California Solar Initiative

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

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Final Project Report:

Integration of High Penetration Renewables Using Distributed Energy Resources: A Case Study on the University of California, San Diego

Grantee:

Viridity Energy

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"Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the CPUC, Itron, Inc. or the CSI RD&D Program."

Preface

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

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

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

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

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

Acknowledgements

The project team would like to acknowledge the support of several organizations and individuals, whose assistance throughout this project were invaluable.

First, we thank the California Solar Initiative program and California Public Utilities Commission for offering the opportunity and funding to support this project. Next, we thank Itron, Inc. and Pacific Gas & Electric for providing grant management, support, and contract management for the project, especially Jonathan Wanjiru, Ann Peterson, Smita Gupta, and Matt Heling. We are particularly grateful to the University of California, San Diego (UCSD) for acting as the host microgrid throughout this project, with special thanks to Byron Washom, John Dilliott, Professor Jan Kleissl, and Jo Frabetti. Their insights, knowledge and generous sharing of data towards this project provided a basis for this project. Key considerations for this project's findings are the benefits to California ratepayers, local utilities, and the California energy market. We wish to thank and acknowledge participation from San Diego Gas & Electric and California ISO. Finally, we thank Power Analytics and OSISoft for their technical assistance at UCSD.

Abstract

Under the California Solar Initiative (CSI) Grant Solicitation #2: “Improved PV Production Technologies and Innovative Business Models”, Viridity Energy, Inc (Viridity) along with Energy and Environmental Economics, Inc. (E3) were awarded a two-year grant project titled, Innovative Business Models, Rates and Incentives that Promote Integration of High Penetration PV with Real-Time Management of Customer Sited Distributed Energy Resources. The scope of this project included proposing new business models for improving the economics and incentives supporting the integration of high penetration Photovoltaic (PV) systems using distributed energy resources (DER) and analyzing these models in simulation and real time using Viridity’s VPower software. VPower optimizes the scheduling of demand-side resources using various economic and operational constraints.

The host site for this project 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 VPower as part of the UCSD master controller system, the team sought to demonstrate how managed campus load flexibility could 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 to support the business models was performed to demonstrate a balanced benefit to California ratepayers, utilities, and California ISO (CA ISO).

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Glossary

Ancillary services	set of services procured by the balancing entity for balancing and power quality maintenance purposes
CEC	California Energy Commission
CHP	Combined Heat and Power plant, also known as cogeneration
CUP	central utilities plant
DG	distributed generation
DER	distributed energy resources at a customer site (e.g., generation, efficiency, demand response, storage)
EMCS/ EMS	energy management control system/ energy management system
GHG	greenhouse gases
Load following	process of eliminating supply and demand deviations within the hour that occur on a ~ 5-20 minute timescale
Ramp	requirement to increase or decrease generation to meet sustained changes in demand; measured in MW / minute; early morning and late evening ramps are typical
RE	renewable energy
Regulation	ancillary service that is procured by the balancing authority to balance all deviations continuously; provide load following and frequency response
RESCO	renewable energy secure communities
Setpoint	refers to a control system input or goal (e.g., temperature setpoint of an HVAC system)

Spinning reserves	on-line reserve capacity that is synchronized to the grid system and ready to meet electric demand within 10 min of a dispatch instruction; needed to maintain system frequency stability during emergency operating conditions and unforeseen load swings
Non-spinning reserve	off-line generation capacity that can be ramped to capacity and synchronized to the grid within 10 minutes of a dispatch instruction by the ISO, and that is capable of maintaining that output for at least two hours. Non-Spinning Reserve is needed to maintain system frequency stability during emergency conditions
PLS	peak load shifting. PLS is frequently used to refer permanent load shifting, which UCSD resources are also capable of providing
PV	Photovoltaic. PV systems convert solar irradiance into electrical power
TES	thermal energy storage
TRC	total resource cost

Executive Summary

Using the University of California, San Diego (UCSD) microgrid as a host site, this study set out to analyze via simulation, and then demonstrate 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).

This report seeks to achieve two purposes: documenting the project process, including the challenges encountered in execution of the project and main findings. The reader is referred to the companion reports for a more focused discussion on the main analysis that supports the key findings, particularly the "Task 6, 7, 8: Strategies and Incentives for integration of renewable generation using distributed energy resources" report.

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Policy context

California has significant clean energy goals. The Global Warming Solutions Act (AB 32) requires greenhouse gas (GHG) emissions to be reduced to 1990 levels by 2020, leading to the legislated 33% (by 2020) Renewable Portfolio Standard. The Million Solar Roofs initiative, net energy metering and zero net-energy goals for new construction encourage the adoption of PV at higher penetration levels. Numerous studies discuss potential challenges of integrating high penetrations of PV generation, ranging from utility concerns on backflow in distribution systems to real-time supply-demand balancing challenges for the CAISO, which must also address long-term resource planning questions.

California's *Energy Action Plan* places distributed energy resources (DER) such as energy efficiency, demand response and distributed generation at the top of the 'loading' order and numerous policies promote their adoption. FERC orders 745 and 755 promote the direct participation of loads and DERs in energy and ancillary service (AS) markets. This project is a timely and important case study to demonstrate how

DERs can help integrate high penetration renewables cost-effectively, as motivated by the vast existing resource of DER in California and declining costs of DER with innovation.

Objectives

The broad goal of this study 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.

With this objective, this project offers useful suggestions to UCSD and policy makers on how to overcome gaps and barriers to promote the use of DER for renewables integration.

Approach

Model campus resources

UCSD resources were modeled within the VPower database, focusing on the UCSD Central Utility Plant (CUP). Figure ES-1 describes the energy flows across UCSD from the primary energy inputs (electricity, natural gas, diesel, solar energy) by end-use at the building level. The outputs of the CUP are electricity, chilled water and hot water. The CUP has two 13.3 MW natural gas generators that can meet ~80-90% of UCSD’s electrical needs. Energy is recovered from the natural gas generators exhaust to produce hot water, chilled water (through steam chillers), and/or electricity (through a 3 MW steam generator). The CUP contains steam and electric chillers and boilers, which generate steam for producing hot water and potentially for the steam chillers. A 3.8 million gallon thermal energy storage (TES) tank provides chilled water during peak periods. Some buildings have individual HVAC systems and are not served by the CUP. Finally, UCSD has ~1.5 MW of onsite behind-the-meter solar PV that supplies non-CUP HVAC, lighting and plug loads.

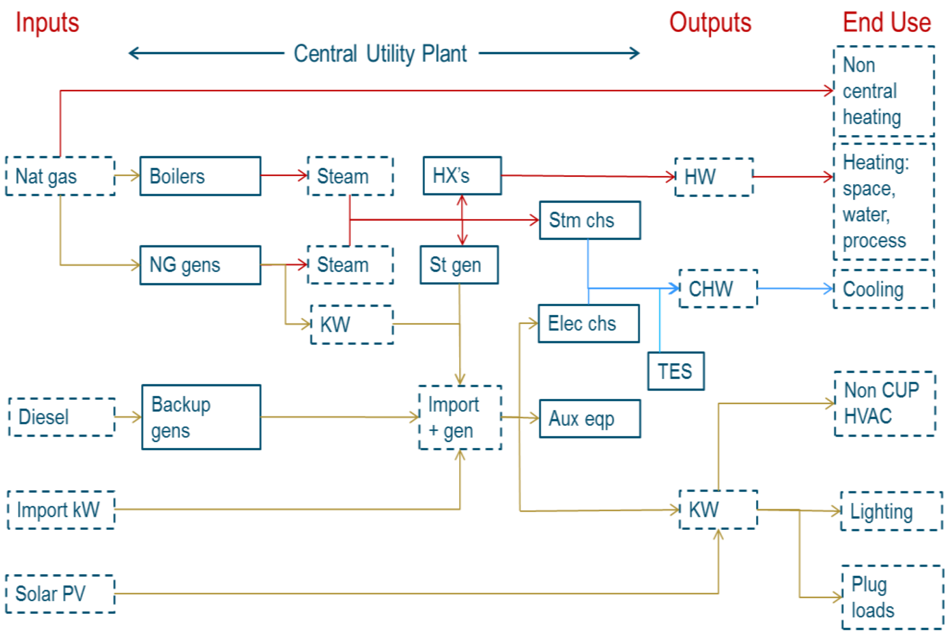


Figure ES-1: Campus resources energy flow diagram

One year of interval historical metered data was used to baseline the CUP resources, understand campus electrical, hot water and chilled water needs, individual system efficiencies (e.g., heat rates of the generators), overall system efficiency and typical operations. Data on UCSD's actual solar generation and their forecasted solar generation was also obtained. The resulting information was used in the modeling and model validation of VPower and the UCSD Dispatch Optimization Tool.

Proposed business strategies

Three strategies of *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 micro grid's status quo. For each strategy, it was determined whether it was technically and operationally feasible and cost-effective from two perspectives: (a) total resource costs and (b) UCSD as a utility customer. If the answer was 'yes' to the first perspective, but 'no' to the second, the tariff and regulatory changes required to motivate greater participation by UCSD and similarly situated large commercial and industrial (C&I) customers were explored.

Peak load shifting. With greater renewables penetration, PLS will become increasingly important to manage later peaks with increasing solar generation and to enjoy abundant nighttime wind generation that is now at times curtailed to maintain the state's real-time system resource-load balance. PLS is clearly technically and economically feasible, as it is already done by UCSD. What is less clear is whether current tariffs could be redesigned to motivate large C&I customers to provide additional load shifting or invest in new PLS infrastructure.

