These objectives included the determination of individual solar limits per feeder, solar limits on a large substation, mitigation measures, voltage impacts under solar shut down and start up, and impact on line regulators and capacitor banks on long distribution feeders.

Before undertaking this study, it was believed that feeders could be grouped into similar profiles to reduce the need to conduct studies on every distribution feeder. However, it was found that every feeder had unique line characteristics and load distributions that make it difficult to classify feeders.

For each utility, the final report includes one or two examples of the feeder analyses undertaken. The full utility reports can be found through the CPUC CSI RD&D project portal listed on the previous page.



Detailed feeder model representation of a single distribution circuit and associated distributed roof-top PV systems (shown in green).

PUBLIC BENEFITS

- A proven methodology acceptable to both the utility and the regulatory agencies that shows positive and negative impacts to high penetrations of renewables in a particular service area or to a region.
- The methodology is available to any size utility with their specific load forecasts, system peak demands, service areas, lengths of distribution lines, customer mixes, and distribution line conductor sizes.
- The methodology enables the utility planner to study one individual feeder, a group or regional group of feeders, an entire distribution system, and secondary service drops to customer's meters.
- This research report provides a list of necessary data requirements and time increments of data to complete detailed distribution steady state, dynamic, and transient studies.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
Electrical Power Research Institute

Partners:
SunSpec Alliance, SMA, Fronius, Sandia National Laboratories, TUV Rheinland, and Xanthus Consulting

CSI RD&D Funding:
$882,193

Match Funding:
$1,228,919

Project Timeframe:
2014-2016

RD&D Project Portal:
calsolarresearch.ca.gov/csi/107

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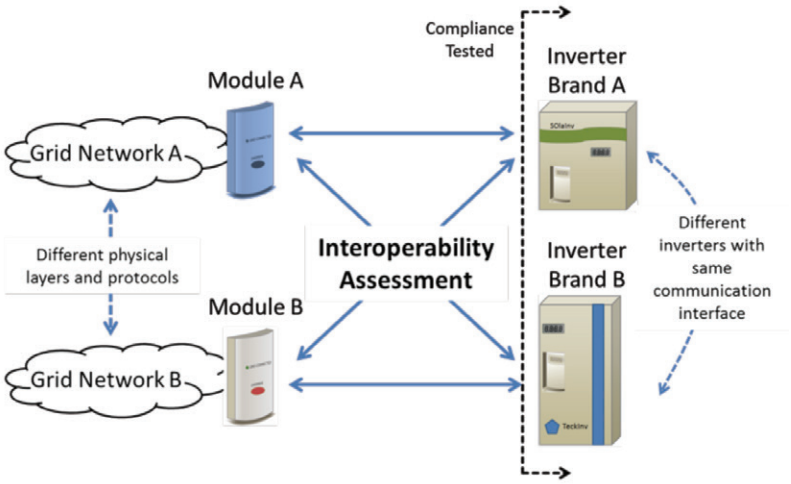
Standard Communication Interface and Certification Test Program for Smart Inverters

OVERVIEW AND OBJECTIVES

As photovoltaic (PV) penetration in the California grid increases, utility and grid operators are looking for technical mitigation solutions. One possibility is to use advanced inverters on the distributed energy resources. Inverters are responsible for converting DC power generated by PV systems into AC power, and advanced inverters possess the capability to use data about the system to increase feeder hosting capacity. Communication from these inverters, however, requires standardization through a modular communication interface. This Electrical Power Research Institute (EPRI) research project focused on assessing the relationship and reliability between two commercial inverters and two commercial communication modules by testing the modules on a variety of inverter functions to certify that both are secure and interoperable in a real-life grid setting.



Tested combinations of communication modules and inverters

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

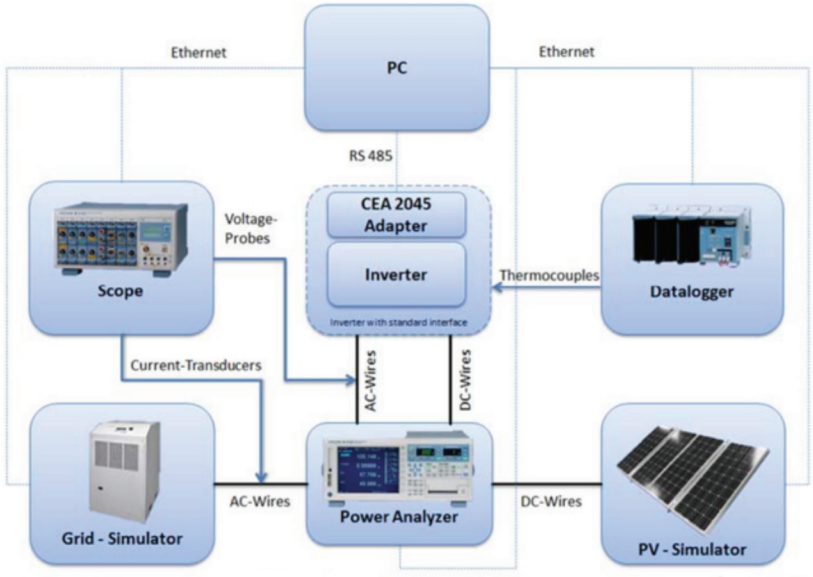
The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

METHODOLOGY

The two inverters, developed by Fronius and SMA, were paired with two communication systems, Kitu's IEEE2 2030.5 protocol and EPRI's OpenADR 2.0b protocol, for a total of four tested combinations. In both cases, the local connection to the inverter was based on the SunSpec protocol, with the communication modules translating to and from their native system. Modules were integrated in compliance with current standards and regulations for both cybersecurity and resilience to both physical and cyber disruptions. The inverter/module combinations were tested in the lab, with both a PV and grid simulator, and on a real distribution grid with a PV system. More than seven common smart inverter functions were tested in each combination. The success of each combination in supporting these functions, along with any complications was analyzed for each environment.

RESULTS AND OUTCOMES

The project found that many of the tested functionalities were successful and supportable. The SunSpec Modbus protocol were able to achieve interoperability with smart inverters, the tested communication systems proved they were functional with any generic inverter, and the inverters proved they could operate with multiple communication modules. The Fronius inverter passed far more tests than the SMA inverter, both in the lab and in the field, failing only in frequency-watt functionality not supported by its design. With further development, commercial smart inverters, in combination with commercial communication modules, will be able to reliably and securely operate a variety of functions in nearly-limitless hardware/software combinations.



Tested combinations of communication modules and inverters

PUBLIC BENEFITS

Providing Consumer Choice:
The project proved the viability of a variety of inverters being integrated with any communication system. As more technologies enter the market, the inverter communication system will grow stronger.

Enabling New Value Streams for Solar PV Owners:
The tested smart inverters support a wide range of functionality that allows numerous services for which markets may exist, and ratepayers will be able to more easily participate in PV systems due to the flexibility of communication systems.

Enabling Marketplace Competition and Innovation:
The demonstration of interoperability between the multiple inverters and communication systems will encourage technological innovations by manufacturers eager to provide more functional products, and barriers to market entry will be reduced.

Avoiding Product Obsolescence:
This interoperable approach provides ratepayers a path for modular hardware upgrades throughout their lifetime using the PV grid.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
Energy and Environmental Economics

Partners:
Sacramento Municipal Utility District, Sunverge, Rocky Mountain Institute

CSI RD&D Funding:
$717,500

Match Funding:
$518,864

Project Timeframe:
2014-2016

RD&D Project Portal:
calsolarresearch.ca.gov/csi/108

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Photovoltaic Integrated Storage: Demonstrating Mutually Beneficial Utility-Customer Business Partnerships

OVERVIEW AND OBJECTIVES

As photovoltaic integration and energy storage become more pervasive on the utility electrical grid, efforts to quantify both the electrical and economic impacts of these technologies are necessary to support widespread distributed energy resource (DER) infrastructure development. The Energy and Environmental Economics (E3) team conducted research on the distribution grid impacts and economic benefits of behind-the-meter PV integrated energy storage deployed at residential customer sites in the Sacramento Municipal Utility District (SMUD). The E3 team leveraged Sunverge's home Solar Integration System (SIS) units in their analysis of demand response during the summer and fall of 2015. These units combine battery storage with a power management platform to provide power and financial benefits to consumers and utilities. Additionally, the team analyzed grid operations throughout a year and modeled the economic benefits. The project aimed to develop robust estimates for local distribution systems, overcome near-term cost barriers by demonstrating long-term customer and utility benefits from energy storage, and translate those savings and estimates into tangible policy and planning recommendations.

METHODOLOGY

Thirty-four homes in an innovative zero net energy housing development in Sacramento were selected to host SIS units for analysis during both typical demand cycles and critical peak pricing (CPP) events. Seventeen events were tested, and both participating and non-participating customers' electrical data were analyzed at one-minute time intervals. Participating customers had their backup power reservation reduced from 40% to 25% state of charge, leaving more energy available for dispatch during peak hours.

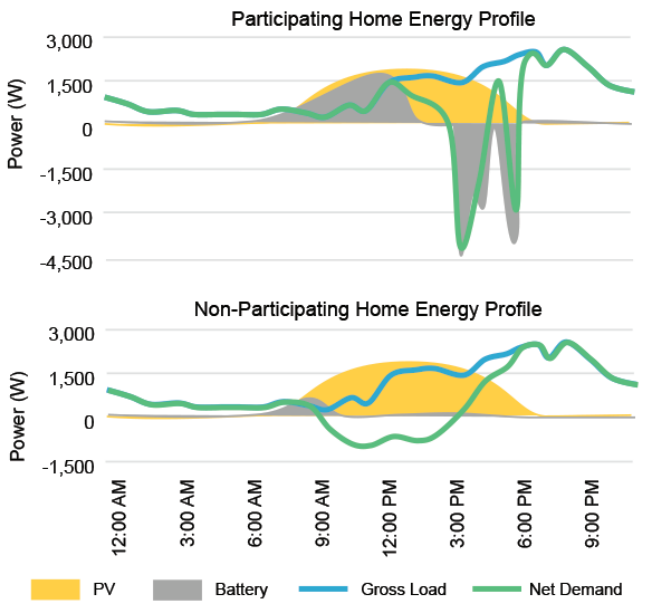
Because of complications regarding accurate calibration of SMUD distribution system models, only a single circuit encompassing two feeders was modeled and analyzed. This modeled circuit and two simulations of the circuit, adjusted to add PV systems with and without SIS units, were analyzed for economic benefits under a wide range of circumstances.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

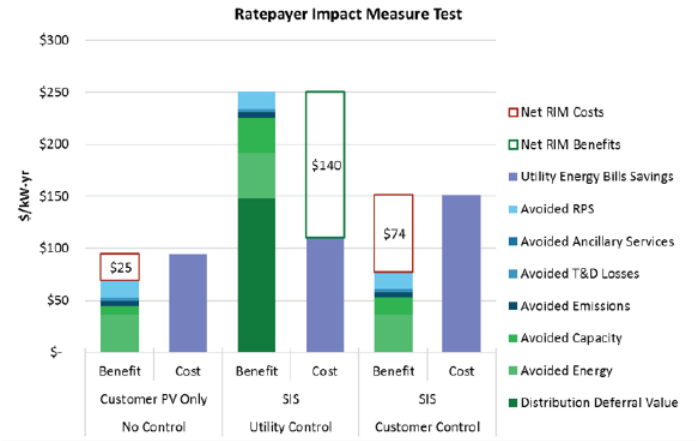
The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

RESULTS AND OUTCOMES

The grid demonstrations of CPP and demand response events resulted in storage dispatches that lowered net demand during peak hours, thus reducing overall grid demand and avoiding payment of peak prices for the customer. The figure below shows the 24-hour profile during one such CPP event averaged over all participating homes and non-participating homes. The batteries for participating homes were charged until full at about 2:00 PM and discharged during the event, from 4:00 to 7:00 PM. Non-participants operating under standard time-of-use rates experienced battery top-offs before 10:00 AM with continuous discharge and grid exportation. Participants experienced average load decreases of about 2.2 kW and 6.5 kWh, about 80% of available energy storage, and the PV generation available to charge the battery exceeded battery capacity during all but one event.



Average SIS participating home energy profile and average non-participating home energy profile during a CPP event



Benefits and costs of PV + storage systems under utility and customer control for one simulated feeder. While customer control of batteries doesn't result in net savings on an annual basis, there is great potential for savings under utility-controlled systems.

The team analyzed the cost-effectiveness of SIS in three scenarios: stand-alone PV without storage, customer-dispatched storage, and utility-dispatched storage. Each case was also rated on its ability to delay the need for transformer upgrades. As expected, the nature of PV generation during off-peak hours means that PV alone does not defer the upgrade, however the model simulating the usage of 34 SIS units deferred the upgrade for five years for a benefit of $148/kW-yr for each kW of energy storage. Analysis of cost-effectiveness resulted in net losses under four scenarios (two feeder substations, under both utility and customer storage controls), indicating that SIS procurement costs are greater than the benefits of ownership. The costs and benefits to the ratepayer for each scenario are shown above.

PUBLIC BENEFITS

Economic: SIS units can provide both utility and customer benefits during peak pricing periods and can defer expensive substation upgrades until further funding is secured. However, they may not be cost-effective enough to recover the cost of equipment and installation in some locations.

Load Reduction: Reduced stress on grid due to discharge of SIS storage systems, in conjunction with PV, eases flow of energy on the grid during peak hours and results in greater overall efficiency.

Utility Support: Dispatch would allow for charging off the grid in the mornings of high load, low PV generation days and increase the reliability of the system, benefiting utilities.

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CSI RD&D PROGRAM

Grid Integration

Grantee:
Southern California Edison

Partners:
Pacific Northwest National Laboratory, Qado Energy

CSI RD&D Funding:
$853,556

Match Funding:
$1,644,346

Project Timeframe:
2014-2016

RD&D Project Portal:
calsolarresearch.ca.gov/csi/111

Advanced Distribution Analytic Services Enabling High Penetration Solar Photovoltaics

OVERVIEW AND OBJECTIVES

In order to meet California's aggressive renewable energy goals, a better understanding of current grid limits for solar penetration is needed as well as improvements for connecting photovoltaics (PV) to the utility grid. To address this barrier, the goal of the Southern California Edison (SCE) project was to conduct research to streamline the interconnection process allowing for higher penetration levels of distributed PV. To achieve this, the SCE team determined the native limits of distributed solar PV on the SCE system. Once native limits were determined, strategies were developed for upgrading the system to allow for higher penetrations of PV. Additionally, the project team developed an online tool that hosts models and provides a platform for model analysis. This platform is called GridUnity™ and has been developed by project partners, Qado Energy. Using the GridUnity™ tool, utilities can have control over how they configure, deliver, and manage sophisticated technology-driven customer programs and analytical services.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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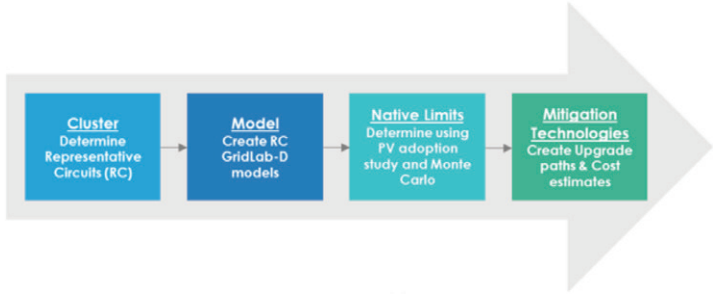


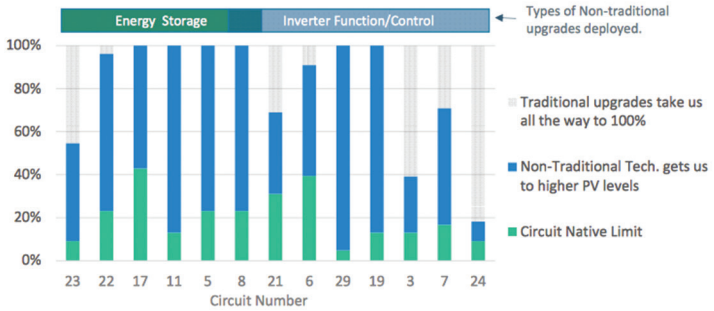
Research Project Steps

METHODOLOGY

It was not feasible to create circuit models for all of the 4,500 circuits in the SCE territory, so a set of representative circuits were chosen to represent all of the utility's circuits. This was done by first clustering all of SCE's circuits based on their characteristics and then determining the circuits that would serve as representative of the rest of SCE's territory. These circuits were clustered into 30 representative circuits and then modeled in GridLAB-D, with behind the meter residential and commercial loads. These models were then incorporated into a connectivity model that encompasses the entire representative feeders and validated with SCE customer usage data. PV was modelled as distributed systems based on customer PV adoption likelihood and Monte-Carlo simulations were then used to deploy adoption scenarios. The PV adoption models helped determine native limits based on 10 operational constraints. Traditional and non-traditional mitigation strategies were then developed for circuit upgrades to achieve 100% PV penetration.