PV firming. This strategy seeks to manage the difference between actual and forecasted solar generation (i.e., forecast error) at UCSD. The operational feasibility of reserving a quantity of flexible capacity from UCSD resources to 'firm' campus PV generation under increasing levels of PV penetration was modeled. As there is currently no explicit cost or penalty to UCSD for PV forecast error, a hypothetical rate scheme (similar to the energy imbalance tariff used by a grid operator of a wholesale market) was developed that penalizes UCSD for deviations from the day-ahead forecast.

Grid support. This strategy aims to use UCSD resources to provide balancing services to CAISO to aid integration of large scale renewables outside of the UCSD campus. The team modeled the flexible range of UCSD's natural gas generators (6.6 MW) to provide a fixed amount of regulation up and down each hour. Then the team evaluated whether additional campus resources can increase the amount of grid support within the context of the existing frequency regulation market. UCSD's costs of providing regulation were compared to determine whether the strategy is cost-effective from both the TRC and customer point of view.

The business strategies are described at a high level in this report and in more detail in the "Task 6, 7, 8: Strategies and Incentives for integration of renewable generation using distributed energy resources" report.

VPower implementation

Viridity's VPower platform is a proprietary software developed to manage and optimally schedule demand-side resources and bidding strategies using numerous economic and operational inputs. VPower was installed on servers at the UCSD campus and integrated with the campus master controller supporting data exchange with

PowerAnalytics' Paladin™ and OSISoft's PI™, which provides access to campus real-time and historical cost, load and resource data. The vision was that VPower would be used to optimize and implement dispatch strategies on campus in real time. Due to challenges with obtaining real time campus metered data, the team decided to focus on simulating campus operations. In addition, the baselining activity revealed complexities of the microgrid operations that would have required extensive software and model structure changes to VPower. These changes could not be accomplished during the project timeframe with sufficient confidence to allow the team to analyze the business strategies proposed. In order to provide sufficient analysis of the strategies, the team focused on expanding the scope of the UCSD Dispatch Optimization Tool.

UCSD Dispatch Optimization Tool

E3 used the *Analytica* software platform to develop the UCSD Dispatch Optimization Tool to quantify the net benefits of each proposed business strategy. This tool performs hourly, rather than sub-hourly, dispatch optimization to implement scenario analysis over hourly, monthly and annual time scales. By incorporating the physical relationships of the CUP resources described in Figure ES-1, it minimizes UCSD's costs by dispatching resources to meet UCSD's electrical and thermal needs, while obeying physical constraints such as capacity and minimum run times are satisfied. The modeling approach and results are described at a high level in this report and in more detail in the "Task 6, 7, 8: Strategies and Incentives for integration of renewable generation using distributed energy resources" report.

Key results and discussion

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 and second, E3's UCSD Dispatch Optimization Tool provided a simulation and analysis environment that allowed the team to study and recommend three strategies that are technically and economically feasible to support PV integration.

Real time management of campus resources was not completed during this project's timeframe. This was due, in part, to the late availability of the real time data feed from the campus and in part due to the team focusing on VPower software modifications and debugging efforts to support the accurate simulation of campus microgrid operations.

A considerable portion of the project was focused on gathering and analyzing campus historical data from several system sources in order to validate models and understand baseline operations under current rates. This scenario is not unusual based on experiences with other customers, but is frequently underestimated.

Conclusions, recommendations, benefits to California

The feasibility of managing DER in a simulation and real time environment was evaluated by using the UCSD Dispatch Optimization Tool and the VPower platform to model and optimize dispatch schedules for micro grids during this project.

The team's findings using the UCSD Dispatch Optimization Tool suggest that DER are technically capable of providing cost-effective integration services. These findings, however, also suggest that incentive and program design changes are needed to strengthen the business case for large C&I customers.

Peak load shifting. Removing the non-coincident demand charge (which would require recovering SDGE's fixed costs elsewhere) could increase a large C&I customer's cost-effective peak-load reduction. In the case of UCSD, the estimated increase is about ~ 1 MW.

PV firming. PV firming by a large C&I with its own resources 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 C&I customer may profitably offer grid support service. For the UCSD case, small energy cost savings were found. But the savings can increase with additional resources enlisted to provide independent up or down regulation bids.

The above findings lead to the following recommendations to policy makers:

- Waive the non-coincident demand charge for PLS customers to promote greater peak load shifting and increased off-peak load to absorb excess generation.
- Allow utilities to negotiate terms on an individual basis with large C&I customers to accommodate unique capabilities and appropriate, site specific baseline calculations.
- Support development of an operationally robust dispatch model that accounts for uncertainty and assesses the benefits and risks from complex operational strategies. Also develop computationally efficient optimization approaches hourly or sub-hourly dispatch over daily, monthly and annual time steps with more powerful optimization engines.
- Support an implementation study of DER integration strategies using UCSD as a pilot site. Modest additional effort would leverage this work and use UCSD as a case study produce a great deal of information on how modeled strategies translate to real world operation.

The insights from this study are relevant beyond UCSD. There is significant technical potential for using existing DER at C&I customers across California to provide renewables integration services. College campuses total 500 MW of load; industrial customers total over 2000 MW of load[1] and have many controllable end-use loads (pumps, fans, motors); there are ~ 8500 MW of combined and heat and power systems at ~ 1,200 sites in California[2]. Many of these customers have similar DER system types as UCSD and could potentially provide renewables integration services. This analysis shows that a simple policy change —removing the non-coincident demand charge can decrease load by ~ 1 MW at UCSD.

This project has generated insights, tools and strategies beyond renewables integration. In particular, similar analysis can be done for California campuses to reduce their

[1] Itron 2007, Assistance in Updating the Energy Efficiency Savings Goals for 2012 and Beyond Task A4 . 1 Final Report : Scenario Analysis to Support Updates to the CPUC Savings Goals Main (2007), at 37.
[2] ICF International, 2012. Combined heat and power: Policy analysis and 2011-2013 market assessment. Report prepared for the California Energy Commission. Report CEC-200-2012-002

overall energy consumption, costs and GHG emissions, which is highly relevant in an era of cost consciousness and university sustainability goals.

Introduction

Viridity Energy, Inc. (Viridity) and Energy and Environmental Economics, Inc. (E3) received a grant under the California Solar Initiative (CSI) Grant Solicitation 2 to study innovative models, rates and incentives to promote integration of high penetration PV with real-time management of customer-sited distributed energy resources (DER).[3] This work is motivated by numerous policies promoting renewable and distributed generation in California. The CSI has a target of 1940 MW of new solar capacity by 2016 in support of the State of California's Million Solar Roofs Program and the California Renewable Portfolio Standard (RPS) that requires 33% of energy procurements by energy suppliers to be procured from eligible renewable energy resources (including solar resources) by 2020. Numerous studies highlight the potential challenges from high penetration of intermittent renewable generation.

The University of California, San Diego (UCSD) provided the host site for this project. The UCSD microgrid has a rich DER base that includes a 2.8 MW fuel cell powered with directed biogas, a central utilities plant with 30 MW of electrical generation, steam and electric chillers, a 3.8 million gallon thermal energy storage (TES) and roughly 1.5 MW of onsite solar PV, including two sites with PV integrated energy storage. UCSD owns and maintains a 69 kV transmission substation and four 12 kV distribution substations on campus, with multiple PMU synchrophasors installed by SDG&E. UCSD is also in the process of installing over 50 Level 2 & 3 electric vehicle charging stations.

The goals of this project were to install Viridity's VPower platform and demonstrate dispatch and optimization strategies using UCSD resources to support the integration of renewable and distributed generation. This project's approach was to characterize the campus resources in both the VPower platform, and the UCSD Dispatch Optimization Tool developed by E3. The models within these applications were used to test the impacts and cost-effectiveness for three types of strategies: peak load shifting, PV firming, and grid support. The results show that cost-effective integration strategies are possible with DER's and identify specific tariff and market barriers encountered.

[3] CSI Solicitation #2 was titled "Improved PV Production Technologies and Innovative Business Models".

Project Objectives

The broad goal of this project was to explore how distributed energy resources (DER) can cost-effectively support the integration of high penetrations of PV systems. The project develops innovative strategies to accomplish this goal and evaluates these strategies using the UCSD campus as a case study. The proposed strategies are designed to overcome current gaps and barriers in energy markets, utility programs and tariffs.

More specifically, this project focused on the following objectives:

- Develop dispatch and optimization strategies for DER to reduce energy costs, integrate renewable generation and support reliable grid operation

- Develop tariffs, incentives and business models to promote the adoption of the identified strategies

- Enhance the VPower model and smart grid master controller at UCSD in order to test and demonstrate identified strategies with centralized dispatch and optimization of campus DER in real time and simulation modes

- Perform cost-benefit analysis for the feasible strategies from societal, utility, customer and ratepayer perspectives

- Provide documentation and an analysis tool to disseminate actionable findings to other large commercial and industrial customers and policymakers

The project scope included eight tasks to accomplish these objectives as described in detail under subsequent sections of this report.

Project Approach and Results

The project team focused on three key areas: (1) analyze and demonstrate how load management and shifting can serve as a flexible resource to integrate a high penetration of PV systems, (2) demonstrate that barriers to the deployment of high penetration PV systems can be overcome through providing appropriate incentives and tariff changes coupled with real-time resource monitoring and management and (3) demonstrate that the optimization of distributed energy resources in support of increased deployment of PV systems can provide economic, reliability and market price benefits to California .