RESULTS AND OUTCOMES

The research team found that 42-53% of SCE circuits are limited to approximately 50% PV penetration or less and at least 2 to 7% of the circuits have a native limit at or above 100% PV penetration. The most common violations experienced were power factor and voltage based. Determining how to achieve 100% penetration on legacy circuits was found to be challenging with possible mitigation measures leading to new violations. Controlling circuit voltage and circuit power factor simultaneously with capacitors was not found to be practical at high penetrations of PV. Energy storage is a technically viable solution for power factor, but may not be cost effective unless it is part of a larger multi-objective control strategy. Inverter-based Volt-VAR did not address low lagging power factor and high voltages at the same time, however Volt-VAR combined with other traditional upgrades can be highly effective. To develop complete upgrades for each circuit to reach 100% PV penetration was found to be problematic. It was observed to be relatively easy to clear violations on circuits with up to 70%-80% PV penetration, however clearing all violations in the last 20% became more difficult.



Traditional upgrades alone can reach 100% PV penetration. Emerging technologies can help surpass native limits, but may still require traditional upgrades.

PUBLIC BENEFITS

- Provide utilities insight into how to proactively develop cost effective mitigation strategies incorporating non-traditional technologies and better plan for the high PV penetration future
- Inform on-going grid modernization efforts and Distribution Resources Plan demonstrations which target increased penetration of distributed energy resources and understanding the value of these resources
- Increase understanding of the issues associated with high solar PV penetration and improve quality of interconnection applications

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CSI RD&D PROGRAM

Grid Integration

Grantee:
University of California, San Diego

Phase I Partners:
Vertum Partners, San Diego Gas and Electric

Phase II Partners:
San Diego Gas and Electric

CSI RD&D Funding:
Phase I $868,522
Phase II $99,673

Match Funding:
Phase I $1,214,850
Phase II $35,000

Project Timeframe:
Phase I 2014-2016
Phase II 2014-2016

RD&D Project Portal:
Phase I
calsolarresearch.ca.gov/csi/112
Phase II
calsolarresearch.ca.gov/csi/122

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Comprehensive Grid Integration of Solar Power for San Diego Gas and Electric

OVERVIEW AND OBJECTIVES

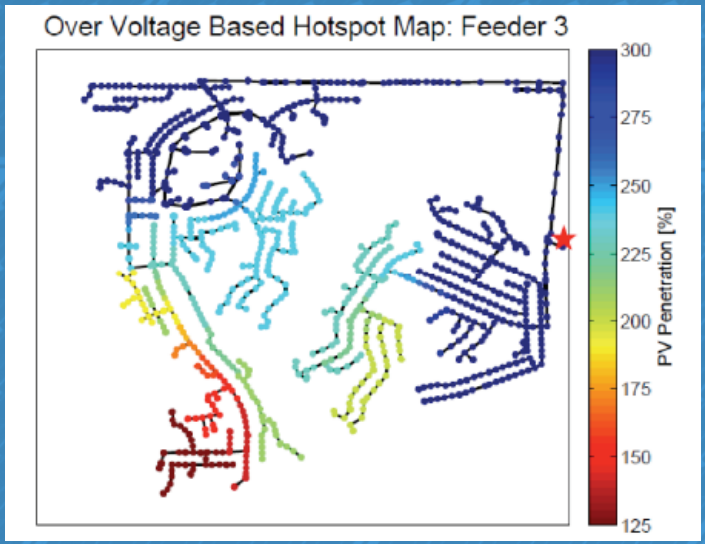
Solar forecasting is an important tool for effectively managing the electricity grid. Distributed solar power represents a negative load, and knowledge and information about net load supports more efficient distribution system operation in terms of scheduling repairs, feeder switching, and emergency operations.

Phase I: The University of California, San Diego (UCSD) team sought to advance solar and load forecast modeling in San Diego Gas and Electric (SDG&E) territory by improving and implementing previously developed forecasting tools at high temporal and spatial resolution. The objectives of this project were to build an operational solar and net load forecasting system and to develop and demonstrate energy storage siting and dispatch for solar power optimization. Using solar and net load forecasting, SDG&E identified feeder issue hot spots and prioritized feeder upgrades and energy storage sites. The team developed a tool that integrates solar forecasting with planning and simulation software to determine the best locations for energy storage based on system performance and expected solar performance. Additionally, a control algorithm was developed to interface with existing utility software and solar forecasting to maximize energy storage, photovoltaic (PV) performance, and PV integration.

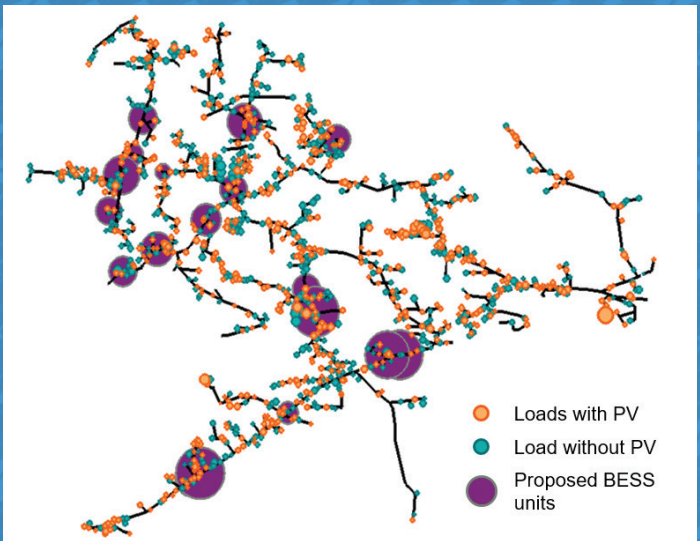
Phase II: A primary application of energy storage is mitigating fluctuations in net load, aiding the integration of intermittent renewable energy resources. For the second phase of the project, the UCSD team investigated whether battery energy storage system (BESS) controls for ramp mitigation would achieve the same benefits while reducing storage capacity requirements. Coupling power prediction solar forecasting to a feed-forward battery controller allows for the adjustment of battery charge state in advance of sharp changes in solar energy production. More intelligent and efficient utilization of battery capacity will reduce required battery size and frequency of deep discharges, thus extending battery life and reducing system lifecycle costs.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).



The star indicates the distribution substation, and the color bar indicates PV penetration levels that correspond to a thermal over-load and/or voltage exceedance.



Optimal BESS Solution on top of the One-Line Diagram of the IEEE8500 Feeder. Purple dots indicate proposed BESS units; orange dots, loads with PV; and turquoise dots, loads without PV.

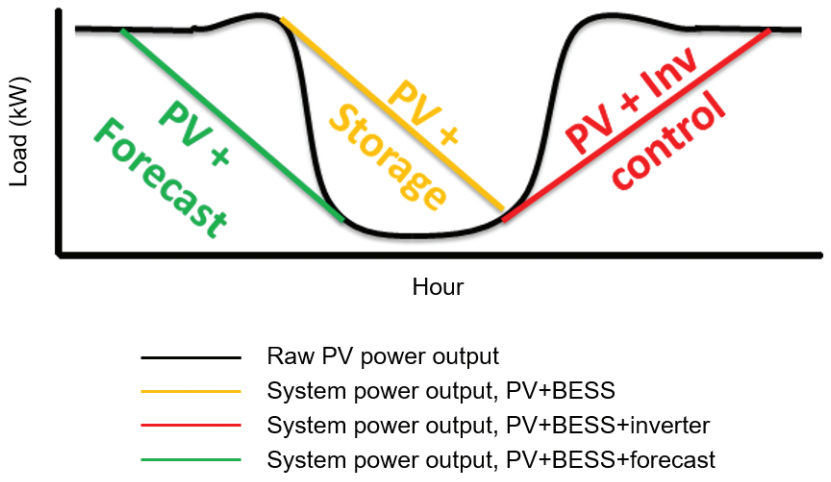
PHASE I: METHODOLOGY

The UCSD team began by developing a tool that integrates solar forecasting with planning simulation software to determine the best locations for energy storage deployment based on actual and expected system performance. The team then improved real time operations by developing a control algorithm to interface with existing utility control and data acquisition software and solar forecasting, with the goal of maximizing the performance of energy storage with PV through coordinated control. The team conducted power flow simulations for 14 representative SDG&E feeders with high PV penetration to quantify the impact of solar power variablility on voltage variations, overvoltage conditions, and load tap changer operations. Feeder voltage profiles and electrical conductor thermal ratings informed the algorithm that identified feeder hotspots arising from both solar variability and feeder stress. These improvements were then demonstrated on the SDG&E system, which is a unique testbed for forecasting and storage technology integration due to its large variations in PV penetration, meteorology, and voltage regulation equipment.

PHASE I: RESULTS AND OUTCOMES

Operational solar and net load forecasting systems were demonstrated for 68 SDG&E substations and validated for forecast horizons ranging from ten minutes to four days. A numerical weather prediction atmospheric modeling system for coastal Southern California was implemented to improve forecast accuracy. The solar forecast system has been operational since May 2015 at high reliability and is expected to remain operational past the end of this grant project.

The results highlighted that significant increases in PV penetration levels across all 14 feeders are feasible without network augmentation. Battery energy storage can further increase high PV penetration, but the ideal siting of storage is a practical challenge. A methodology was developed and demonstrated for optimal allocation of energy storage to maximize support for the integration of high penetration PV in residential distribution networks and minimize cost. This was demonstrated on a feeder in the SDG&E territory, and the algorithm is available for use by other researchers and industry.



A conceptual schematic shows the operation of the control algorithm. The "system" consists of a PV array, BESS, inverter, and solar forecasting. Without BESS and inverter control, ramp violations are frequent (black). The addition of a BESS and inverter provides reactive ramp smoothing (yellow, red). The further addition of forecasting provides proactive ramp smoothing (green); the response is proactive because the BESS charges prior to the ramp violation.

PHASE II: METHODOLOGY

The UCSD team developed an optimization routine that uses solar forecasting to control BESS and a PV inverter to mitigate ramp rates in PV power output. The efficacy of ramp rate control was evaluated for a summer and winter period using real irradiance data and real sky imager solar forecasts. A cloud base height algorithm was developed to improve solar forecast accuracy.

PHASE II: RESULTS AND OUTCOMES

A ramp rate control algorithm for BESS and inverter control to mitigate ramp rates in power output from a PV system was developed. The control algorithm uses image-based solar forecasts to predict future ramps in PV output and schedules optimal control of a BESS and inverter. The BESS provides and absorbs power in concert with fluctuating power output from the PV system to mitigate up- and down-ramps; the inverter curtails energy by adjusting the efficiency of the PV system to mitigate up-ramps. For the majority of battery configurations, the use of sky imager forecasts reduces ramp violations compared to the same method without forecasting. However, this requires greater battery energy dispatch and energy curtailment via the inverter.

PUBLIC BENEFITS

This research on improving the accuracy of solar forecasting is a common good that is unlikely to be funded by the private sector. These findings assist California utilities as they deal with meteorological issues such as the marine layer clouds specific to the coastal region.

The integration of short-term solar forecasting using sky imagery, control algorithms, and relatively small energy storage systems presents a unique synthesis of technologies with high potential in firming solar generation.

Solar forecasting combined with energy storage can reduce or mitigate the need to dispatch fossil fuel generators and reduce operating costs.

PRODUCTION TECHNOLOGIES PROJECTS

Grantee	Project Title	Solar Resource/Forecasting	Utility Tools/Models	Interconnection/Rule 21	Grid Impact Studies	PV + Storage	Concentrated PV	Solar Thermal +	Financial Analysis	Balance of System Cost	Innovative Business Models	DER Tools	DER Projects	Demonstration
SunPower Corporation	PV and Advanced Energy Storage for Demand Reduction				■	■								■
Amonix, Inc.	Improved Cost, Reliability, and Grid Integration of High Concentration Photovoltaic Systems						■							■
Solaria Corporation	Proving Performance of the Lowest Cost PV System						■							■
Cogenra	Hybrid concentrating photovoltaic/thermal tri-generation (CPV/T-3G) technology							■						■

Primary Target Area:

- Grid Integration
- Production Technologies
- Business Development and Deployment
- Distributed Energy Resources Integration

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CSI RD&D PROGRAM

Production Technologies

Grantee:
SunPower Corporation

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

CSI RD&D Funding:
$1,385,286

Match Funding:
$747,326

Project Timeframe:
2011 – 2015

RD&D Project Portal:
calsolarresearch.ca.gov/csi/69

Photovoltaics and Advanced Energy Storage for Demand Reduction

OVERVIEW AND OBJECTIVES

The overall goal of this project was to demonstrate that the integration of photovoltaics (PV) and energy storage (ES) is of higher value than either technology alone. SunPower originally proposed a team that included three energy storage vendors (Ice Energy, ZBB Energy, and Prudent Energy) with the intention of identifying, siting, designing, installing, operating, and measuring energy storage systems with existing commercial PV systems at Target stores. This was to be a two-year research project; however numerous site, design, vendor, and installation issues were encountered along the way, resulting in revisions to the project scope and timeframe. The revised project included tasks to increase demand reduction, verify benefits of solar coupled with storage, and also assess the reliability and performance of two different storage technologies. Ice Energy and ZBB are the two storage manufacturers that participated in this demonstration project. The two main objectives were:

- Determine if the combined value of PV and energy storage is greater to the commercial customer and utility than either one alone.
- Assess storage capabilities, reliability and potential degradation of the technologies to assess lifetime characteristics. Kohl's in Redding, CA and the campus of the University of CA, San Diego provided the demonstration sites for this project.