The eight tasks identified for the grant project can be broadly categorized as:

Project Management and Reporting

Task 1: Project Management, Reporting, Technology Transfer and Outreach

Preparation and Environment Setup

Task 2: Identify and specify strategies for integrating high penetration PV with DER management at UCSD in the California market using VPower™

Task 3: Identify and develop tariffs and incentives that promote the adoption and optimal dispatch of promising DER technologies and load management strategies

Task 4: Install and Integrate VPower System (in simulation and real time)

Baseline Campus Resource Performance

Task 5: Establish baseline performance for the UCSD DER operation under current rates and incentives

Test and Analyze Scenarios and Publish Results

Task 6: Refine and test business models, management strategies, tariff and incentives with VPower in simulation and real-time mode

Task 7: Cost Benefit Analysis

Task 8: Analysis Tool

Project Management and Reporting

Task 1 focused on project management and dissemination of information through a variety of reports and presentations to stakeholders. Monthly status reports and bi-annual reports highlighted the project progress and challenges. The final report (this report) summarizes the project activities, findings, recommendations and lessons learned.

Project stakeholders were further informed through an introductory presentation in early 2011 (California Solar Initiative (CSI) Grant Project Overview) and a mid-project overview and demonstration of VPower (California Solar Initiative (CSI) Research, Development, Demonstration and Deployment Program Grant #2 Demonstration) in early 2012.

Preparation and Environment Setup

Objectives

The main objectives of tasks 2, 3 and 4 were to (1) identify dispatch and optimization strategies for DER and load management at UCSD to reduce energy costs, support the integration of renewable solar generation and support reliable grid operation, (2) identify and develop tariffs and incentives that can encourage cost-effective incorporation of DER into the California power grid; and (3) enhance the VPower model and microgrid master controller at UCSD in order to test and demonstrate the identified strategies with centralized dispatch and optimization of campus DER in real time and simulation modes.

A further objective was to receive real time and forecast information from the various mix of metered campus resource types including generation, load, hot and cold water requirements, price data, and weather data, and to recommend an optimized campus dispatch. The recommended dispatch was to be reviewed and validated by the campus operators and eventually used in a real-time dispatch.

Approach

DER integration strategies were developed that considered the new challenges to grid operators, utilities and consumers associated with large scale distributed and centralized renewable generation.

Figure 1 illustrates the diverse nature of renewable generation integration challenges, from procuring sufficient flexible capacity years in advance to managing rapid variations in load and generation over minutes to seconds. The project work focused primarily on how DER can address integration challenges at the 15 minute to 1 hour timescale, both at the distribution and system grid level.

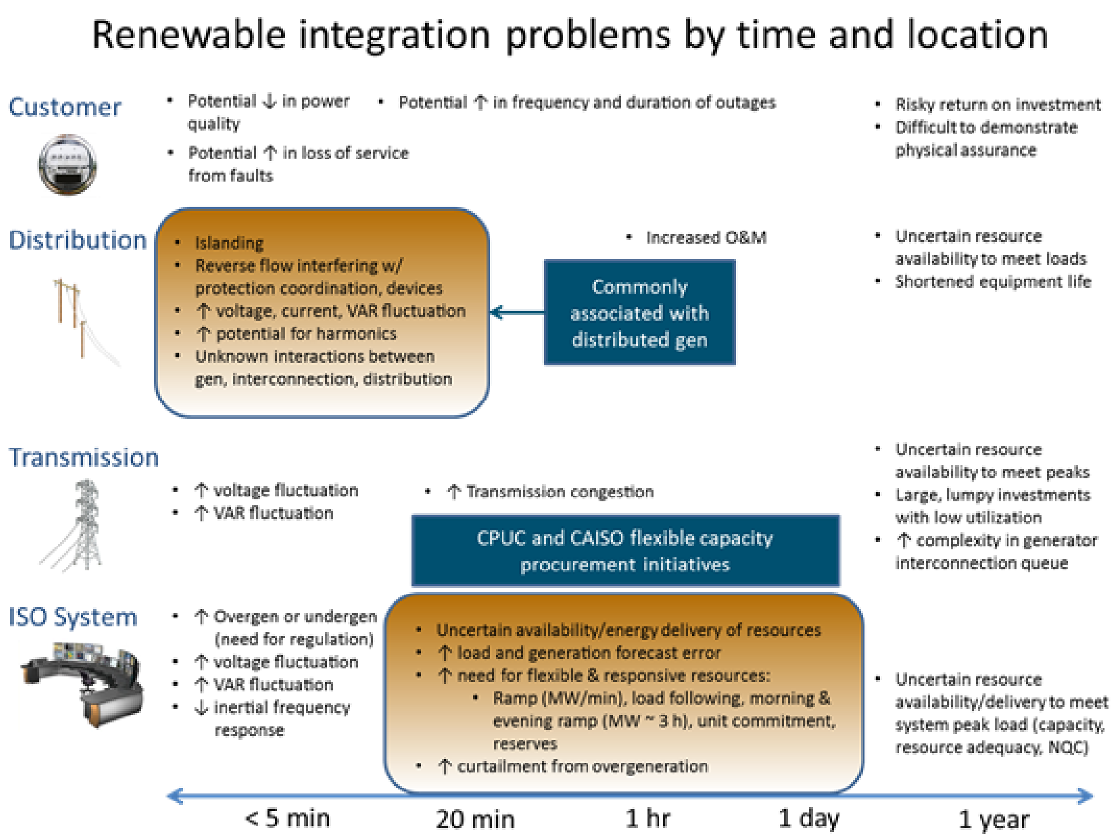


Figure 1: Potential grid problems from increased renewables

With increasing PV adoption, net energy metering has become more controversial and is challenged by utilities and ratepayer advocates. Determining rates and incentives that address multiple stakeholder needs and that are cost-effective across different perspectives is essential for continued viability of DER. The potential for developing rates and incentives that can simultaneously motivate consumer adoption and provide net benefits to the utility, ratepayers and society was assessed. Mirroring the strategies that were developed under Task 2, the rates and incentives proposed for study focused on encouraging customer response in short (5-30 minute) timeframes.

In preparation for analyzing resource behavior, and testing the proposed strategies, Viridity's VPower™ software platform was installed on virtual servers provided by UCSD. VPower is designed to create half-hourly dispatch schedules that optimize DER participation to meet campus energy demands, lower costs, and take advantage of market programs for revenues.

As a first step, the campus resources, requirements, and constraints needed to be identified and understood. Information obtained from campus staff, from Power Analytics and extracted from campus historical repositories were the primary sources of data describing the campus resources. The goal was to build a model within VPower that would be used to create dispatch schedules that could be validated using campus historical data from multiple sources.

Figure 2 illustrates an off-line working diagram of how the resources fit together.

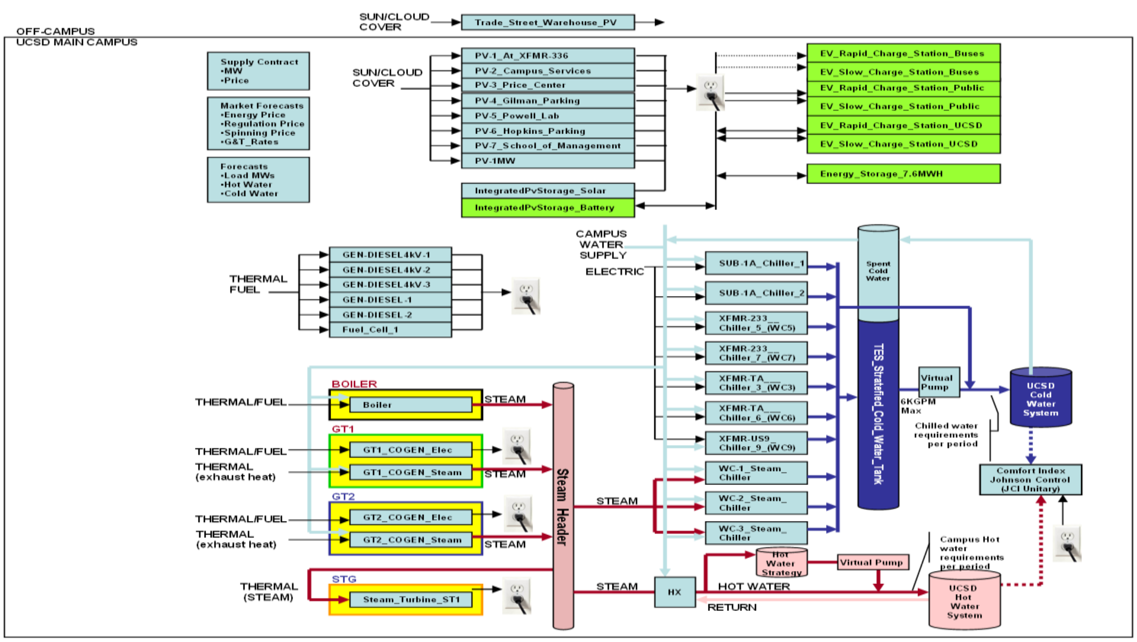


Figure 2: Block Diagram of UCSD Resources Modeled in VPower

Models with static defaults, and capability for dynamic updates with system data (when data is available) were developed and tested so that dispatch schedules could be created using simulated inputs as well as real-time inputs. On and off campus energy resources were evaluated for use in the models based on their suitability to support the project's broader goals. External inputs, such as real-time weather, day-ahead and real-time market prices and real-time data feeds from campus DER, were included in the optimization. Real-time data feeds coupled with the UCSD Master Controller's ability to re-optimize based on changing conditions, would allow rapid responses to pricing and dispatch signals to support intra-day price sensitive scheduling in market programs.