Ice Energy Installation at Kohl's in Redding, California

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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METHODOLOGY

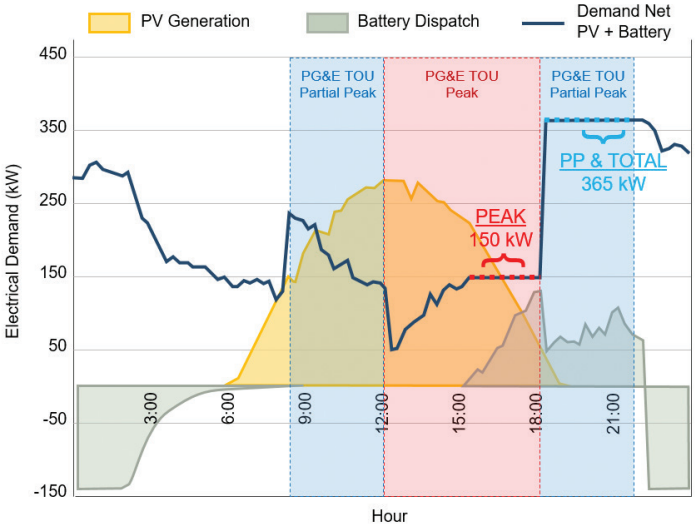
The SunPower team recruited Target to be the original host site for the demonstration. The team identified which storage technology would be hosted at each of the store sites. However, an agreement could not be reached as neither ZBB nor Prudent had prior commercial qualifications, and Target would not accept an experimental project without some promise of commercial benefit or indemnification. While the team looked for alternate host sites, one of the storage vendors (Prudent Energy) exited the project. Ultimately, the Ice Energy storage system was installed at a Kohl's store in Redding, California, where it was designed, permitted, installed, and monitored with no issues or delays. This demonstration consisted of three key activities:

- Assess storage system operations, performance and reliability.
- Compare alternatives of deploying PV or ES separately.
- Measure the impact on electricity demand reduction, economic modeling and greenhouse gas reduction.

The ZBB storage system was redirected to the University of California, San Diego (UCSD) campus. While the system did go through the design, review, and permitting process, ZBB's equipment was severely damaged in route, rendering the entire system unusable. After significant delays, the equipment was repaired, reshipped, and installed on the UCSD campus. However, during commissioning, the ZBB equipment experienced a serious failure, was removed from the UCSD site, and shipped back to ZBB.

RESULTS AND OUTCOMES

The original goal of analyzing the performance of three unique energy storage systems integrated with existing, similarly-sized, commercial PV installations was not realized due to multiple siting and equipment issues. Of the several technologies originally pursued, only the Ice Energy storage system at Kohl's in Redding, CA 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 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 incentive can be applied.



Conceptual Operation of Energy Storage in Parallel with Existing PV System

PUBLIC BENEFITS

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

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CSI RD&D PROGRAM

Production Technologies

Grantee:
Amonix

Partners:
University of California Irvine Advanced Power and Energy Program, National Renewable Energy Laboratory, Department of Energy, Southern California Edison

CSI RD&D Funding:
$1,938,772

Match Funding:
$988,366

Project Timeframe:
2011-2013

RD&D Project Portal:
calsolarresearch.ca.gov/csi/71

Improved Cost, Reliability, and Grid Integration of High Concentration PV Systems

OVERVIEW AND OBJECTIVES

Concentrating photovoltaic systems (CPV) represent a very small portion of the total solar market due to long-term reliability and performance uncertainty, high cost and potential issues with integrating this technology into the electricity grid. Amonix has developed a high-concentration photovoltaic (HCPV) system that uses lenses to focus 500-times incident sunlight onto small, highly efficient PV cells. An emerging technology in solar markets, CPV is well-suited for large multi-megawatt solar projects. The purpose of this research project was to install and monitor the performance of CPV units and the associated circuits within the University of California, Irvine (UCI) electric infrastructure and to evaluate and compare grid interconnection and energy management strategies.

Amonix installed two of its 7700 CPV systems (53 kW each) on the UCI campus for studies of grid integration by UCI and joint studies of CPV reliability with the National Renewable Energy Laboratory (NREL). As part of this deployment, the UCI Advanced Power and Energy Program (APEP) identified and documented the challenges and opportunities for installing large CPV systems on UCI's distribution circuits. NREL looked at how to correlate measured weather data with accelerated testing in order to predict lifetime and reliability validation that will help to secure financial investments for future HCPV system deployment. The NREL model provides project owners and the financial community with data on system reliability and lifetime performance, supporting the acceleration and adoption of HCPV technology on a much wider scale. This project is complementary to UC Irvine's Renewable Energy Secure Communities (RESCO) project that received grant funding from the California Energy Commission, in part, for renewable generation deployment on the campus.

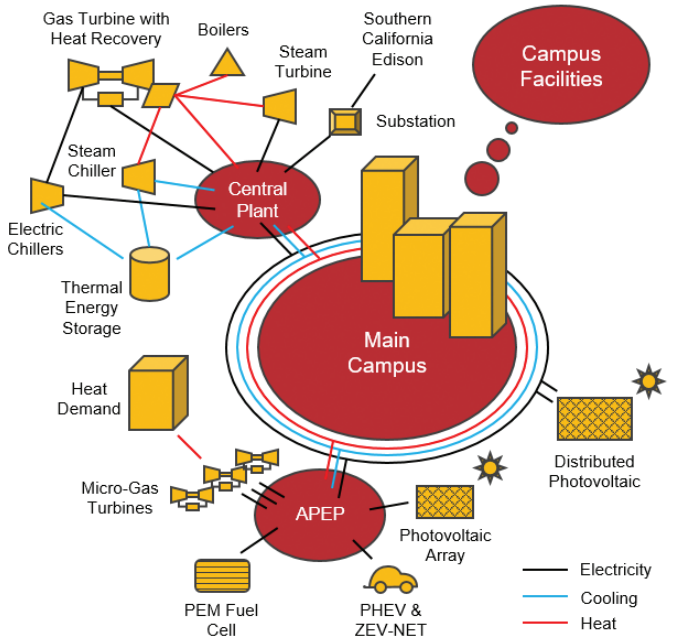
This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

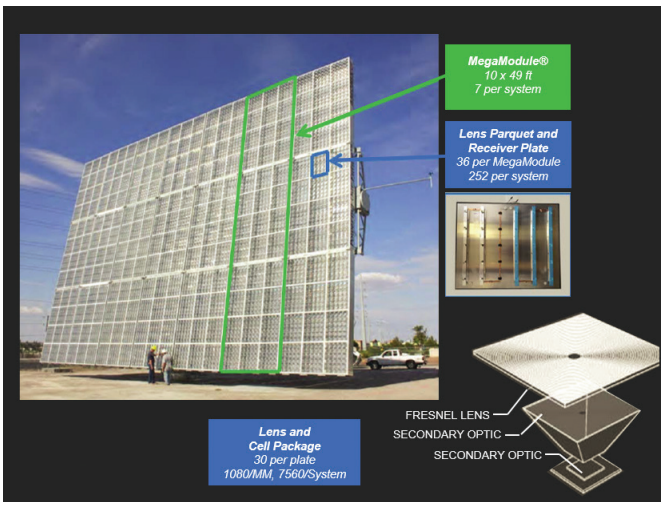
Itron CSI RD&D PROGRAM MANAGER

METHODOLOGY

The two Amonix systems were equipped with independent high-resolution power meters that collected voltage, current, real and reactive power, frequency, phase, and harmonic distortion measurements at a one-minute sampling rate. Current meters monitored the outputs of individual solar panel strings. An onsite meteorological weather station recorded wind speed, temperature, and insolation measurements. The data were collected by Amonix and then mirrored onto a FTP server for access by APEP researchers. NREL conducted accelerated testing and compiled field data to develop a method to evaluate the reliability and lifetime of CPV technologies. Lifetime and reliability validation will be essential to secure major investment and financing of future CPV system deployment. The NREL team conducted Highly-Accelerated Lifetime Tests (HALT) and correlated field data with HALT, developed a thermal fatigue model as well as a lifetime test protocol.



Electrical Infrastructure at UC Irvine



Amonix 7700 High-Concentration PV System

RESULTS AND OUTCOMES

Outcomes of this research include the manufacturing of two CPV systems and the installation of the systems on UCI's distribution grid where they have operated successfully for over three years. UCI's APEP developed a central power plant and CPV dynamic models for system operation. Their models were used to investigate the CPV penetration limits on a campus circuit, and it was found that only when CPV capacity reached ten times the baseline-installed capacity (about 1,200 kW), did effects on the circuit become noticeable. UCI's APEP team also documented the interconnection and operation of CPV systems within the UCI energy system. NREL developed a thermal fatigue model to predict CPV solar cell lifetime. The model became the basis for an international CPV durability standard IEC 62925. This is the first international lifetime reliability standard for CPV. The research project identified no major barriers to CPV's distribution grid integration and no issues with the long-term reliability of CPV.

PUBLIC BENEFITS

- Experience that can inform and guide similar CPV projects in California.
- Models for CPV generation which enable an evaluation of the benefits and issues for CPV installations in other California distribution grids.
- One international CPV standard and eight conference presentations/proceedings.
- A durability standard that provides a lifetime protocol for testing CPV, which also benefits other PV technologies.
- A thermal fatigue model that is useful to conventional flat-panel PV technologies since they lack a lifetime prediction model.

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CSI RD&D PROGRAM

Production Technologies

Grantee:
Solaria

Partners:
Pacific Gas & Electric

CSI RD&D Funding:
$1,092,428

Match Funding:
$1,338,013

Project Timeframe:
2010-2012

RD&D Project Portal:
calsolarresearch.ca.gov/csi/72

Proving Performance of the Lowest Cost Photovoltaic System

OVERVIEW AND OBJECTIVES

Concentrating photovoltaics (CPV) is a relatively new technology that provides for much higher efficiencies compared to traditional flat plate PV. This is both beneficial to reducing system costs with less cell material requirements as well as more energy production from a given area. However, the current marketplace lacks data on the reliability and long-term performance of such systems to allow for financing of CPV projects. Providing long-term performance data and information to establish the bankability and reliability of the technology will enable confidence in CPV in the distributed generation market. The goal of the Solaria project was to conduct detailed analysis and reporting on the performance of two CPV demonstrations to help convince investors and the financial community of the viability of this technology. The total system size installed at Solaria's manufacturing facility in Fremont, CA is 110 kilowatt peak. A second system, installed at Alameda County Santa Rita Jail in Dublin, CA has a total system size of 240 kWp. Solaria collected, analyzed, and reported on data and detailed system performance factors for these systems.

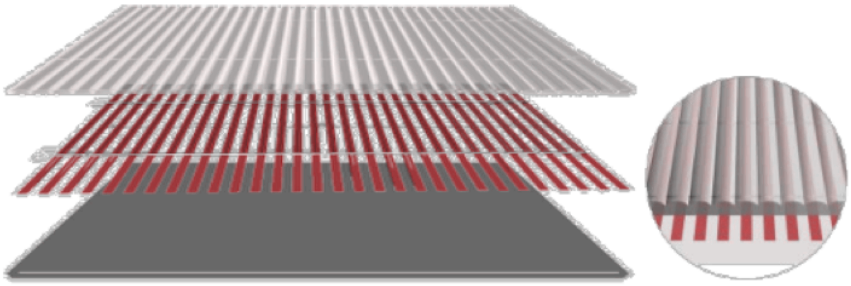

Illustration of low concentration concept using refraction from a patterned glass superstrate onto crystalline silicon cell strips connected in series and parallel underneath

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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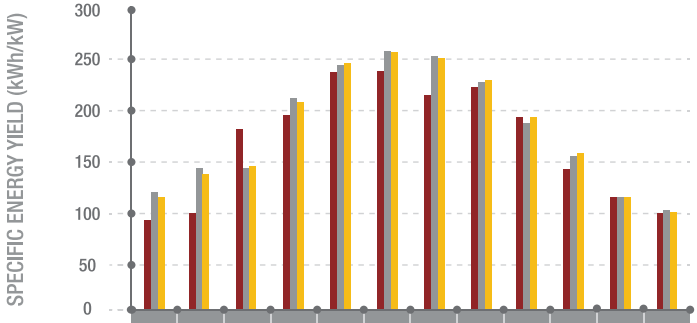
METHODOLOGY

The Solaria team installed and monitored a 110 kWp photovoltaic (PV) tracking system at the Solaria manufacturing facility In Fremont, CA. The installation included two different tracking technologies, 52 kWp installed on azimuth tracking and 58 kWp on a single- axis horizontal tracking installation. This allowed for the comparison of Solaria's high performance technology across a range of industry applications and offered higher granularity of the Solaria module performance characteristics. In addition, the installation of Solaria modules on various tracking system types allowed for further cost and performance comparisons to validate the optimal tracker technology to use with Solaria modules.

The team also procured, installed, and interconnected a 240 kWp tracker installation at the Alameda County Santa Rita Jail in Dublin, CA. The Santa Rita Jail installation demonstrated how Solaria modules perform on a commercial tracker installation. The system uses two different tracker technologies: 220 kWp were installed on azimuth tracking and 20 kWp on a two-axis tracking installation. The use of two tracking technologies allowed for a side-by-side evaluation and helped build the case for Solaria modules across a variety of applications. Measuring actual system data across three different tracking system types and two sites, led to a better understanding of the technology and its associated risks.

Dual-axis tracking system at Santa Rita Jail



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Forecast Yield	93	103	181	198	236	239	214	221	193	143	115	100
Actual Yield	120	142	145	212	244	259	252	225	186	155	115	103
Expected Yield	118	137	146	207	246	258	250	227	193	156	115	101

Actual vs. Forecasted Irradiance for Azimuth Tracking System in Fremont, CA

RESULTS AND OUTCOMES

One key aspect of the financial performance of an emerging energy technology is the ability to reliably predict the energy produced over time, and therefore, a project's cashflow. This research project demonstrated that the energy production of both sites was reliably predicted with performance indexes close to 100%, with the exception of the horizontal tracker in Fremont. These predictions were normalized for the actual conditions occurring at the site so a reasonable assumption is that over the duration of the project (typically 20 years); the project will produce an amount of energy very close to what was originally estimated. For the solar project investment community, this means that an investment in Solaria technologies produces known and calculated returns that can be relied upon. As a result of the data collected over the duration of this research project from the two test sites, Solaria has been able to initiate new projects on almost every continent, including, but not limited to, systems in the following countries: USA, Chile, France, Italy, India, China, and Qatar.

PUBLIC BENEFITS

- Helped overcome the primary obstacle to wide-scale deployment of CPV technology by providing investors and financial institutions with data on the actual performance of the technology.
- Published research data and results on CPV technology, which has led to a better understanding of the technology and project risks, and ultimately increased market penetration.
- Fully leveraged the materials, manufacturing processes, form factor, function, and field experience of the well-established crystalline silicon flat-plate PV industry.
- Was the first ground-mounted tracking system approved for construction in the City of Fremont in a residential location.
- Provided the foundation and necessary data for Solaria to finance new installations around the world.

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CSI RD&D PROGRAM

Production Technologies

Grantee:
Cogenra

Partners:
Sonoma Wine Company, Patch Engineering, Pacific Gas & Electric

CSI RD&D Funding:
$1,466,973

Match Funding:
$2,200,958

Project Timeframe:
2010-2012

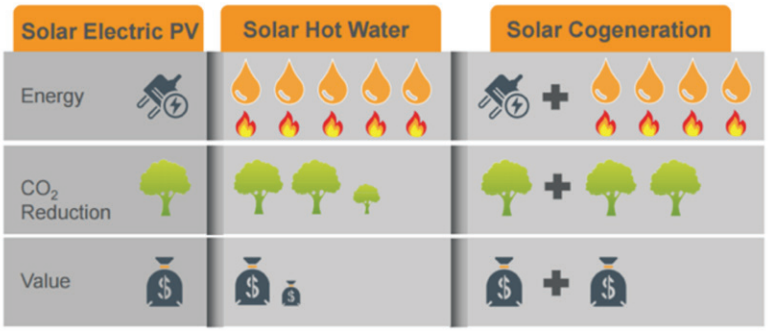
RD&D Project Portal:
calsolarresearch.ca.gov/csi/78

Improved Hybrid Concentrating Photovoltaic/ Thermal Tri-Generation Technology

OVERVIEW AND OBJECTIVES

The marketplace often lacks data on the reliability and long-term performance of new and innovative solar energy technologies and financial institutions are hesitant to finance these projects as they are perceived as risky. Providing long-term performance data and information to establish the bankability and reliability will enable confidence with adoption of photovoltaic (PV) technologies in the distributed generation market. Cogenra is one such project and their research focused on developing, prototyping, and validating the technical performance of an innovative concentrating photovoltaic (CPV)/thermal co-generation technology and conducted an 80 kW demonstration of the technology at the Sonoma Wine Company. This first generation system served as the baseline for performance modeling and evaluation, cost targets and reduction, and future integration with flexible distributed energy systems such as absorption chillers. The objectives for the project were to:

- Complete the specification of a second-generation technology,
- Measure the field performance of the technology and refine the economic and financial models,
- Adapt the system to enable advanced flexible energy delivery capabilities.