The UCSD Master Controller consists of Power Analytics Paladin™ system and OSIsoft's PI System. The Paladin system's function is to monitor and control campus generation, storage and loads and to analyze VPower's optimized dispatch schedules against campus electrical constraints (for example a campus feeder kW limit) to ensure operations based on the candidate schedule would be reliable. The PI System's function is to provide a data repository for real time and historical campus data. An interface with the UCSD Master Controller was developed to provide a link to import real-time and historical data directly into the VPower model. This interface supported the bidirectional exchange of information regarding the status of resources, the proposed optimized scheduling of resources, and the response from power system analyses by Paladin.

Results

During the early months of the project, the team focused on analyzing existing tariffs and UCSD operational practices in order to understand the opportunities and limitations at the campus. Several strategies were outlined to explore how load participation through demand response, permanent load shifting and/or responsive load/load following in the wholesale market could help support the integration of large amounts of renewable energy into the grid. The report "Task 2: Strategies for integrating high penetration renewables" was produced outlining some of the challenges and market-supported technical solutions resulting from a high penetration of renewables on the electric system. The report outlines the strategies that would be explored as part of this project. These are further developed later in this report.

As a compliment to the strategies outlined, several alternative rate designs and incentives, intended to motivate responsive customer load management in the 5-30 minute time frame, were proposed for evaluation in the report "Task 3:Tariffs and incentives for integrating high penetration renewables". The report outlines challenges that utilities face in encouraging real-time customer load management with DER, how current rates and incentives do and do not address the challenges, and describes several alternatives that might incent customers without burdening ratepayers. The rate and incentive levels were developed further and evaluated in the various strategy scenarios as part of the project and described later in this report.

In order to analyze the feasibility and impacts of each of the strategies and study scenarios as outlined in the above reports, the VPower software was integrated into the UCSD Master Controller System (Power Analytic's Paladin™ and OSIsoft's Pi Systems) and a more detailed VPower model of the campus DER was developed. Prior to installation at UCSD, the VPower product software had not been integrated with non-Viridity applications (other than building management and meter data systems). To provide meaningful schedules that were achievable given campus system conditions, and to ensure reliable operations, it was necessary to get status information in real-time, and to subject the optimized schedules to power system analyses.

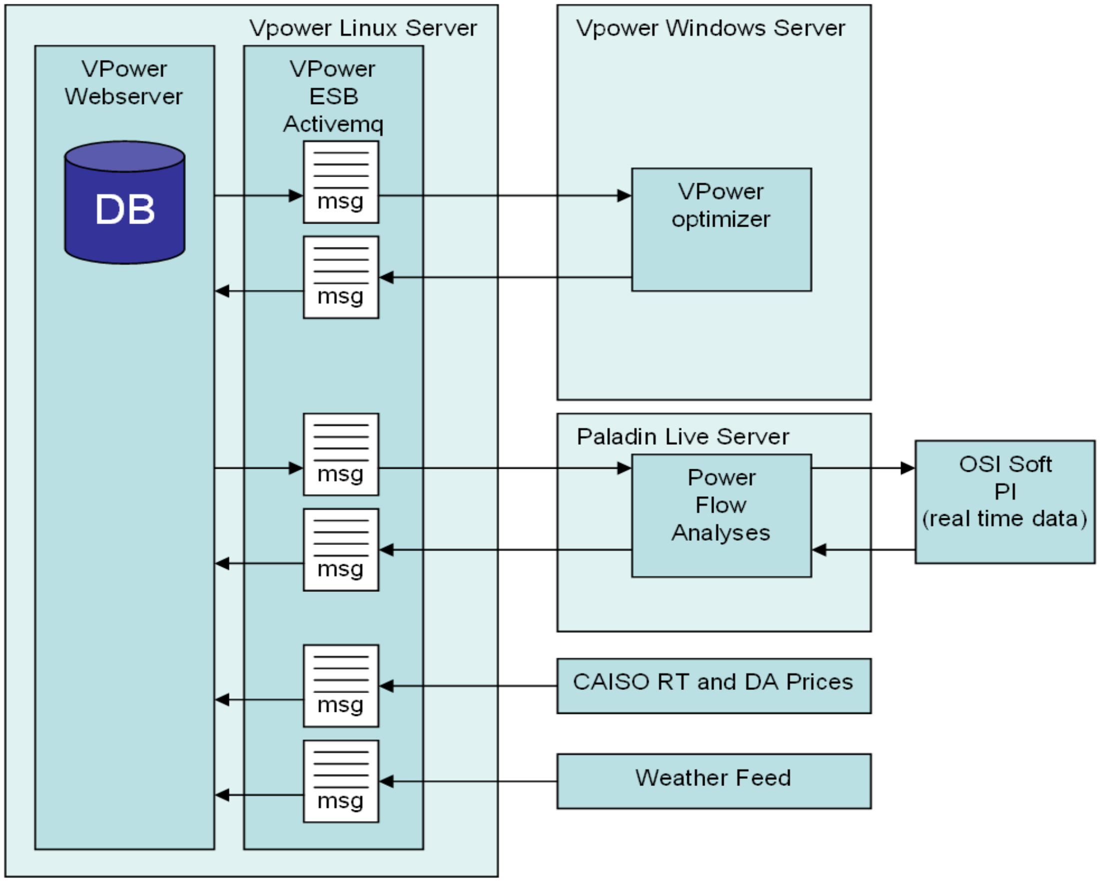


Figure 3: Interface flow with UCSD Master Controller

The interface to the Paladin system as illustrated in Figure 3 was developed to exchange data to confirm campus resource availability, receive real time and historical meter readings from campus resources, and evaluate proposed dispatch optimization schedules against system constraints. The interface was based on a loose integration using an open source lightweight Enterprise Service Bus (ESB) called ActiveMQ. While this approach aided development for the partners, troubleshooting issues with the partner application and getting actual data from the interface proved somewhat problematic.

Data requested via the interface included resource actual status ON/OFF, output level information, updates to availability, and forecasted campus needs for electrical campus load, campus hot water MMBTU requirements, and campus chilled water MMBTU requirements. The report "Task 4.1: Report on Installation and Integration of VPower™ into the UCSD System" details the installation and integration of VPower on campus.

Leveraging work from a prior grant (the CEC RESCO grant), the campus model in VPower included a simple generation, storage and load model. To more comprehensively model demand response and load flexibility, thermal resources (steam generators, stratified cold water storage or hot and chilled water requirements) were added to the model. The large storage tank, the interruptible load (Johnson Control Comfort Index) and the hot water temperature reduction strategy meant that VPower could simulate shifting multiple MWs of load associated with heating and cooling the campus facilities to the hours where the energy was least expensive.

Several off-campus facilities were considered to be added to the model in order to broaden the applicability of the study scenarios. Ten sites in San Diego County were pre-screened to determine the value to the program. The screening criteria for the sites was more than 300kW of solar generation installed behind the meter, some controllable/flexible load, some storage capacity and located in SDG&E's service territory. Meetings were conducted with site managers in order to explain the project and to better understand the site resources. Ultimately, due to insufficient quantities of controllable load, insufficient solar capacity, or concerns about site security, it was decided to focus solely on the UCSD campus resources. The report "Task 4.2: Report on the expansion of the Distributed Energy Resource (DER) Model" further details the model expansion activities.

As the campus model was expanded, the VPower software was enhanced to include new resource types. Additional updates include enhanced optimization algorithms, and user interface improvements, resource specific, period-by-period estimates of emissions (e.g., carbon dioxide); a summary of the period-by-period steam production being modeled; and additional information pushed to the dashboard UI in Power Analytics' Paladin application. The report "Task 4.3: Report on Enhancement of VPower™ to Provide Active Real-time Management of DER" outlines the VPower enhancements in greater detail.

A parallel UCSD project was in progress to consolidate the historical data from the various campus sources into the PI System and to provide real-time links from the PI System to monitor and control campus equipment. Readiness of the centralized data source developed by that project was a key dependency in the provision of real-time data and historical data to VPower. However, for the resources modeled in VPower, the data consolidation was not ready until beyond the mid-point of this project. This interfered with the ability to present VPower with any real-time or historical data.

As real-time telemetry became available through the UCSD Master Controller and centralized repository, the team conducted “point to point” tests. This involved observing the source data values, validating that naming translation was occurring as expected, and confirming that it could be received into the VPower database correctly. Since each piece of data has several ‘tags’ depending on the source of the data, the process is very time consuming and troubleshooting is often difficult. In some cases a single input required by VPower, such as energy to chill water by hour, required combining several data points for each hour (e.g., water flow rate, ambient temperature, chilled water output temperature, return water flow rate, etc.).

Eventually due to project schedule constraints, use of the real-time data interface was abandoned for CSI studies and historical data dumps and forecasted data were used for the study scenarios. While the collection of historical data from disparate sources took more time than it would have from a central repository, a year’s worth of fairly complete data included enough variability to support model validation. The data set was loaded into VPower using database scripts so that it could be utilized to populate planning studies/cases.

Baseline Campus Resource Performance

Objectives

Task 5, the baseline task, aimed to identify UCSD’s energy needs and how these needs have been met using a combination of imported resources and campus resources, as well as to gain insights on how these resources may be utilized for providing renewables integration services. The desired outcome of the task was representative data sets with which different renewables integration strategies and business cases could be tested.

Specific goals of the baselining effort included the following.

- Understand the regular modes of operation of UCSD's systems
- Understand the performance of UCSD's solar PV resources and forecast error
- Understand UCSD's thermal & electrical needs
- Quantify efficiencies at the microgrid system level and individual equipment level
- Determine and quantify the flexibility available within the UCSD resources
- Identify opportunities for operational improvement

Overview of UCSD resources

The UCSD microgrid is a complex system that meets much of the campus's electrical and thermal needs. Figure 4 describes the energy flow from the primary energy inputs to end-use service.

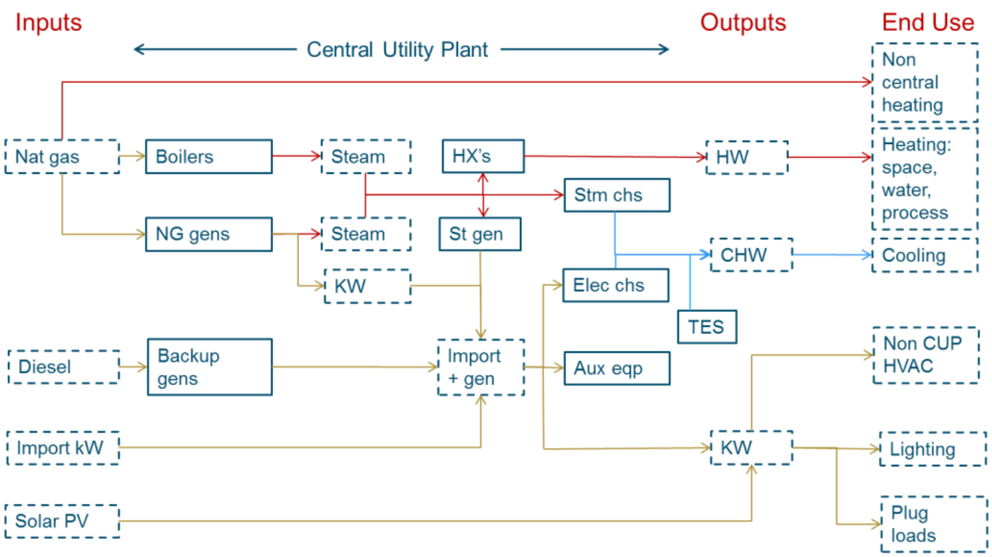


Figure 4: Campus resources energy flow diagram

At the heart of the central utility plant (CUP) are two natural gas generators ("NG gens") each with a 13.3 MW capacity. The generators typically operate at all times. Energy is recovered from the generators' exhaust to produce steam, which is used to produce hot water; generate additional electricity through a 3 MW steam turbine; or generate chilled water through steam driven chillers.

The CUP generates chilled water through a combination of the three steam driven chillers (~ 10,000 tons of capacity) or five electric chillers (~ 7800 tons of capacity). The CUP has an approximately 3.8 million gallon thermal energy storage (TES) tank that provides chilled water during peak periods; the TES tank pump allows the TES to provide ~ 3100 tons of chilled water. The TES tank is discharged with the goal of avoiding electric chiller operation in peak periods. UCSD's hot water needs are met by utilizing recovered waste heat from the generators and by operating the boilers.

Some campus buildings have individual HVAC systems and are not served by the CUP. UCSD has roughly 1.5 MW of behind-the-meter solar PV; a 2.8 MW fuel cell and PV integrated energy storage were installed after this analysis was conducted.

Approach

Scope

The UCSD campus is vast; this task did not involve characterizing every building and energy utilizing equipment on campus but focused on the UCSD microgrid or central utility plant (CUP), which houses the microgrid resources. This focus was an appropriate level of scope because many of the renewables integration strategies focus on exercising the microgrid systems: specifically, the operation of the natural gas generators, steam generator, thermal storage tank, and electric and steam chillers. UCSD participates in demand response programs and has the ability to provide ~ 1.4 MW of interruptible load over a 2-4 hour period. However, this resource was not central to the renewables integration strategies explored in this project since the focus was on fast response strategies and those that can be provided routinely (in contrast to event-based demand response).

For purposes of the baselining effort, the electrical need of UCSD are defined as the total electricity consumption minus the electric chiller consumption. The thermal needs of UCSD, for purposes of the baselining effort, are defined as the hot water and chilled water loads met by the CUP. Although individual buildings may have separate HVAC systems to meet these needs, they are not considered within the scope of the renewables integration strategies.

Data collection

More than one year of interval data were obtained from the campus to characterize UCSD's electrical, hot water and chilled water demand; UCSD solar generation and forecasted generation; electric and steam chillers, thermal storage system, boilers, and natural gas generators. For each system, information on operating capacity and efficiency was obtained. Collectively, these data were used to inform the efficiency of UCSD's 'combined heat and power' system which includes the natural gas generators and systems that utilize the recovered energy (i.e., steam chillers, hot water heat exchanger, steam generator), including its efficiency and operating heuristics.

Information was collected on historical prices; namely SP15 market prices[4]. More than 3 years of data were obtained for some data points, namely hourly values of whole campus electrical, chilled water and hot water needs.

Assemble, visualize and analyze data

The team assembled the multiple data sets from several campus sub-systems, visualized the data using graphical methods and analyzed the data using binning analysis and descriptive statistics.

Three levels of analysis of the UCSD system were conducted:

- System level analysis of the CUP operations
- Analysis of individual equipment performance
- Assessment of campus electrical and thermal needs

The system level analysis involves analyzing the input and output relationships across Figure 4, focusing primarily on the combined heat and power system: the dispatch of the natural gas generators, how the steam generated by these systems is utilized towards hot water production, chilled water production or electricity generation via steam turbines. The system level analysis requires analyzing historical data from multiple sub-systems. The team assembled the data into data sets with comparable time stamps and intervals to facilitate the analysis of input/output relationships across Figure 4.

The team analyzed the components in Figure 4 and characterized their operating capacities and efficiencies, for the example the operating levels (million British thermal units per hour (MMBtu/hr), or 'tons') and efficiencies (kW/ton) of the electric chillers, or

[4] The UCSD campus is on direct access service.

the discharge and charge rates of the thermal storage tank. Each operating characteristic was described in terms of median, average, 10^{th} and 90^{th} percentiles. For purposes of identifying operating efficiencies, the data sets were filtered for start-up conditions since such data is not indicative of steady-state operating efficiencies.

The campus hourly, daily, monthly, season and yearly electrical and thermal needs were assessed using a binning analysis and visualization techniques. The team explored how these needs vary as a function of weather, time of day, day type, month, season and year. Use of a regression analysis was considered for developing a predictive load estimation tool but based on the results determined a binning analysis / look up table to be a more robust approach. Although regression based approaches are used for individual building load forecasting, campus loads are more complex and include a combination of industrial, residential and commercial loads.

Results

UCSD's overall monthly electrical and thermal needs were assessed across the entire data set (2008-2011). As shown in Figure 5, UCSD's thermal needs (chilled water and hot water demand) are characterized by seasonal variability but have a strong base load component. Onsite generation satisfies much of UCSD's needs (as defined by the non-central utility plant or 'non-CUP'), roughly 80-90%. The data exhibits low load growth over the monitoring period.

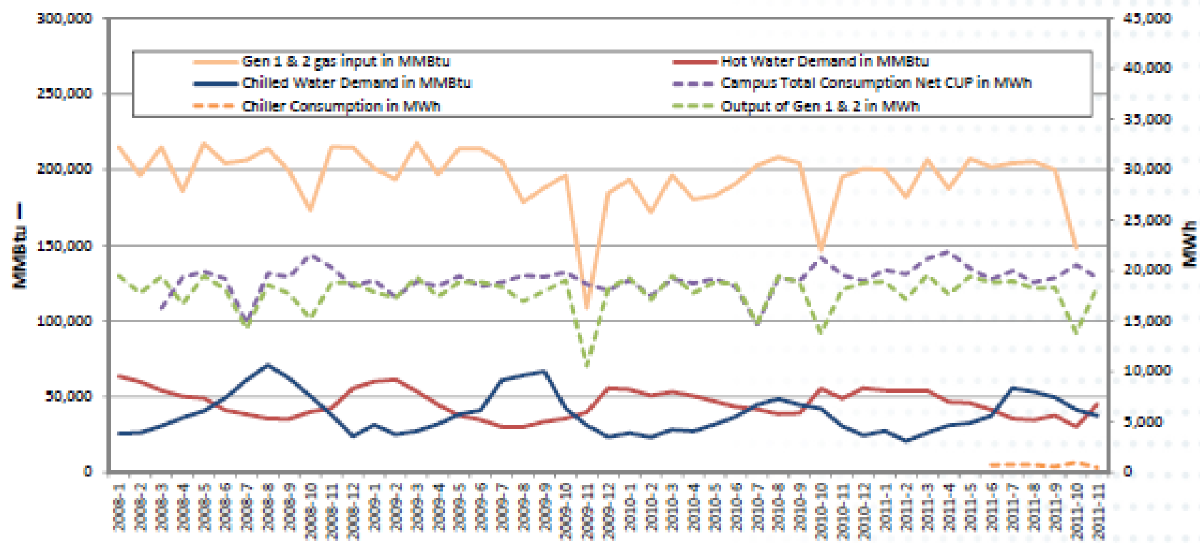


Figure 5: Overview of monthly campus needs over entire data set

Figure 6 shows the variation in UCSD' s chilled water and hot water demand along with the capacities of the systems providing hot water and chilled water. Based on these results, it is clear that there is significant flexibility to meet the chilled water needs through different combinations of electric/steam chilling and combinations of boiler and CHP operation for meeting hot water needs. For just a few hours, a combination of electric, steam chiller and thermal energy storage (TES) are needed.