Comparison of Energy, CO_2 Reduction and Value

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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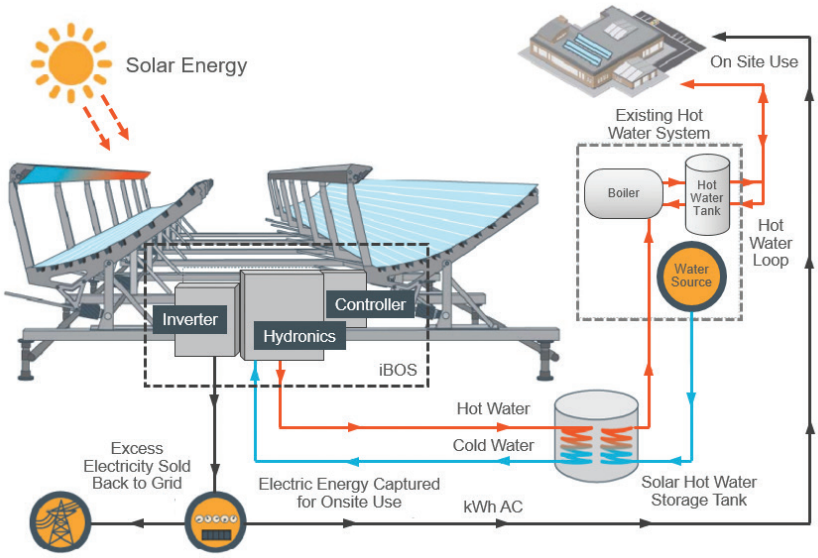
METHODOLOGY

The Cogenra team designed a second generation system with the ability to reduce overall system cost by up to 20%. The improved technology includes balances of system design for hydronics that reduces site engineering and permit requirements and allows for easy connection on site. The team collected detailed performance data from the Sonoma Wine Company demonstration system and used the data to develop more detailed generalized models both to control and optimally run systems and to support marketing, sales, and financing of subsequent systems. The team modified the system design to support delivery of higher temperature water, enabling tri-generation of electricity, heat, and cooling and variable water flows, enabling energy storage and *boost-on-demand* operation. *Boost-on-demand* allows the customer to capture additional value by generating more electricity when it commands the highest rates under variable time-of-use tariffs and by taking advantage of demand reduction incentives.



SunPack, Cogenra's Second-Generation Product

RESULTS AND OUTCOMES

As a result of this research, the materials, installation, and operational cost of the Cogenra system were reduced 50% from the baseline product installed at Sonoma Wine Company. The new product uses shared components and modular subassemblies and is able to be installed without heavy machinery or custom jigs. Modifications to the core Cogenra receiver yielded increased thermal and electrical performance while minimizing weight and installation time. The Cogenra energy models were validated and refined with a demonstrated 97% accuracy. A return on investment tool was developed that uses the energy models to provide detailed and comprehensive project financials both internally and to customers. Providing validated energy and financial modeling ensures accurate payback analysis and, ultimately, successful projects and repeat customers. The Cogenra receiver was successfully modified to perform at high temperatures allowing for tri-generation of solar heat, electricity, and cooling. The high temperature water output can be delivered to a thermal chiller (absorption or adsorption) to produce cooling. The first installation of the Cogenra product with an absorption chiller was installed at the Southern California Gas Company in Downey, CA in May 2012.

PUBLIC BENEFITS

Local component manufacturing and fully local installation provides revenue to California businesses.

Distributed energy generation reduces the stress on California's electrical grid and natural gas transmission lines.

Integration of distributed solar cogeneration at customers sites while lowering grid congestion and local greenhouse gas emissions.

Software tools that enable calculations of the energy output from a cogeneration system and supporting the financials models including the California CSI Thermal Rebate Program.

Use of California's wealth of human capabilities, mainly in engineering and software development.

Demonstration of financial viability for solar systems with improved economics with cogeneration.

Demonstration of tri-generation, which can lower electrical usage for air-conditioning, on hot days, on peak demand when the grid is congested.

BUSINESS DEVELOPMENT AND DEPLOYMENT PROJECTS

Grantee	Project Title	Solar Resource/Forecasting	Utility Tools/Models	Interconnection/Rule 21	Grid Impact Studies	PV + Storage	Concentrated PV	Solar Thermal +	Financial Analysis	Balance of System Cost	Innovative Business Models	DER Tools	DER Projects	Demonstration
SolarCity	Advanced Grid-Interactive Distributed PV and Storage					■					■			■
Viridity Energy	Innovative Business Models, Rates, and Incentives for Integration of High Penetration Photovoltaics								■					■
SunLink	Reducing Photovoltaic Costs by Automating Array Design, Engineering, and Component Delivery									■				
Strategic Energy Innovations	Solar Energy & Economic Development Fund (SEED Fund)											■		■
Clean Power Research	Distributed Solar and Plug-In Electric Vehicles: An Interactive Software Platform										■			

Primary Target Area:

- Grid Integration
- Production Technologies
- Business Development and Deployment
- Distributed Energy Resources Integration

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CSI RD&D PROGRAM

Business Development and Deployment

Grantee:
SolarCity

Partners:
Tesla Motors, University of California Berkeley Renewable & Appropriate Energy Laboratory, University of California Berkeley Energy & Resources Group & Mechanical Engineering, Pacific Gas & Electric

CSI RD&D Funding:
$1,550,867

Match Funding:
$564,743

Project Timeframe:
2011-2013

RD&D Project Portal:
calsolarresearch.ca.gov/csi/76

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Advanced Grid-Interactive Distributed Photovoltaic & Storage

OVERVIEW AND OBJECTIVES

The output variability of solar energy can pose operational challenges for the electricity grid; however, photovoltaics (PV) coupled with energy storage can reduce this variability. The ability to firm intermittent renewable resources will likely result in peak demand reductions and system-wide grid network benefits. To address this, SolarCity demonstrated an integrated PV and energy storage technology to enable cost-effective load shifting, demand reduction, and reduced needs for conventional ancillary services. The goals of the project were to show how these systems can reduce cost and carbon emissions and improve grid reliability and security and to identify market mechanisms necessary to bring combined PV and storage to new markets.

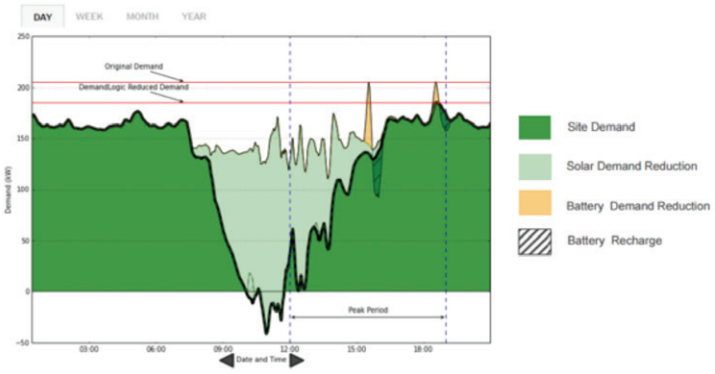
This project built upon an operational FirmPV installation in San Francisco, which is a combination of Tesla Motors' vehicle battery system with SolarCity's SolarGuard dispatch and monitoring platform. The SolarCity team conducted demonstrations at nine sites to assess system performance along with economic, reliability, and carbon reduction impacts of large-scale deployment of a FirmPV product. Additional tasks included conducting analysis to determine an optimal tariff product or rate plan that can provide the benefits of FirmPV at the lowest overall cost. Lastly, the SolarCity team explored a range of financing mechanisms to best enable FirmPV deployment.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

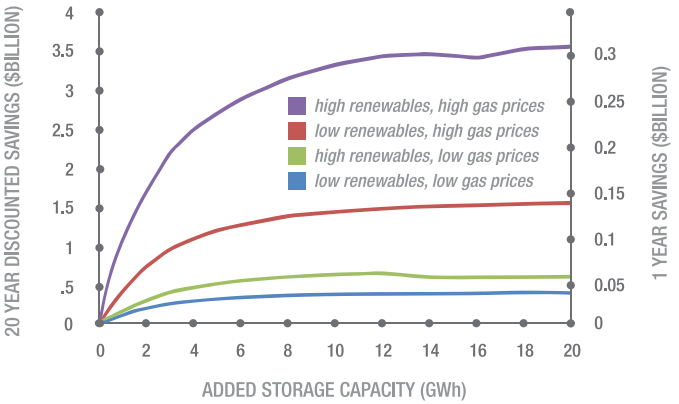
The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

METHODOLOGY

The SolarCity team explored existing technology, both in terms of energy storage systems and communications hardware. This initial research and prototyping phase was especially crucial to the development of the Tesla lithium-ion battery product and to the selection of accompanying communications, controls, and equipment. The team completed the process of locating, designing, permitting, building, and interconnecting nine grid-interactive FirmPV systems. Once the technology was deployed, use cases were developed identifying the regulatory environment needed for the benefits of storage to be accessible. New technologies, like PV paired with grid-interactive storage, have the potential to provide substantial cost savings for utilities, ratepayers, and customers and reduce carbon emissions to a far greater degree than either PV or storage could achieve on its own, while also helping ease the strain on an aging utility infrastructure. Perceived customer benefits were analyzed along with storage financing methods, PV variability, retail and distribution benefits, and control methods to monetize FirmPV value.



User Interface for Assessing Benefits of PV and Energy Storage at a Site



System Cost Savings vs. Added Storage Capacity

RESULTS AND OUTCOMES

This research project resulted in the creation of energy storage technology that can be easily integrated with PV installations. Tesla was able to implement the design feedback in the initial pilot research and to develop both commercial and residential pilot products. Key lessons were learned in regard to equipment design, system communications and control, ease of installation, compliance with building code, and regulatory barriers. The battery technology was deployed successfully in a series of pilot installations on both commercial and residential sites. Despite some initial barriers to the interconnection process, all sites are fully operational. Valuable insights included installation constraints, the importance of education for permitting authorities, and customer feedback. The knowledge gained during the course of this project, along with the inclusion of storage projects in the CPUC's Self Generation Incentive Program (SGIP) have enabled SolarCity and Tesla to bring both commercial and residential energy storage products to market. Over a hundred of these systems have already been installed across California and both companies are continuing to explore the value that energy storage can provide.

PUBLIC BENEFITS

- Substantial cost savings and carbon emissions reduction for utilities and customers to a far greater degree than either PV or storage could achieve on their own.
- Shared interconnection, communications, power conversion, and labor.
- Innovative finance mechanisms that have enabled recent growth in deployments of distributed energy storage systems for residential and commercial use.
- Cost effective load shifting, demand reduction, transmission and distribution asset deferral, and reduced needs for conventional ancillary services (voltage regulation, PV ramp rate limiting).
- Faster deployment —through simplified site qualification and design.

As grid penetrations of PV increase it is important to understand ways to firm and increase the quality of the energy that PV delivers to the grid. Advanced energy storage paired with new or existing PV generation is likely to be one of the primary tools to achieve this goal.

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CSI RD&D PROGRAM

Business Development and Deployment

Grantee:
Viridity Energy

Partners:
Energy & Environmental Economics, University of California, San Diego, San Diego Gas & Electric, California Independent System Operator

CSI RD&D Funding:
$1,660,000

Match Funding:
$840,000

Project Timeframe:
2010-2013

RD&D Project Portal:
calsolarresearch.ca.gov/csi/73

Innovative Business Models, Rates, and Incentives for Integration of High Penetration Photovoltaics

OVERVIEW AND OBJECTIVES

One of the key barriers to fully integrating renewable energy into the electricity grid is the uncertainty of the availability and delivery of the energy resource at the time of need. To address this barrier, the Viridity team simulated and then demonstrated in real time, new business models for improving the economics and incentives for integrating high penetration photovoltaic (PV) systems and intermittent renewables using campus distributed energy resources (DER). The broad goal of this research was to explore how optimizing and managing DER dispatch schedules in real time and planning time horizons, coupled with changes in incentives and tariffs can cost-effectively support the integration of high penetrations of solar PV to meet California solar initiatives. The host site for this research was the University of California, San Diego (UCSD) microgrid, which has a rich DER base that includes a 2.8 MW fuel cell powered by directed biogas, 30 MW of onsite generation, steam and electric chillers, thermal storage, and roughly 1.5 MW of onsite solar PV. Using Viridity's VPower[1] software as part of the UCSD master controller system, the team demonstrated how managing the flexibility of campus load can be used to support PV integration while still meeting campus energy needs and taking advantage of potential cost savings and market revenue opportunities. A cost-benefit analysis of proposed tariffs and strategies was performed that balances costs and benefits from the utility, customer, and ratepayer perspectives.

[1] *Viridity's VPower platform is proprietary software developed to manage and optimally schedule demand-side resources and bidding strategies using numerous economic and operational inputs.*

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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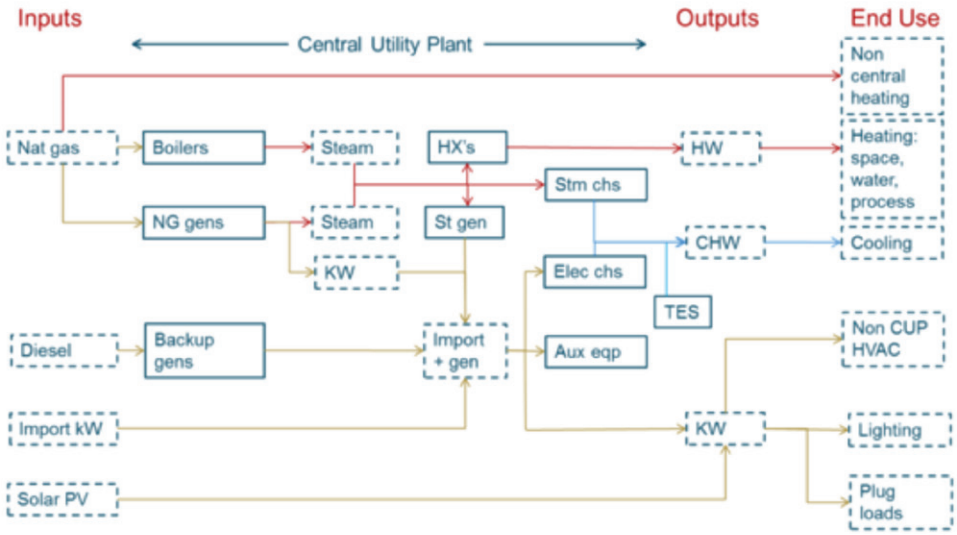
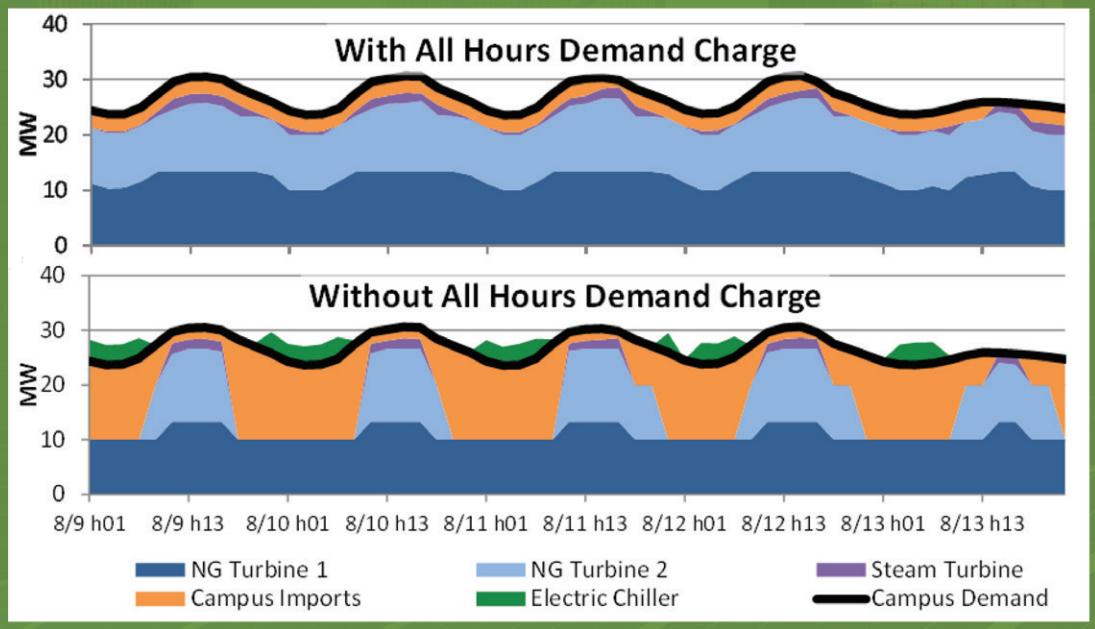
METHODOLOGY

The Viridity team modeled UCSD resources within the VPower database, focusing on the UCSD Central Utility Plant (CUP). One year of historical metered interval data was used to baseline the CUP resources and to understand overall system efficiency and typical operations. Three strategies (peak load shifting, PV firming, and grid support) were developed to test DER's operational and economic viability and flexibility. The energy impacts, costs, and benefits for each strategy were evaluated against a base case defined by UCSD microgrid's status quo. VPower was installed on servers at the UCSD campus and integrated with the campus master controller supporting data exchange with campus real-time and historical cost, load, and resource data. The team developed the UCSD Dispatch Optimization Tool, built on the Analytica software program, to quantify the net benefits of each proposed business strategy. This tool performs hourly dispatch optimization to implement scenario analysis over hourly, monthly, and annual time scales.



UCSD Microgrid: Campus Resources Energy Flow Diagram

Example output of model optimization tool for scenarios that include and exclude all hours demand charge

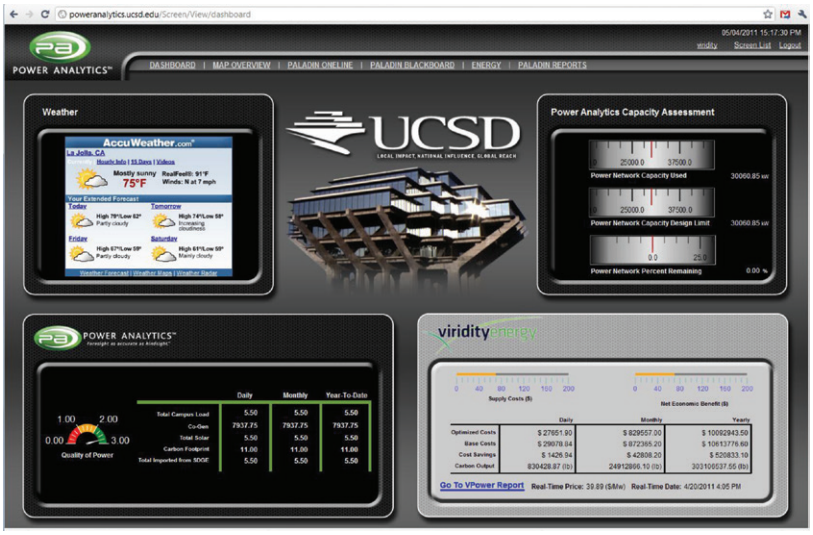


RESULTS AND OUTCOMES

Two key results were accomplished during this project. First, Viridity's VPower platform was expanded to manage key aspects of a microgrid and integrated as part of the UCSD master controller. Second, the UCSD Dispatch Optimization Tool provided a simulation and analysis environment that allowed the team to study and recommend three technically and economically feasible strategies to support PV integration. The team's findings suggest that DER are technically capable of providing cost-effective integration services, however program design changes are needed to strengthen the business case for large commercial and industrial (C&I) customers. These changes include: Removing the non-coincident demand charge could increase customer's cost-effective peak-load reduction. Peak load shifting: In the case of UCSD, the estimated increase is about 1 MW.

PV firming: PV firming with a customer's own resources is feasible but may be more costly than relying on the grid. Based on the UCSD case, there is a need for further research to assess the cost-effectiveness of using alternative cost and tariff structures applied at the distribution level.

Grid support: A large customer may profitably offer grid support services. For the UCSD case, small energy cost savings were found, but the savings can increase with additional resources enlisted.



Power Results Dashboard with Viridity's VPower. Information includes real-time base and optimized costs, cost savings, and carbon output.

PUBLIC BENEFITS

Technical potential: C&I loads have significant technical potential to provide renewables integration strategies in California.

Policy changes: Analysis shows that removing the all-hours demand charge can decrease load by ~ 1 MW at UCSD. The value of reducing load by 10 MW (2% of California campus load) is about $1.0 million annually using 2013 avoided capacity costs.

Integration at the distribution level: Analysis suggests UCSD can firm its solar PV using its own resources at a cost comparable to relying on the grid.

Grid support: Analysis suggests it is economical for UCSD to provide grid support based on regulation prices but the net benefit to UCSD is relatively low. Ancillary service revenue alone may be insufficient for motivating loads to provide grid support, and alternate products and incentives may be required.

Beyond renewables integration, this project provided insights, tools, and strategies that can be used by California colleges and others to support efforts in reducing energy consumption, costs, and greenhouse gas emissions.

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CSI RD&D PROGRAM

Business Development and Deployment

Grantee:
SunLink Corporation

Partners:
Pacific Earthquake Engineering Research Center, Rutherford & Chekene, Autodesk, Computers & Structures, Inc.

CSI RD&D Funding:
$996,271

Match Funding:
$1,263,465

Project Timeframe:
2011-2012

RD&D Project Portal:
calsolarresearch.ca.gov/csi/77

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Reducing Photovoltaic Costs by Automating Array Design, Engineering, and Component Delivery

OVERVIEW AND OBJECTIVES

Approximately one-half of the installed cost of a photovoltaic (PV) system is the modules, which continue to see cost reductions. The remaining half (balance-of-system) includes the inverter, labor, and other components and fees (engineering, permitting, interconnection). To see any significant decline in the total cost of a system, balance-of-system costs must be reduced. SunLink, a provider of PV mounting and balance-of-system components, leveraged past research, and established the following research project objectives:

- Reduce the time for PV array design.
- Reduce the time for project permitting.
- Enable fully optimized designs for smaller commercial roof-top systems.
- Decrease 'on-roof' time through factory manufacturing of array harnesses and matching combiner boxes.

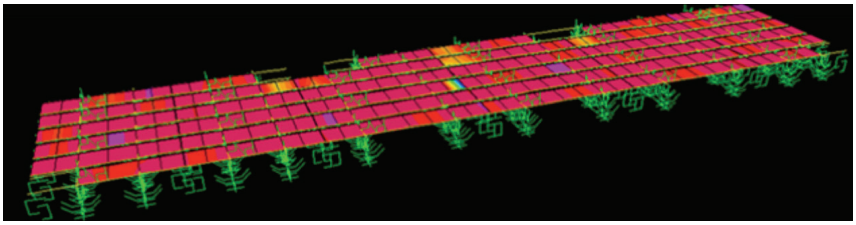
This project scope included automation of structural engineering, full-scale seismic testing of PV array behavior, analysis of wind tunnel testing for dynamic modeling of wind loads, development of a publicly accessible database of permitting agency requirements in jurisdictions across California, the creation of an automated document management system, and work that will facilitate code updates to overcome barriers to non-attached (non-roof-penetrating) designs that are necessary for wide-scale building owner acceptance of rooftop solar. Each of these separate tasks demonstrates opportunities for balance-of-system cost reduction.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

METHODOLOGY

The SunLink team automated array structural analysis to significantly reduce engineering time requirements. They also developed the SunLink String Layout Tool, which automates project-specific wiring layouts. These layouts are used for the off-site fabrication of wiring harnesses. In addition to system design tasks, the team conducted seismic and wind array research to quantify the structural integrity of unanchored arrays. SunLink conducted seismic testing of two full-scale production systems at the Pacific Earthquake Engineering Research (PEER) center. The tests were used to validate and calibrate non-linear seismic analysis models that predict total horizontal displacements for unattached PV arrays. Lastly, the team created a web-accessible database application that includes contact information for the engineering and permitting of solar projects within building departments across all 58 California counties.



SunLink String Layout Tool

RESULTS AND OUTCOMES

SunLink created a suite of integrated design tools for layout and model generation that significantly reduces the time required for structural and project engineering of a typical roof-mounted commercial installation. The tools SunLink created enable accurate and consistent documentation as well as rapid iteration of the custom designs required for maximizing solar power output on rooftop installations.

The team developed a database of local permitting requirements which can be expanded as projects arise in new localities. Solar stakeholders can use this information to facilitate the delivery of documentation that best illustrates to building officials the code compliance of optimized design and better meets the requirements of local permitting agencies in California. The PV arrays tested at the PEER center successfully withstood the complete matrix of test loads, which included approximately 100 earthquakes. The testing validated the analytical models developed by SunLink and demonstrated that the analysis can accurately and consistently predict array response to a wide range of seismic events. These validated models support the position that unattached PV arrays can be safely and predictably utilized in seismic regions.

PUBLIC BENEFITS

Will help the industry to cost-effectively provide optimized designs for PV systems as small as 5 kW.

Will expand the range of contractors who can successfully install fully-engineered PV installations, including general and electrical contractors.

Provides the functionality and features worthy of consideration for a document management system and serves as a starting point for solar organizations to pursue document management.

Will help inform new structural permitting standards that support the use of unattached PV mounting installations in areas of high seismic activity. Because ballasted systems are less expensive to install and maintain than connected systems, these test results will ultimately help to lower costs for rooftop solar and open up the potential for projects on building roofs previously considered unsuitable.

Resulted in The California Agency Permit Document Requirements Database, a single point of access for information to support building code officials and the California solar industry with new structural permitting standards requirements. The database has been populated for 1,527 cities and towns in California.

Resulted in significant outreach with numerous technical publications, white papers, peer-reviewed and trade journal articles, and conference and webinar presentations.

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CSI RD&D PROGRAM

Business Development and Deployment

Grantee:
Strategic Energy Innovations, Inc.

Partners:
Optony, Inc.

CSI RD&D Funding:
Phase I: $300,000
Phase II: $99,959

Match Funding:
Phase I: $304,462
Phase II: $110,616

Project Timeframe:
Phase I: 2012-2014
Phase II: 2015-2016

RD&D Project Portal:
Phase I:
calsolarresearch.ca.gov/csi/90

Phase II:
calsolarresearch.ca.gov/csi/116

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Solar Energy & Economic Development Fund (SEED Fund)

OVERVIEW AND OBJECTIVES

Public entities, such as school districts, are motivated to adopt solar photovoltaics (PV), however high upfront costs and a lack of technical expertise prohibit many of them from identifying potential projects and fully assessing options. To address this barrier, Strategic Energy Innovations (SEI) and Optony developed the Solar Energy & Economic Development (SEED) Fund Project and demonstrated an innovative solar procurement business model that utilizes a public-private revolving fund mechanism to support public entities in adopting solar technologies. The SEED project demonstrated that a 1-2% upfront investment in collaboration results in a 10-12% project cost savings, lower project risks with higher returns, reduced transaction costs, and reduced administrative efforts. The SEED project demonstrations were done in two phases.

Phase I: The first demonstration was conducted in 2013-2014 in the North Bay Area of Sonoma, Marin, and Napa Counties with the following objectives:

- Sign memorandum of understanding (MOUs) with 10 public partners to participate, conduct 100 site evaluations, and identify at least 10 MW of viable solar projects across all participants.
- Include at least 5 MW of solar projects in the request for proposals.

Phase II: To capitalize on the existing program momentum and to demonstrate reduced time-to-market based on lessons learned in Phase I, the SEI team conducted a second demonstration in 2015-2016. The location of this demonstration was the Central Coast region of California including Monterey, Santa Cruz, and San Benito Counties. This demonstration had the following objectives: sign MOUs with eight public partners to participate and at least 5 MW of new public non-utility solar PV across 20-30 sites.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

METHODOLOGY

The SEI team followed the same approach with both demonstrations. The team distributed information about the collaborative partnership to schools and local governments and conducted technical and economic feasibility analyses to identify viable sites of new solar potential for deployment. Request for proposals (RFPs) were developed to meet participant requirements, attract qualified contractors, and result in contracts that realize cost savings for participants and efficiency for vendors. Lastly, the team worked to ensure the SEED fund business model approach and outcomes were sustainable, with attention to replication and scalability of fund replenishment, investor reimbursement, and subsequent cycles of project development.

PHASE I: RESULTS AND OUTCOMES

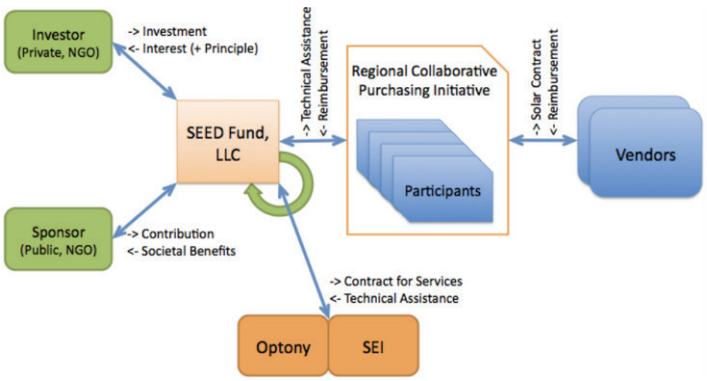
Summary of Outcomes	Objective	Outcome
Number of Participating Agencies	10	13
Number of Site Assessments	100	143
MW of Solar in RFP	5	6.8
Transaction Cost Reductions	10-12%	5-15%

The SEI team conducted 143 site evaluations and identified the potential for over 130 MW of solar power installation, including several sites with the potential for utility-scale PV installations. The team issued a joint RFP for 32 sites across 13 public agencies with a combined 6.8 MW estimated solar generation capacity. As of August 31, 2014 (the end of the grant term), 25 sites for 12 public agencies have entered into purchase or power purchase agreement (PPA) contracts with the selected vendor with a range of cost reduction of 5% to 15%.

PHASE II: RESULTS AND OUTCOMES

Summary of Outcomes	Objective	Outcome
Number of Participating Agencies	8	9
Number of Site Assessments	25	32
MW of Solar in RFP	5	37.7
Transaction Cost Reductions	8%	TBD: Winter 2017

The SEI team identified over 50 MW of viable solar projects across the 99 prescreened sites. The RFP, expected to be issued in August 2016, includes 9 participating agencies with 32 sites representing 37.7 MW of viable solar projects. Vendor proposals are expected in October 2016 with the County of Santa Cruz acting as Lead Agency. By leveraging the effort and lessons learned in the first collaborative procurement process, net costs for implementing the second demonstration are expected to be significantly reduced. With the SEED revolving fund mechanism in full deployment, the team will be able to launch the next round of project procurement once repayments are made.



Solar procurement business model utilizing a public-private revolving fund.