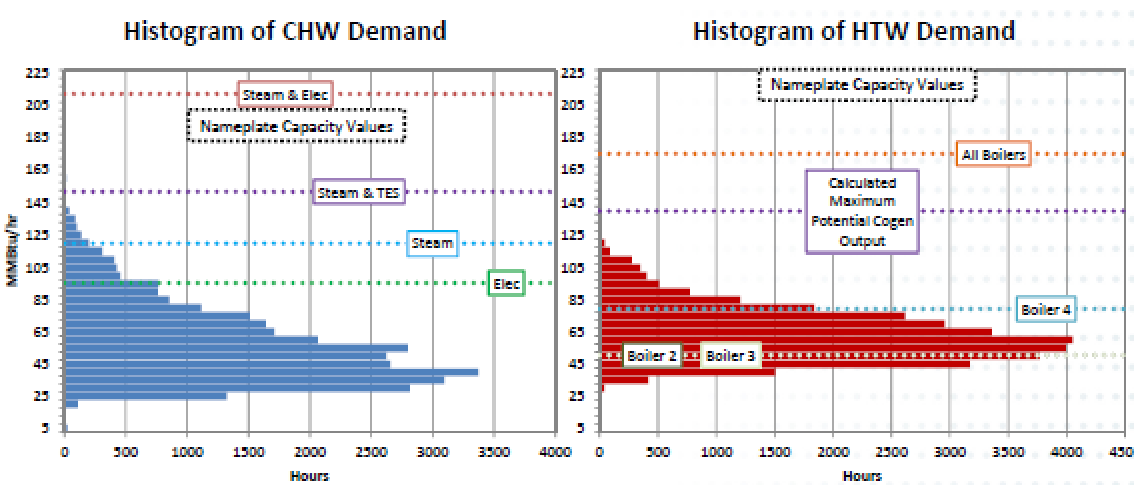


Figure 6: Histogram of hourly chilled water and hot water demand, 2008-2011

The variation of electric and thermal loads over the course of a day were examined (Figure 7 and Figure 8). UCSD's electrical load is characterized by a high load factor throughout the year and monthly variation is minimal (~ 5 MW or 10-15%).

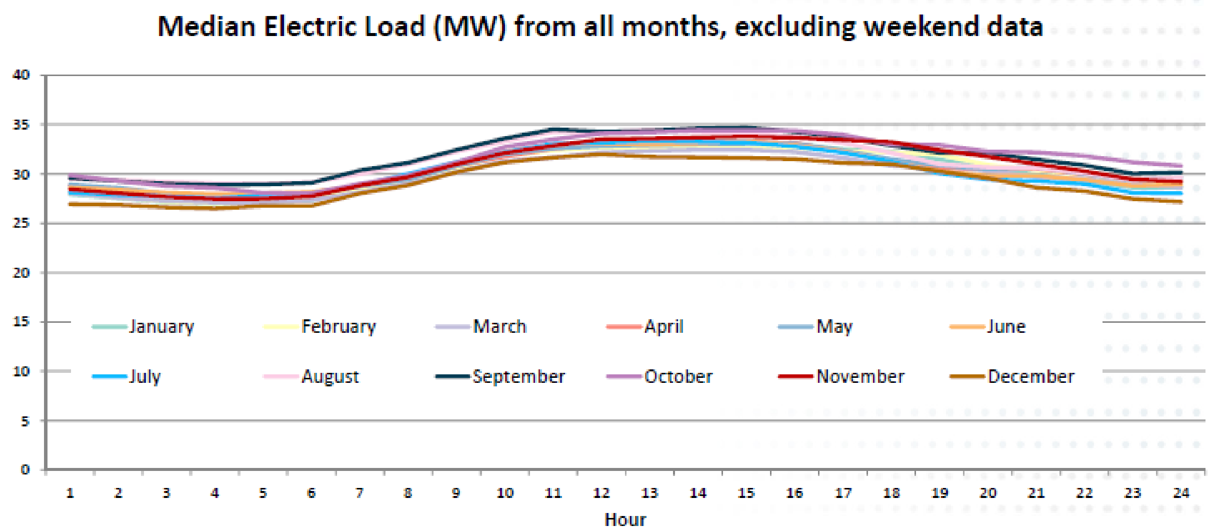
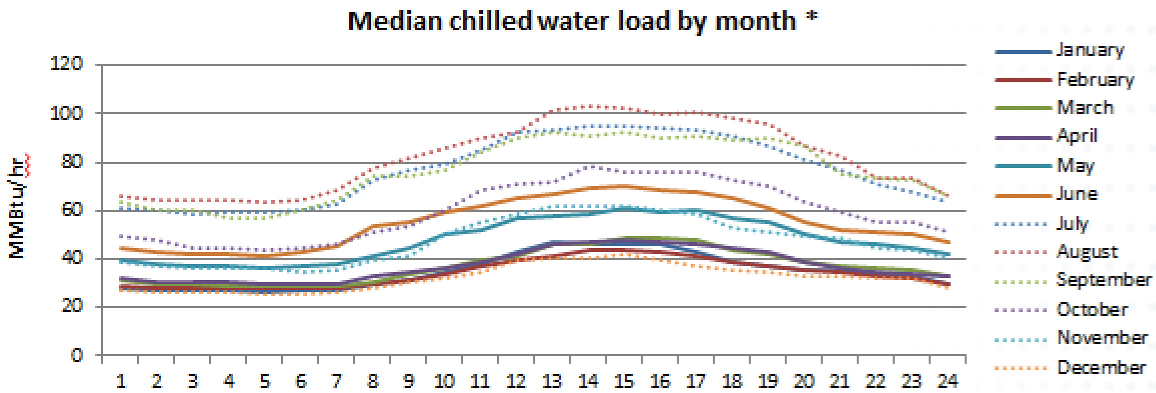


Figure 7: Hourly UCSD electrical needs, excluding weekend data, 2008-2011

The thermal loads show strong seasonal and hourly dependence; chilled water loads peak in the mid-afternoon and hot water loads peaking in the morning. The seasonal dependence is intuitive, also, with chilled water loads larger in the summer and hot water loads larger in the winter. The thermal loads are characterized by significant base load components.



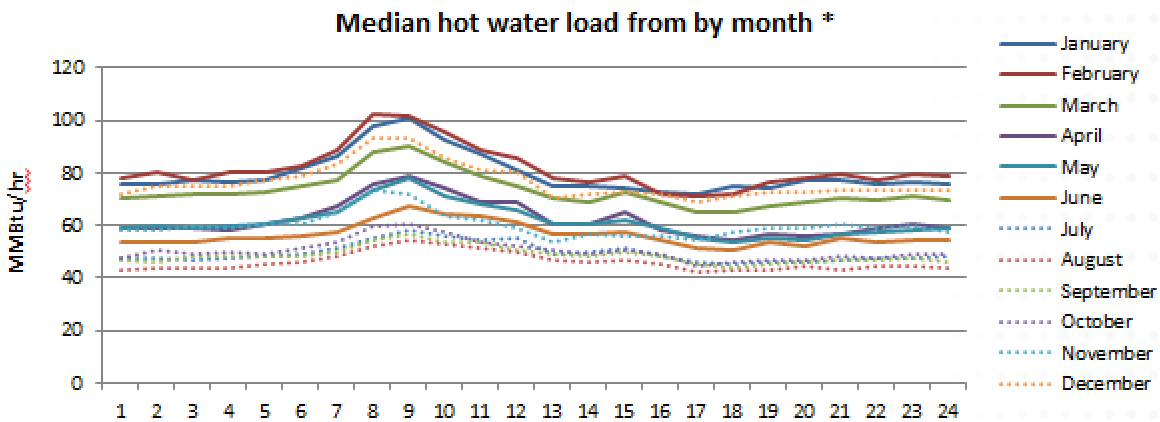


Figure 8: Hourly UCSD thermal needs, *excluding weekend data, 2008-2011

The variation of UCSD's thermal and electrical needs on weekends and from year to year were investigated.

Overall findings on UCSD's electrical and thermal needs are as follows.

- Thermal and electrical loads exhibit significant base load across all hours with electrical load factors significantly larger than thermal load factors
- Electrical consumption exhibits the least amount of variability; hourly profiles follow typical shapes with high load factors
- Thermal loads exhibit significant variability across months and hours; thermal loads show strong seasonal dependence
- Variability for a specific hour within the month is due both to year-to-year and day-to-day varying conditions
- Variability in loads exists across years but these do not appear to be load growth related; year to year effects likely driven by temperature variability

The historical loads provide insight into future loads. The time series data along with statistical characteristics of the load data can be used to develop dispatch schedules and assess how sensitive these schedules are to uncertainty in future loads.

Central plant efficiency and daily operations

The loading order, steam utilization and overall efficiency of UCSD's CHP system were assessed. The overall efficiency is defined as the ratio of useful output to useful input. The steam utilization by 'dispatchable' variable load systems is defined as the fraction of steam generated by the natural gas generators that is used by steam chillers, turbine, or hot water heat exchanger (other 'base load' systems use a constant amount of steam year-round); thus the steam utilization will be less than 100% for the dispatchable variable load systems. The results of this analysis are shown in Figure 9 and Figure 10.