PUBLIC BENEFITS

- Contributes to California's energy goals by enabling public participants to adopt solar energy in an efficient way. An estimated 40 MW of new PV for 22 public agencies are likely to be installed at the close of the first two collaborative procurement demonstrations.
- Contributes to California's energy goals by reducing green house gas emissions and increasing the amount of renewable energy in California utilities' power mix.
- The financial model enables the SEED Fund program to launch additional collaborative procurement rounds in other regions, thereby extending the impact of the CSI RD&D grant and its contribution to California's energy goals.
- Detail practical knowledge of how a revolving fund mechanism can be leveraged to extend the benefits of collaborative procurement efforts. This information is freely accessible and can be used by all other interested parties.

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CSI RD&D PROGRAM

Business Development and Deployment

Grantee:
Clean Power Research

CSI RD&D Funding:
$99,658

Match Funding:
$114,229

Project Timeframe:
2014-2015

RD&D Project Portal:
calsolarresearch.ca.gov/csi/123

Distributed Solar and Plug-In Electric Vehicles: An Interactive Software Platform

California is the nation's largest plug-in electric vehicle (PEV) market with 100,000 vehicles and new sales adding about 3,500 cars in the state each month. In response to this growth, Clean Power Research developed a web-based tool that consumers can use for decision-making for solar photovoltaics (PV) and PEV. This new online tool, called WattPlan®, helps customers in California understand the benefits of combining an electric vehicle purchase with solar PV. The tool's personalized analysis tailors results for each user and includes a breakdown of the economic, energy, and environmental savings of investing in an electric vehicle plus solar PV. The tool can be found at *https://csi.wattplan.com.*

This decision-making tool was made freely available to all Californians for a minimum of one year after completion of the grant. In the longer-term, the software tool may be licensed to utilities, energy agencies, PEV and PV stakeholders, and the financial community. Armed with confidence, information, and a newfound understanding of each technology, consumers will be better prepared to make the complex purchase decision to install solar and purchase an electric vehicle, two innovative technologies that offer the potential to save energy and money.

WattPlan PV and PEV Calculator

WattPlan Summary Page

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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DISTRIBUTED ENERGY RESOURCES INTEGRATION PROJECTS

Grantee	Project Title	Solar Resource/Forecasting	Utility Tools/Models	Interconnection/Rule 21	Grid Impact Studies	PV + Storage	Concentrated PV	Solar Thermal +	Financial Analysis	Balance of System Cost	Innovative Business Models	DER Tools	DER Projects	Demonstration
Davis Energy Group/National Renewable Energy Laboratory	Beopt-CA (EX): A Tool for Optimal Integration of EE/DR/ES+PV for California Homes											■		
kW Engineering	Specify, Test and Document an Integrated Energy Project Model									■	■	■		
BIRAenergy	Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar Energy Efficiency Results												■	■
University of California, Davis	West Village Energy Initiative: CSI RD&D Project				■	■		■	■				■	■
Electric Power Research Institute	Demonstration of Locally Balanced ZNE Communities Using DR and Storage and Evaluation of Distribution Impacts				■	■							■	■
BIRAenergy	Monitoring and Evaluation of a Zero Net Energy Retrofit Home with Energy Storage, Demand Response and Home Energy Management System					■							■	■
Tri-Technic	Supervisory Controller for PV and Storage Microgrids				■				■					
National Renewable Energy Laboratory	BeOpt Multifamily Modeling Capabilities for Zero Net Energy (ZNE) and Integrated Demand-Side Management (iDSM) in California												■	
University of California, Davis	Comprehensive System Assessment of the Smart Grid-tied Energy Storage System Using Second-Life Lithium Batteries					■								

Primary Target Area:

- Grid Integration
- Production Technologies
- Business Development and Deployment
- Distributed Energy Resources Integration

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CSI RD&D PROGRAM

Distributed Energy Resources Integration

Grantee:
National Renewable Energy Laboratory

Phase I Partners:
Davis Energy Group, Pacific Gas & Electric, Energy and Environmental Economics, Inc.

Phase II Partners:
Davis Energy Group, Pacific Gas & Electric, Sacramento Municipal Utility District

CSI RD&D Funding:
Phase I: $982,934
Phase II: $97,989

Match Funding:
Phase I: $230,540
Phase II: $75,596

Project Timeframe:
Phase I: 2011-2014
Phase II: 2014-2015

RD&D Project Portal:
Phase I
calsolarresearch.ca.gov/csi/62
Phase II
calsolarresearch.ca.gov/csi/121

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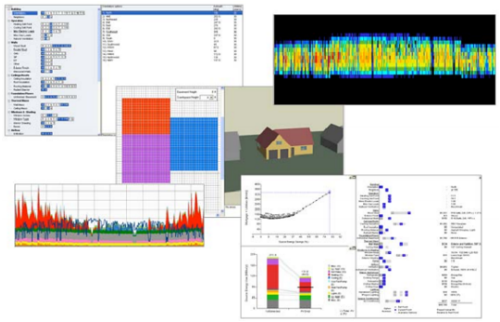
BEopt: Modeling Capabilities for Zero Net Energy Single-Family and Multifamily Homes in California

OVERVIEW AND OBJECTIVES

Combining and optimizing energy efficiency (EE), demand response (DR), and photovoltaics (PV) in the residential market can be very challenging, because the skills and expertise do not reside within a single company or organization. The market also lacks tools that support quantitative analysis for these options. To meet California's energy policy goals, a tool that can accurately model and optimize for energy efficiency and solar energy is essential. To address these barriers, the National Renewable Energy Laboratory (NREL) was funded to conducted research in two phases.



BEopt Inputs and Outputs

Phase I: The goal of the project was to develop a software tool, BEopt-CA (Ex) (Building Energy Optimizer for California Existing Homes), that facilitates the integration of energy efficiency and demand response with PV in the residential retrofit market. This software tool provides utility program managers, contractors, consultants, architects, and engineers with a means of balancing this integration and optimization for existing homes.

Phase II: Building on the Phase I work, the NREL team extended the software tool to the multifamily sector (duplexes, triplexes, townhouses, flats, and low-rise apartment buildings). Specific multifamily modeling additions include developing multifamily-specific operating conditions, adiabatic surfaces, enhancements to input screens (geometry, option, and site screens), enhancements to output screens (aggregate results), multithreading capacity (parallel simulations and use of multiprocessors for faster simulations), and multifamily heating, ventilation, and air conditioning (HVAC) and domestic hot water (DHW) systems (including solar).

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

PHASE I: METHODOLOGY

The approach began with the existing BEopt software to develop a new modeling tool, BEopt-CA (Ex), to properly accommodate the analysis of certain aspects of existing buildings. Retrofit options and costs were tailored to the characteristics of existing California buildings to streamline analysis. Modifications to the model allowed the use of typical California utility tariffs, custom tariffs, incentives, rebates, and tax credits. The project team modified BEopt to include currently available demand response measures and technologies that shift loads away from peak times. The new BEopt-CA (Ex) was then validated and calibrated with statistically relevant data from typical California communities.

PHASE I: RESULTS AND OUTCOMES

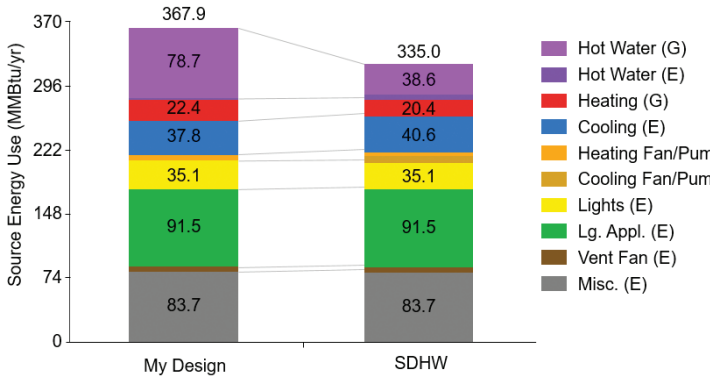
This research resulted in the BEopt-CA (Ex) version 2.2 software tool that optimizes EE, DR, and PV in existing homes. The enhanced software now includes retrofit analysis for existing homes, retrofit measures and cost data, utility tariff capabilities, utility cost-effectiveness tests, incentives for PV and whole house efficiency, and DR.

PHASE II: METHODOLOGY

Building on the Phase I research, the NREL team developed multifamily building analysis capabilities for BEopt, including a multifamily drawing tool which enables users to quickly define the geometry of multifamily buildings. Additional HVAC and DHW technologies were also developed and implemented. Throughout the project, the software framework was tested to ensure that the BEopt multifamily enhancements were accurate and reliable.

PHASE II: RESULTS AND OUTCOMES

The outcome of this project is an enhanced BEopt tool for analysis and optimization of multifamily buildings. BEopt version 2.5, released in October 2015 by NREL, enables users to quickly define the geometry of multifamily buildings. All of the enclosure and equipment options from BEopt's single-family mode are now available for multifamily analysis. New categories added for the multifamily mode include central water heaters, central hot water recirculation, central solar water heating, central solar photovoltaic systems with virtual net metering, steel stud wall construction, and corridor lighting. This enhanced tool is now available for use on California's four million multifamily homes.



BEopt Multifamily Output – End Uses

PUBLIC BENEFITS

Building owners, remodelers, architects, and builders can use BEopt to comprehensively analyze and optimize EE, DR, and PV across California's existing single-family and multifamily buildings. The tool is ideal for zero net energy building design.

For energy professionals, BEopt provides an analytically sound platform, enabling them to quantify the benefits of energy performance enhancing upgrades. BEopt can become a standard for analytic tools in use to make recommendations to building owners and home owners by architects, designers, home rating professionals, and builders.

Utility program planners can use BEopt to develop preferred cost-optimal packages of EE, DR, and PV in planning and designing demand-side programs for single-family and multifamily buildings. These can be tailored for particular climate zones and building types and optimized for subsequent solar installation.

BEopt serves as a valuable tool for developing new measures for California's 2019 Title 24 Zero Net Energy standards for both single-family and multifamily building types.

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CSI RD&D PROGRAM

Distributed Energy Resources Integration

Grantee:
kW Engineering

Partners:
SolarNexus, SaveEnergy123, Solmetric, Geopraxis

CSI RD&D Funding:
$942,490

Match Funding:
$258,653

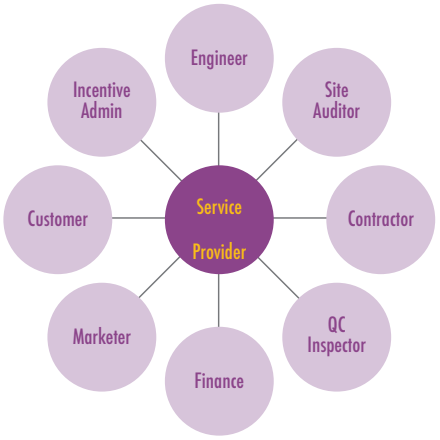
Project Timeframe:
2010-2012

RD&D Project Portal:
calsolarresearch.ca.gov/csi/68

Integrated Energy Project Model

OVERVIEW AND OBJECTIVES

The process of finding, documenting and communicating information on possible energy efficiency, and solar energy projects to customers is cumbersome and confusing and represents a barrier to the adoption of these technologies. The industry lacks tools that facilitate a comprehensive approach for integrating both energy efficiency measures and energy generation by solar photovoltaics (PV). Energy service providers often use tools to automate their business processes to market, bid, contract, and manage projects. Unfortunately, these tools are not integrated and lack a common standard to easily share information about customers, buildings, energy use, projects, products and services. The lack of a common data format for integrated energy project information prevents easy data transfer between software tools, resulting in redundancies, data entry errors and higher contractor and customer costs.



The IEP model is designed to capture and share common information among all involved stakeholders

The Integrated Energy Project (IEP) model was an effort to develop a new open-source extensible markup language (XML) format for information exchange that improves the speed and reliability of communications among stakeholders of integrated energy efficiency and renewable energy projects. The goal of this research project was to create an open format that enables all IEP stakeholders to easily collect, transmit, and store information about integrated energy projects through various software tools used within the energy industry.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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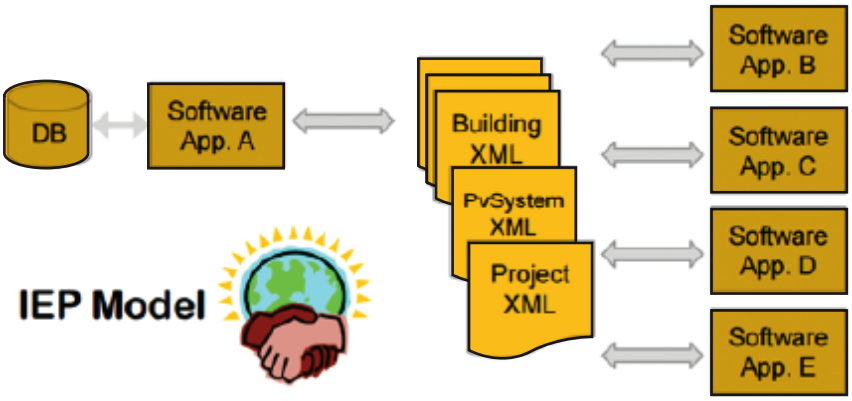
METHODOLOGY

The project consisted of three phases: initial research, development of the data model, and a demonstration deployment of IEP XML in two existing web applications.

IEP Model Software

The team conducted initial research to identify the business processes, software needs and required parameters of solar installers and energy service providers. This extensive inventory of parameters was used to organize and develop a comprehensive IEP Model. For the deployment phase, data exchanges using the IEP Model XML Schemas between the SolarNexus and SaveEnergy123 software tools were implemented to identify any potential deployment issues and identify any user interface changes needed for these software tools to support implementation of the IEP Model.

RESULTS AND OUTCOMES



Read and write IEP XML

The kW Engineering team leveraged their existing software products and skills to develop and test an IEP Model. This model integrates the building energy analysis process with the implementation of energy efficiency and solar projects. The model is expected to streamline the process of integrating energy efficiency and PV reducing time and costs for both consumers and contractors. The kW Engineering team described the model components, documented the communication interchange between systems, implemented a test version of the model, identified regions to conduct consumer and contractor tests, conducted a pilot test of the model, and documented the results. The final product is available for integration with other consumer energy efficiency audit, contractor bidding or project management tools on the market. For more information on the model, please visit: *http://www.iepmodel.net.*

PUBLIC BENEFITS

Received very positive feedback from numerous industry stakeholders involved with the model development.

Offers an open, flexible data communication standard that facilitates the transmission, analysis, and storage of integrated energy project information with the internal and external tools of any user group.

Avoids the redundancy of developing a service providers' own version of an existing tool and with the easy transfer of project data as well as more choices in vendors.

Provides the ability to maintain a history of many different energy projects.

Allows vendors to develop portable, audit, data collection tools that may be implemented on tablets and smart phones.

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CSI RD&D PROGRAM

Distributed Energy Resources Integration

Grantee:
BIRAenergy

Phase I Partners:
General Electric, San Diego Gas and Electric, Sunverge

CSI RD&D Funding:
Phase I: $999,999
Phase II: $74,500

Match Funding:
Phase I: $962,557
Phase II: $108,788

Project Timeframe:
Phase I: 2010-2013
Phase II: 2014-2015

RD&D Project Portal:
Phase I
calsolarresearch.ca.gov/csi/74
Phase II
calsolarresearch.ca.gov/csi/117

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Solar Re-Roofing and the Evaluation of a Zero Net Energy Residential Retrofit

OVERVIEW AND OBJECTIVES

The overall goal of these two research projects was to reduce the first cost barrier for zero net energy (ZNE) residential retrofits. For the first phase of the project, the BIRAenergy team focused on testing General Electric's (GE) new low-cost PV system (Grid-Ready Plug-and-Play PV Kit) as a cost-effective retrofit measure during a residential re-roof. Six test homes were selected in the San Diego Gas and Electric (SDG&E) territory. One of the test homes received a zero net energy (ZNE) home retrofit, which included additional efficiency measures, GE's demand-responsive appliances, an integrated home energy management (HEM) system, and an energy storage system. Phase II of the research focused on the monitoring and evaluation of this ZNE retrofit home.