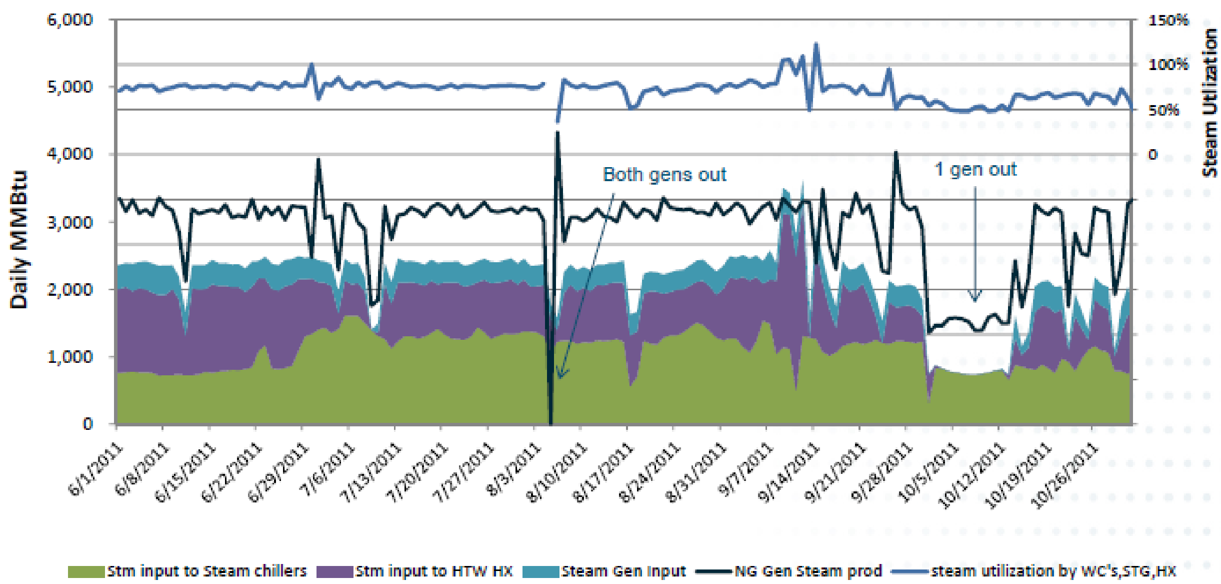


Figure 9: Steam utilization of combined heat and power system

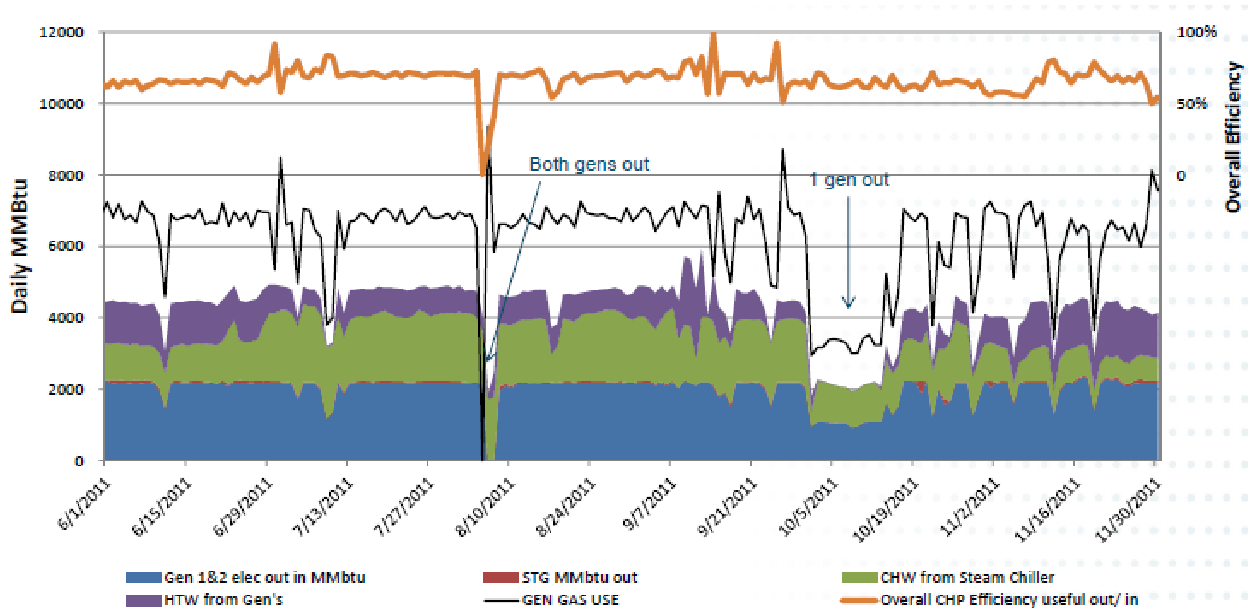


Figure 10: Combined heat and power system operation and efficiency

The overall efficiency of UCSD's CHP system is ~ 60-70% with a median value of 65%; for context, the CPUC 2010 Impact Evaluation report for the Self Generation Incentive Program reported total system efficiencies ranging from ~40-65%. The natural gas generator components are ~ 30% (12,000 Btu/kWh heat rate). The median steam utilization was estimated as ~ 75%. (Due to improvements in base load steam utilization systems, future utilization of ~ 85% is expected.)

The loading order can be observed in these figures. The steam chillers are fueled with steam, followed by the hot water systems, and lastly by the steam turbine. This empirical loading order is largely consistent with UCSD's heuristics, although in the winter, hot water generation may be favored over chilled water generation.

Figure 11 shows an example of daily onsite generation, solar production, thermal needs, chiller operation and thermal storage operation using data from June 7, 2011. The generators typically operate at full capacity and in steady state mode; they are generally operated no lower than 10 MW (or 77%). The steam chillers are operated at constant rate across most hours. Electric chiller output is avoided during peak hours (11-6 pm) and greatest when charging the thermal energy storage (TES) tank. The TES tank is charged at night until the early morning and discharged during peak hours. The

TES tank is operated conservatively such that it maintains capacity to compensate for unexpected steam chiller outages; that is, the TES tank is not discharged at the 'optimal' rate assuming perfect foresight on chilled water demand. For the example shown, solar PV output is ~ 1 MW or 3% of the electrical load.

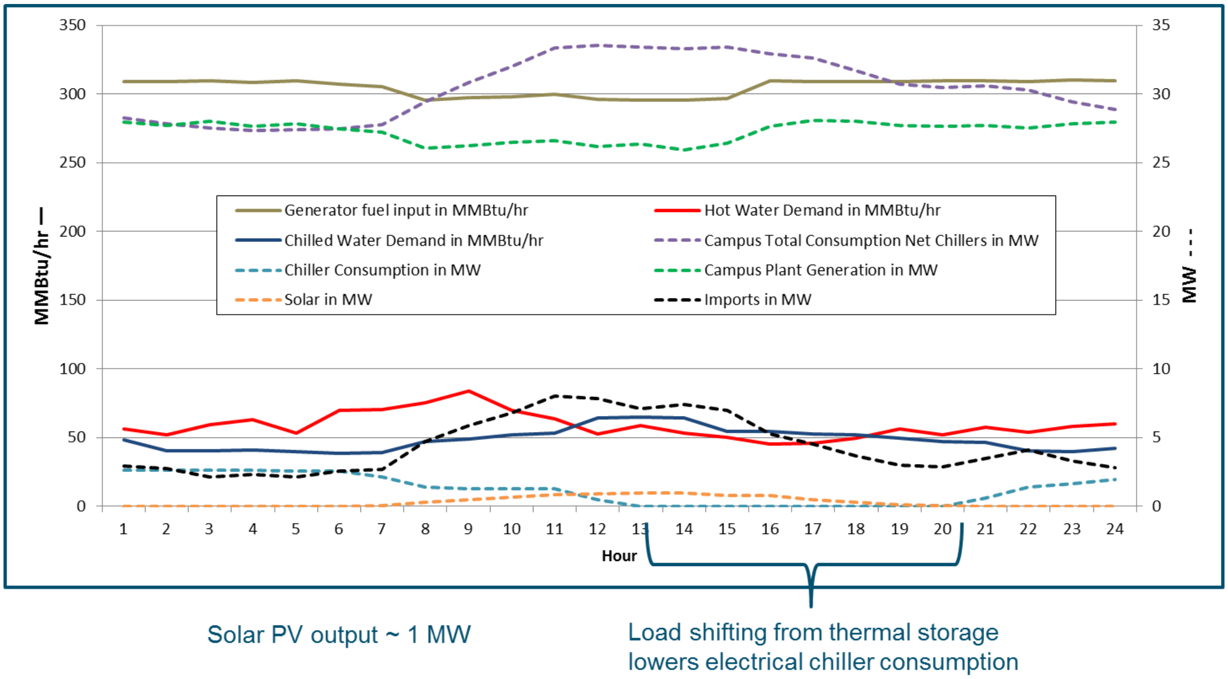


Figure 11: Daily operations, June 7 2011 example

Minimizing campus energy costs is a complex process that involves optimizing the CUP generation for optimal use of recovered energy and operating the TES tank and electric chillers to minimize energy and demand charges. The presence of an all hours demand charge complicates the operations because turning on the electrical chillers and turning off the generators during off-peak periods risks moving the maximum demand, which determines the all-hours demand charge, to the off-peak period.

Efficiency and output of individual systems

The efficiencies and operating capacities of the following systems were characterized: the natural gas and steam generators, chillers, boilers, and thermal storage tank. An example is shown in Figure 12 which shows the efficiency curve for an electric chiller.