Phase I: The PV kit was installed on six homes in different climates and on different house styles to evaluate and develop a new business model to increase the market penetration of rooftop PVs, particularly in the retrofit market. The evaluations included installation procedures and processes, training approaches, materials and processes, electricity generation, and integration with other energy and/or power saving retrofits in a ZNE home. Research results from all aspects of the installations, combined with market research, reviews, and assessments of financing programs formed the basis from which an innovative business model for the PV kit was developed.

Phase II: A more extensive evaluation of this ZNE retrofit home involved the testing of the interactions between the PV, distribution and battery storage systems, and demand response (DR) through different operational modes of the home. These included occupant control through the HEM system and utility operation of DR and storage to provide load management.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

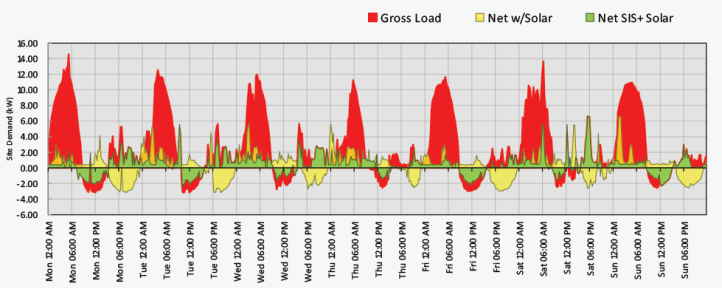
The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

PHASE I: METHODOLOGY

The BIRAenergy team conducted an evaluation of the GE Plug-and-Play PV Kit including an analysis on system components and installed costs. Innovative financing approaches were identified and reviewed for installing PV along with energy efficient upgrades. The team developed an innovative business model appropriate for the PV kit that could increase the rate of market adoption of rooftop PV, especially in the retrofit market. Lastly, the team evaluated the integration of energy efficiency, demand response, HEM system and energy storage, and PV in the ZNE home.

PHASE I: RESULTS AND OUTCOMES

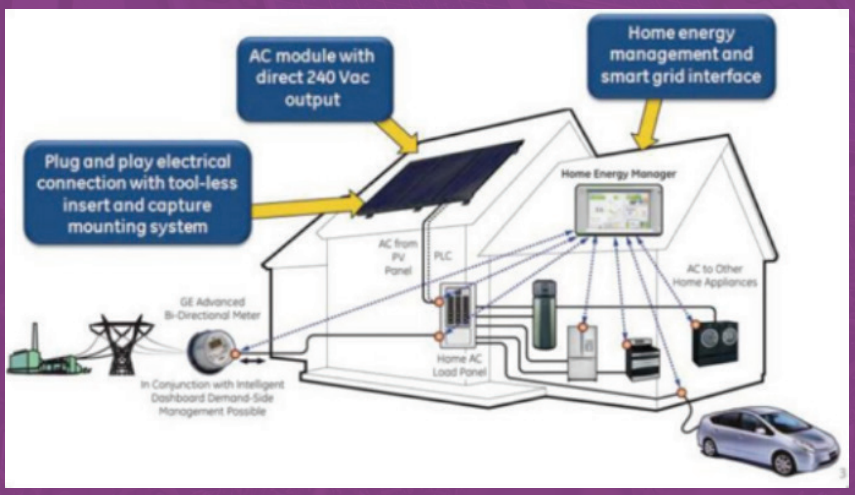
The successful installations and subsequent evaluation demonstrated that the Grid-Ready Plug-and-Play PV Kit can provide roofing contractors with a business opportunity and a whole new market channel by adding PV installations to their product offerings. The roof-top installation can be completed entirely by a trained roofing contractor and one or two assistants. A best practices training guide was developed for both the roofing contractor and electrician contractor, providing detailed instructions for the installation of the PV kit. At the start of this research project, GE estimated the PV kit would have an installed cost below $4/Watt, assuming a 1,000-unit production volume, with the system cost expected to drop to below $3/Watt by the end of 2014. The PV kit employs PVac panels that are connected in parallel instead of the typical PVdc panels that are connected in series. This results in the PV kit arrays being relatively insensitive to shading, compared with the typical dc string arrays. This can be a very important factor to energy production and cost-effectiveness in the retrofit market, where shading is a prevalent problem.



Total home electricity demand (red), demand from the utility meter when generation from the PV is included (yellow), and net demand with PV, energy storage, and electricity needed from the grid (green). Data is the average for each day of the week for October 2013.

PHASE II: METHODOLOGY

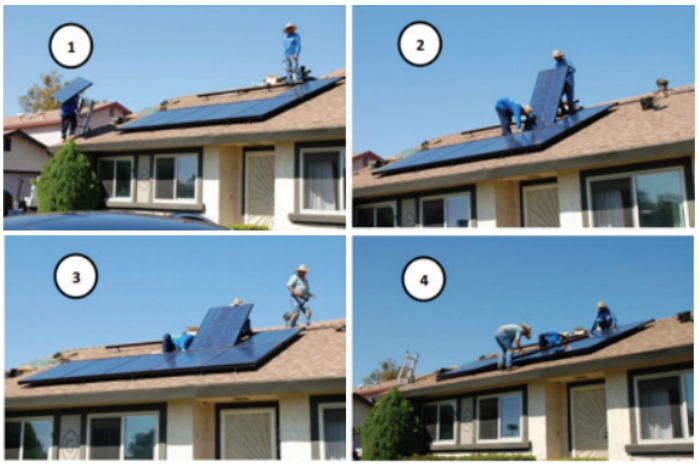
For the second phase of the project, the BIRAenergy team continued the data collection which began during the first phase. The team collected additional 15-minute interval data for an 18-month period, resulting in approximately four years of energy use and generation data from the occupied home: 1.5 years pre-retrofit and 2.5 years post retrofit. Simulations of the baseline home (before retrofits) were compared with the home's actual energy use under baseline conditions. The performance of the ZNE design and features and their impacts on energy reduction and summer peak-demand were examined.



GE Smart Grid Ready Residential Solar Electric System

PHASE II: RESULTS AND OUTCOMES

The efficiency package was developed to provide zero net energy on a site basis. While the retrofitted efficiency package did not reach this goal, site electricity was reduced by over 70%, as determined by a comparison of baseline, pre-retrofit to post-retrofit data. This project also showed that DR as a peak-reduction tool is much more valuable in standard homes as compared to ZNE homes. During peak periods, the ZNE home's electricity use is negative (net producer) and therefore does not have a peak to reduce. In contrast, the baseline home had a distinct and higher peak than the ZNE home, which can be substantially reduced by DR actions during the peak period. The energy storage system was programmed to charge the batteries using PV energy generated that exceeds the home's energy demand and to discharge stored electricity when insolation and PV output decline. This programmed charge/discharge results in an overall leveling-out of the demand curve, resulting in more value to the utility than to the consumer. The data from this research project has been useful in the evaluation of ZNE-retrofit performance compared with building simulations, the lack of effectiveness of DR in ZNE homes, and insights into the use of residential battery-storage and their value to consumers and to utilities.



Panel installation: 1) Bring panel onto roof. 2) Insert panel into bottom rail. 3) Connect to electrical harness. 4) Capture panel with top rail.

PUBLIC BENEFITS

This project successfully tested, demonstrated, and evaluated the new GE Grid-Ready Plug-and-Play PV Kit and found that it is a valuable addition to the PV market, based on its performance and relatively low cost.

New market channel: The PV kit provided proof of concept and practical implementation of a new class of residential retrofit PV products. The successful installations and subsequent evaluations show that the PV kit provides a new business opportunity for roofing contractors to expand their market offerings.

A new, cost-effective retrofit PV product: At less than $4/Watt, this system was below the market prices for residential retrofits in 2013. Ease of installation results in an overall cost savings by minimizing labor requirements.

Excellent performance: In addition to being less expensive than most competing products, the PV kit performed as well or better than computer simulations predicted.

Shade tolerance: The use of AC modules in the PV kit make it much less affected by shading than the (predominant) PVdc systems. Given that shading is a key barrier to the retrofit market, this tolerance could remove this market barrier to wide-spread adoption of PV on existing homes.

The features in the ZNE home provided a dramatic reduction in peak-demand from the home, and the smart storage system provided the capability to shape residential loads to assist the utility with grid optimization, while being transparent and unobtrusive to the homeowner.

The extensive data sets captured during the nearly 4-year monitoring period of the ZNE home are available to others conducting relevant research.

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CSI RD&D PROGRAM

Distributed Energy Resources Integration

Grantee:
University of California, Davis

Partners:
University of California Davis Energy Institute, Energy & Environmental Economics, Davis Energy Group, General Electric

CSI RD&D Funding:
$1,718,004

Match Funding:
$1,300,000

Project Timeframe:
2011-2014

RD&D Project Portal:
calsolarresearch.ca.gov/csi/75

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West Village Energy Initiative

BACKGROUND

West Village is an on-campus neighborhood designed for students, faculty and staff at the University of California, Davis (UC Davis). The UC Davis West Village Energy Initiative (WVEI) is one of the first large scale communities to be zero net energy (ZNE) entirely through energy efficiency and on-site generation. This unique community also provides an outstanding opportunity for sustainable energy development because the community is a living laboratory for UC Davis faculty, staff and students. This research is complimentary to a project being funded by the California Energy Commission's Renewable Energy Secure Communities (RESCO) Program. The UC Davis research project is broken into two target areas:

Target Area 1:
Improved Photovoltaic (PV) Production Technologies

Target Area 2:
Innovative Business Models to Achieve ZNE

West Village, UC Davis

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

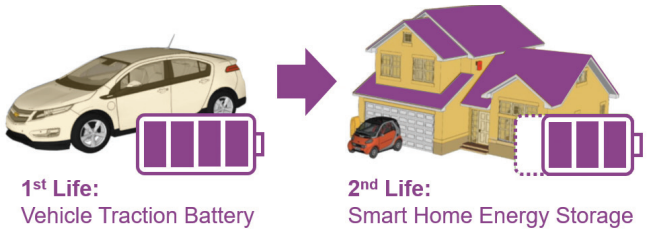
The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

Target Area 1: Improved PV Production Technologies

OVERVIEW AND OBJECTIVES

The UC Davis team developed, designed, installed and evaluated advanced PV technologies as part of the West Village Energy Initiative. There were three primary tasks, two of which included demonstrations of integrated solar power and hybrid solar thermal systems and energy storage and another to evaluate advanced metering infrastructure for West Village. The project was intended to enhance PV production technologies in these key areas:

- Testing and demonstration of existing energy storage technologies capable of working with smaller PV systems in residential and commercial applications.
- Research on the integration of advanced metering infrastructure (AMI) with solar PV and other distributed energy resource (DER) technologies and providing recommendations to optimize existing PG&E and developer owned meters and power systems.
- Testing and demonstration of innovative hybrid solar (thermal/PV) development in multifamily and single family applications.



Single-family home 2nd life Li-ion battery energy storage

METHODOLOGY

The stationary battery energy storage demonstrations consisted of:

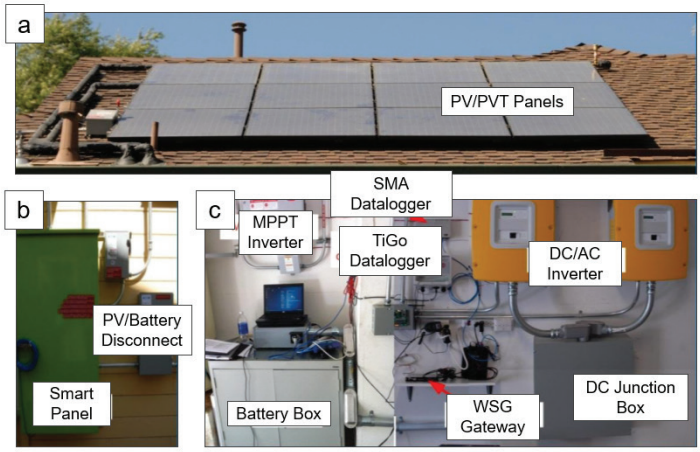
- An energy storage demonstration focused on a commercial, workplace electric vehicle (EV) charging application. The system stores energy from local PV generation and uses the stored energy to charge electric vehicles. This demonstration attempted to optimize EV charging from the PV resource.
- An energy storage demonstration that evaluated the use of second-life batteries for application in single family homes. This demonstration was deployed at an existing residential home, and the batteries were retired from EVs. This demonstration provided the opportunity to evaluate the grid benefits of storing PV energy to shift loads off-peak and to better align with remaining on-peak energy use.

The integration of AMI with solar PV and other DER technologies can offer opportunities to improve overall system performance and efficiency. The two research objectives were to:

- Understand baseline energy performance for the existing and planned new construction buildings at UC Davis West Village.
- Recommend the functional specification for a monitoring and control systems architecture that integrates the customer demand side AMI with solar PV production and other DER technologies, to be able to measure and adjust performance against the ZNE goal on a dynamic, ongoing basis.

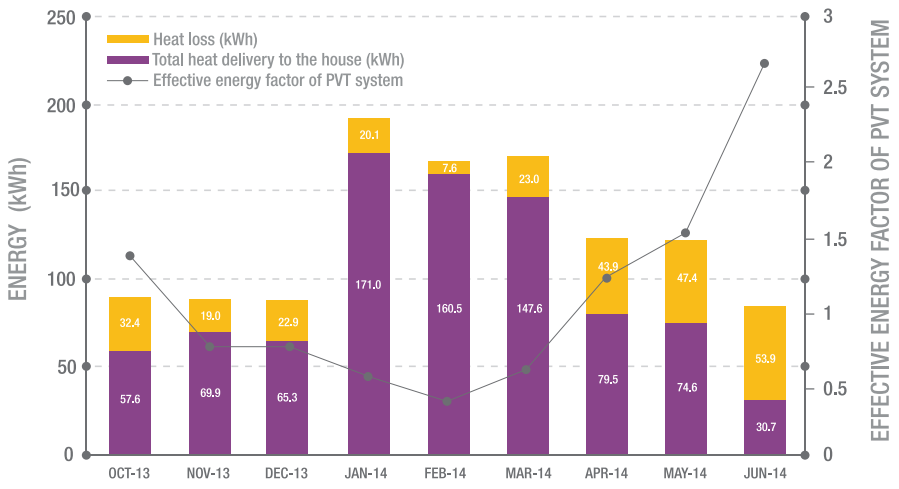
Single-family and Multifamily Hybrid Solar Technology demonstrations consisted of:

- A demonstration to evaluate existing and innovative hybrid photovoltaic/thermal (PVT) technologies and strategies for solar hot water production in multifamily installations. The team developed, designed, purchased, installed, tested and assessed the electricity and hot water production from a hybrid photovoltaic/thermal (PVT) system for two West Village apartment units.
- A demonstration to evaluate hybrid PVT technologies and strategies for solar hot water production in a residential single family environment. The research team developed, designed, purchased, installed, tested, and assessed the electricity and hot water production from a PVT system for a single-family home at Aggie Village. By collecting actual data from the PVT system, assessments can be made as to the performance and energy savings in comparison to the existing means of hot water production.



Smart Grid PV Battery System (a) Roof-mounted PV/PVT panels (b) Smart panel and PV/battery disconnect (c) Battery box, inverter, dataloggers

RESULTS AND OUTCOMES



Monthly heat delivery, heat loss, and effective energy factor of PVT system

The key findings and challenges from the stationary battery energy storage demonstrations include difficulty with system permitting and that no turn-key solution is available in the market and system components must be pieced together from various vendors. The second life battery storage was found to be extremely effective in providing significant load shifting in a residential application. From a time-of-use perspective this did not necessarily optimize the value of the PV system, however it provided load-shifting benefits to the utility and grid.

The AMI integration research found that, at the time of the analysis, the overall energy consumption to production ratio for West Village was projected at 1.25, indicating that additional means would be required to achieve ZNE for the community. Implementation of a master energy management system was recommended to automate ongoing tracking of energy performance and to communicate with residents and addressable devices (programmable communicating thermostats). Encouraging greater energy savings among residents may also be needed to meet the ZNE goals for West Village including both behavior modification approaches and greater centralized control of thermostats with temporary local override capability.

The hybrid solar technology research demonstrations found that in the near term, both flat-plate PVT and solar concentrator PVT are available in the market. Flat-plate PVT has lower efficiency but is better adapted to the roofs of individual houses or buildings. In comparison, most concentrated solar PVT has greater total energy output for the same area but also requires a tracking system, increasing system cost, and hindering applications for residential use.

PUBLIC BENEFITS

Continues to yield critical information for use by other communities in California on mitigating utility impacts as the number of electric and hybrid-electric vehicles increases.

Demonstrates that improved monitoring of energy supply and demand is critical in providing information relevant to control end use decisions in meeting ZNE objectives.

Installed one of the first hybrid PVT systems in California. The fully instrumented system has distinct advantages and can be monitored continuously to the benefit of enhanced design and performance.

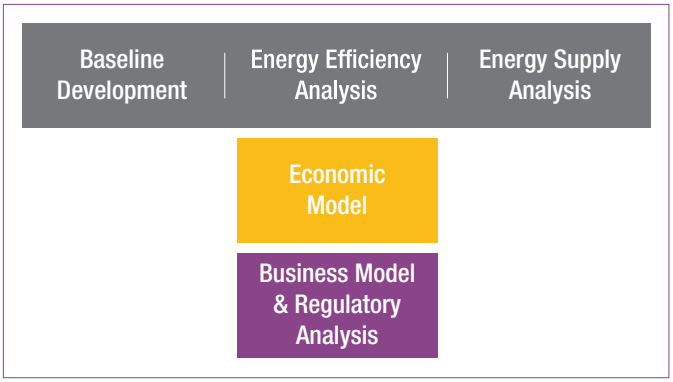
Demonstrates new control strategies for PVT that can influence the pattern of energy use by the building occupants and increase energy efficiency at a reduced cost.

Ongoing monitoring will support highly applicable assessments on potential for commercialization, economic and environmental impacts, and replication throughout the state.

Target Area 2: Innovative Business Models To Achieve ZNE

OVERVIEW AND OBJECTIVES

The UC Davis team avaluated alternative business models for the construction, ownership, and operations of the UC Davis WVEI to achieve ZNE in faculty and staff single-family homes. The overall goals of the WVEI were to achieve ZNE with no higher cost to the developer or the consumer, utilizing multiple renewable resources developed on-site at a community scale. Additionally, West Village would be used as a living laboratory for other energy-related topics.



Model Framework for Economic Model

METHODOLOGY

The UC Davis West Village Project research team performed financial modeling of alternative business models feasible under the current regulatory environment. A roadmap for the development of ZNE homes was completed and included the following three main components:

- Baseline home development.
- Energy efficiency analysis.
- Energy supply analysis.

The potential roles for PG&E were also considered. These roles included:

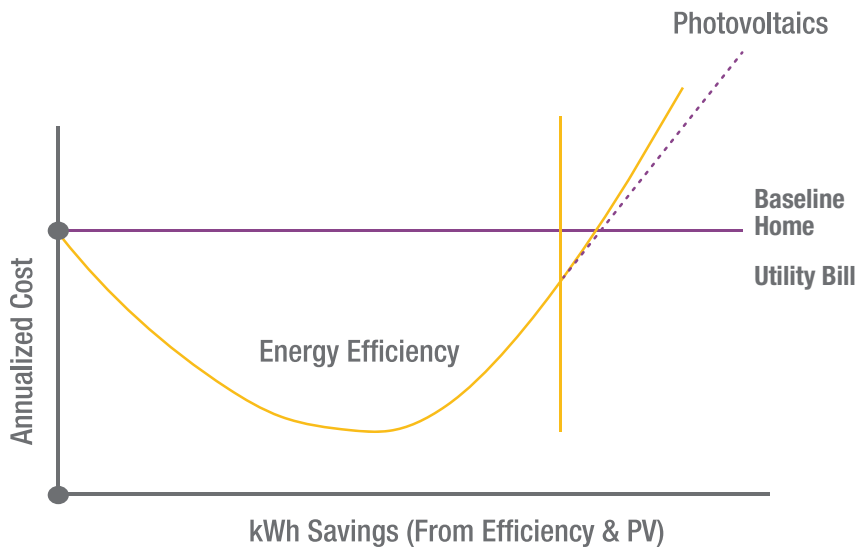
- Tax equity participation in solar PV ownership.
- Biogas offset provider.
- Pilot program for sub metering of EVs.
- Billing mechanisms, such as on-bill energy efficiency financing.
- Participation in West Village visitor center or lab house.

The team also documented regulatory barriers to adopting alternative business models, including net energy metering, virtual net metering, the CPUC's Rule 18 (owners of multifamily residential buildings cannot charge building occupants for electricity) incentive programs, and utility policies. It was not possible to complete two of the research tasks (implementation of alternative business models and metrics of success) since the construction of the faculty and staff housing was delayed and has not yet begun.

RESULTS AND OUTCOMES

Financial Feasibility: The research team found that achieving ZNE at no higher cost to the developer or the homeowner was possible, even assuming no regulatory change. Depending on the assumptions used for the financial model about absorption rates and construction costs, the proposed ZNE homes would cost the same or less than comparable conventional homes.

Virtual Net Metering: Under a community virtual net metering model, one community solar PV array would be sized for the electrical demand of the entire faculty and staff housing community and directly connected to PG&E's grid, rather than being tied to individual meters. Homeowners would be billed based upon their consumption less their share of the community array. By using a virtual net metering model for West Village, the project economics would be improved by approximately $1.8 Million (net present value). Currently, virtual net metering has not been extended to single-family homes.



Cost Effective Comparison between Energy Efficiency and PV

PUBLIC BENEFITS

Other communities pursuing ZNE can leverage the methods, approaches, analysis, and findings from this research project.

The *Zero Net Energy Project: Single-Family Homes Roadmap* and the Excel financial model developed as part of this project are available to other stakeholders interested in pursuing ZNE communities and strategies.

Provides insight on state energy policy concerning community-scale solar projects. If New Solar Homes Partnership incentives were expanded to include community arrays, project economics for West Village could improve by at least $3 million and encourage future community developments.

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CSI RD&D PROGRAM

Distributed Energy Resources Integration

Grantee:
Electric Power Research Institute

Partners:
Meritage Homes, Southern California Edison, BIRAenergy, Proclus Engineering, Pathway Technologies

CSI RD&D Funding:
$1,485,476

Match Funding:
$2,778,825

Project Timeframe:
2014-2016

RD&D Project Portal:
calsolarresearch.ca.gov/csi/109

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Demonstration of Locally Balanced Zero Net Energy Communities

OVERVIEW AND OBJECTIVES

California's *Long Term Energy Efficiency Strategic Plan,* released in 2008, establishes a policy that all new homes in the state be Zero Net Energy (ZNE) by 2020. As ZNE neighborhoods and communities become more prevalent, there is a need to better understand the impact that these homes, which include high-levels of energy efficiency and PV, will have on the utility grid.

To address this gap, the Electric Power Research Institute (EPRI) team evaluated the impacts of a Meritage ZNE neighborhood in Fontana on the local distribution system and to develop mitigation strategies using building energy management systems and energy storage. The team developed ZNE packages including photovoltaics (PV), home energy management systems (HEMS), storage, and demand response (DR) for inclusion in 20 ZNE homes across two transformers. Modeling approaches were used to predict the impacts on distribution systems and demonstrated how HEMS, DR, and storage can mitigate potential grid challenges at the transformer level. The primary goal of this project was to ensure that the widespread development of ZNE communities and the resulting grid integration is beneficial, rather than detrimental, to the operation of the electrical grid and the distribution systems.

The 20 ZNE homes on two separate transformers were equipped with monitoring and controls of solar and loads to measure grid impacts. To compare the impact of storage, (a) nine homes were also installed with energy storage systems while (b) eleven homes did not include energy storage.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

METHODOLOGY

The energy-modeling tool BEopt was used by the team to develop a package of energy efficiency features for inclusion in the Meritage home community in Fontana, CA. PV was included on all homes to help off set the energy towards ZNE. Energy storage requirements were evaluated with consideration for both thermal and electrical storage both at the individual home and transformer level. The research team developed approaches that employ energy storage, HEMS, and DR that ideally are beneficial to distribution-system efficiency and utility grid stability while maintaining operational flexibility.

Various storage options and technologie were evaluated to make determination for implementation. Due to various exteneous conditions the storage deployment at transformer level was not feasible. Therefore storage was deployed at the home level on all homes in one transformer and studied as a comparison to the other transformer with no storage. The distribution modeling used scenarios of Title 24 compliant homes and the upgraded ZNE homes to determine the impact on distribution feeders. The storage and PV load profiles along with net load profiles were analyzed both at individual home and distribution feeder level to determine impact of controls potential for the utility grid operation.

RESULTS AND OUTCOMES

The 20 ZNE homes were designed, constructed, and occupied within a year of the start of the research project. Based on modeling results, the added energy efficiency measures had a net cost of less than $1,000 and resulted in a reduction of 1.4 kW in the size of the 4 kW PV system (savings of about $5,000). The total incremental cost to achieve ZNE was approximately $17,000 per home. To alleviate distribution impact, these homes were set up with controllable loads and with behind-the-meter energy storage. Resource aggregation strategies were developed to connect measurements at the transformer with loads, storage and PV.

The results of the testing showed that energy storage when optimized for grid integration (charge in the morning, discharge in the evening) could reduce the peaks and valleys on the distribution network. The connected thermostat could absorb excess solar production through pre-cooling of homes, and a similar strategy is being implemented with water heating. Two important take-aways from the project were that the control strategy of energy storage could either strengthen or in some cases, accentuate distribution problems, and that modeling tools still have a way to go to address the prominent or “needle” peaks that will be more common in future buildings.

PUBLIC BENEFITS

Demonstrates technical and economic feasibility of ZNE (including PV) for California new homes.

Helps reduce system cost to ratepayers by offering multiple ways to mitigate grid impacts.

Informs utilities and developers about distribution system architecture, specifications, cost, and interconnection properties.

Fosters a better understanding of how ZNE communities impact the electrical grid and provides technological strategies to enhance grid benefits.

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CSI RD&D PROGRAM

Distributed Energy Resources Integration

Grantee:
Tri-Technic

CSI RD&D Funding:
$96,001

Match Funding:
$67,040

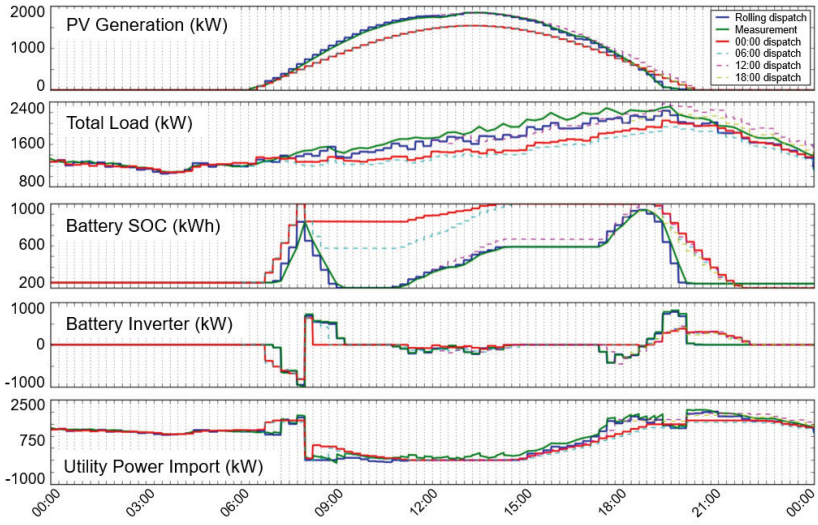
Project Timeframe:
2014-2015

RD&D Project Portal:
calsolarresearch.ca.gov/csi/119

Supervisory Controller for Photovoltaic and Storage Microgrids

Smart microgrid control systems use large datasets to forecast photovoltaic generation, energy, demand, and battery charge and discharge events in an effort to minimize both cost and grid interactions. Tri-Technic installed a combination photovoltaic (PV) panel and battery system at Fort Hunter Liggert Army base. This system is controlled by the Distributed Energy Resources Customer Adoption Model (DER-CAM), a decision support tool designed at Berkeley National Labs.

DER-CAM reads in current, historical, and forecasted weather data to predict energy generation throughout the day. Forecasts are adjusted in real time to reflect actual demand and accuracy improves as more data become available. The system optimizes utility purchase, energy storage and export decisions based on both the values of these forecasts and the established priorities linked to statewide grid demand and energy prices at peak, near-peak, and off-peak hours, which could result in significant cost savings.



Predictions and actual values of five state variables at various times of day. The dispatch time is the time at which the prediction was made.

This document provides a brief project description. For more detail on the project and the California Solar Initiative's (CSI) Research Development, Demonstration & Deployment (RD&D) Program, please visit calsolarresearch.ca.gov

The CSI RD&D Program is managed by Itron on behalf of the California Public Utilities Commission (CPUC).

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CSI RD&D PROGRAM

Distributed Energy Resources Integration

Grantee:
University of California, Davis

CSI RD&D Funding:
$99,943

Match Funding:
$36,917

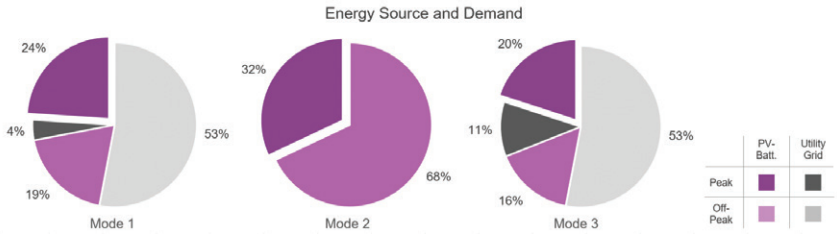
Project Timeframe:
2014-2015

RD&D Project Portal:
calsolarresearch.ca.gov/csi/122

Assessment of Smart Grid-tied Energy Storage Using Second-life Lithium Batteries

The addition of a photovoltaic (PV) array significantly changes the demand profile of a home. The greatest solar energy production occurs during the day, when electricity is cheapest and customer demand is often lowest. Without energy storage, this can result in a surplus of energy during off-peak hours but an undersupply during on-peak periods. The University of California, Davis (UCD) developed three separate control modes to optimize the flow of energy storage using second-life lithium ion batteries in order to maximize economic benefit and reduce grid dependency.

Mode 1 instructed the battery to utilize grid energy during off-peak hours while selling energy back to the grid during peak hours for maximum economic benefit. Mode 2 instructed the battery to meet the house demand with as little grid interaction as possible, resulting in nearly 100% renewable energy use but at the cost of increased battery degradation. Mode 3 optimized the use of solar energy to meet demand, charging the battery during the daytime and discharging to meet energy demand at night, resulting in less back-feeding to the grid but reduced grid interaction. Ideally, all three modes would be used and cycled for an optimal balance of savings, grid interaction, and battery longevity.



Energy source and demand corresponding to the system in modes 1, 2, and 3 (over four days' usage).

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