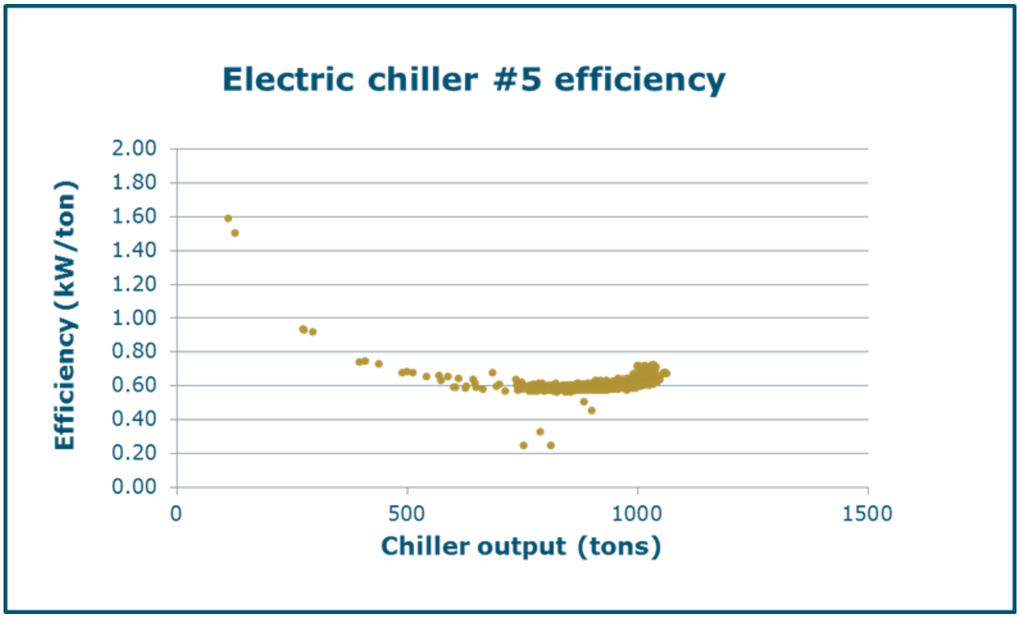


Figure 12: Example of chiller efficiency, electric chiller #5

The salient points from the analysis of the CUP's individual systems are summarized as follows:

- UCSD's electric chillers are centrifugal and their efficiencies ranges from ~ 0.5 to 0.7 kW/ton (coefficient of performance, COP ~ 5-6).
- The steam driven chiller efficiency ranges from ~ 8000 Btu/hr/ton to 10,500 Btu/hr /ton (COP ~ 1.4-1.7)[5]. The chillers' operating capacities are generally ~ 70-90% (50th & 90th percentiles) of nameplate capacities.[6]
- The two natural gas generators have a median heat rate of ~ 11.5 MMBtu/MWh & have an output of ~ 98% of nameplate capacity; steam generator is ~ 15% efficient
- Three boilers have median efficiency of ~ 75%
- The TES tank has a median daily discharge of 16,250 ton-hours; overall losses of ~ 4.4%; median hourly discharge rate of ~ 1330 ton or 15 MMBtu/hr (capacity of ~ 3100 ton or 35 MMBtu/hr).

Figure 13 shows the solar output of UCSD solar PV system by month for 2011. The winter output peaked at ~ 500 KW and summer output at ~ 850 KW.

[5] The relative COPs Electric chillers are known to have greater efficiencies than condensing steam-turbine driven chillers; the efficiencies observed here are within range of that expectation.
[6] Exceptions include steam chiller WC1 ~ 40-50% and electric chillers WC 7 & 9 ~ 50-80%. WC1 underwent a refrigerant retrofit, which accounts for its low loading.

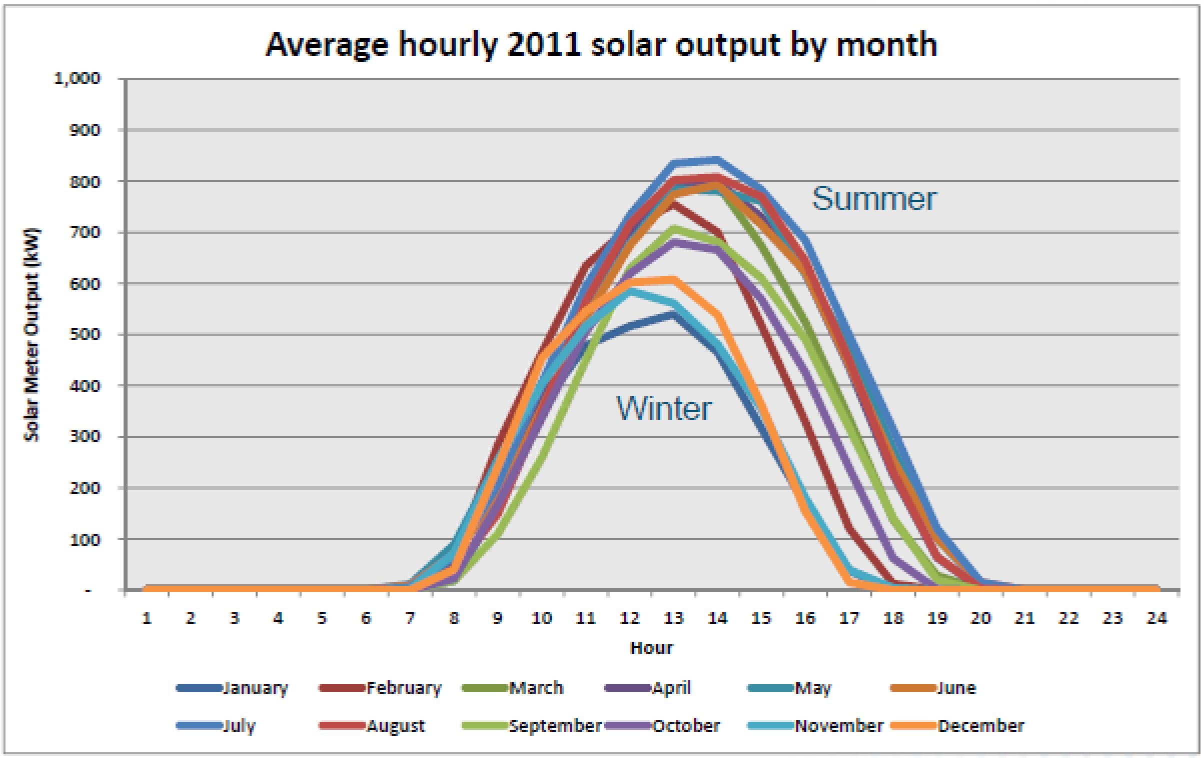


Figure 13: Average hourly solar output by month

Preliminary business analysis

Using the system efficiencies and capacities identified, a simple dispatch model using Excel was developed to compare the costs of four basic operating scenarios:

- UCSD imports its electrical needs fully
- UCSD imports its electrical needs and operates the TES tank
- UCSD operates its onsite generation
- UCSD operates its onsite generation and TES tank

This model was limited in that ramp rates, minimum run times were not explored. The generator schedules were also not varied from day to day but was assumed to be constant throughout the year. The model also assumes a loading order of the steam utilizing systems and operation of the TES tank, rather than solving for the optimal dispatch solutions.

Estimated energy costs between June 1 and October 31 2011 for the idealized scenarios							
$Millions		Electrical		Gas		Total	Savings
Full import	$	6.8	$	1.3	$	8.2	0%
Full import w/ gas cooling	$	6.1	$	2.7	$	8.8	-8%
Full import and thermal storage	$	6.7	$	1.3	$	8.0	2%
Cogeneration	$	1.1	$	5.4	$	6.48	21%
Cogeneration & thermal storage	$	0.9	$	5.2	$	6.10	25%

Table 1: Estimated Energy Costs between June 1 and October 31, 2011

Table 1 shows the results of the preliminary business analysis. This analysis illustrates that UCSD is motivated economically to operate its cogeneration (CHP) system and TES tank. This finding is important because these systems are anticipated to be important for providing renewables integration services.

Summary of baseline task

The baseline task provided the following information:

- Quantitative inputs for the business models, such as individual and system level efficiencies (e.g., kW/ton, Btu/kWh, thermal utilization)
- Characterization of campus electrical and thermal loads
- Typical system capacity factors
- Demonstrated there are opportunities to move loads among central plant systems by identifying ‘slack’ in the microgrid
- Verification of operating heuristics
- Preliminary business evaluation demonstrated that UCSD is economically motivated to operate its CHP system and TES system, which is expected to be integral to the renewables integration strategies.

Further research could improve upon the baseline task deliverables. More detailed models for individual systems could be developed, for example, the chiller efficiency as function of condenser supply and chilled water output temperature. A thermal and electrical load forecasting tool could be developed. Analysis of individual building loads could enhance the overall understanding of campus operations.

The Task 5 exercise also included an analysis of the impact of day type on electrical and thermal loads and of solar forecasting error.

The report "Task 5: Report on baseline performance for UCSD DER operation under current rates and incentives" further details the baselining task and results.

Test and Analyze Scenarios and Publish Results

Objectives

The main objectives of Tasks 6, 7 and 8, were to (1) perform simulations to test the DER strategies, rates and incentives developed and once validated and refined, implement the strategies in real-time and continue to refine the strategies based on the real-time results, (2) provide a robust cost-benefit analysis of the testing results, and (3) provide a transparent analysis tool for public use to assist managers and operators in selecting DER management and PV integration strategies.

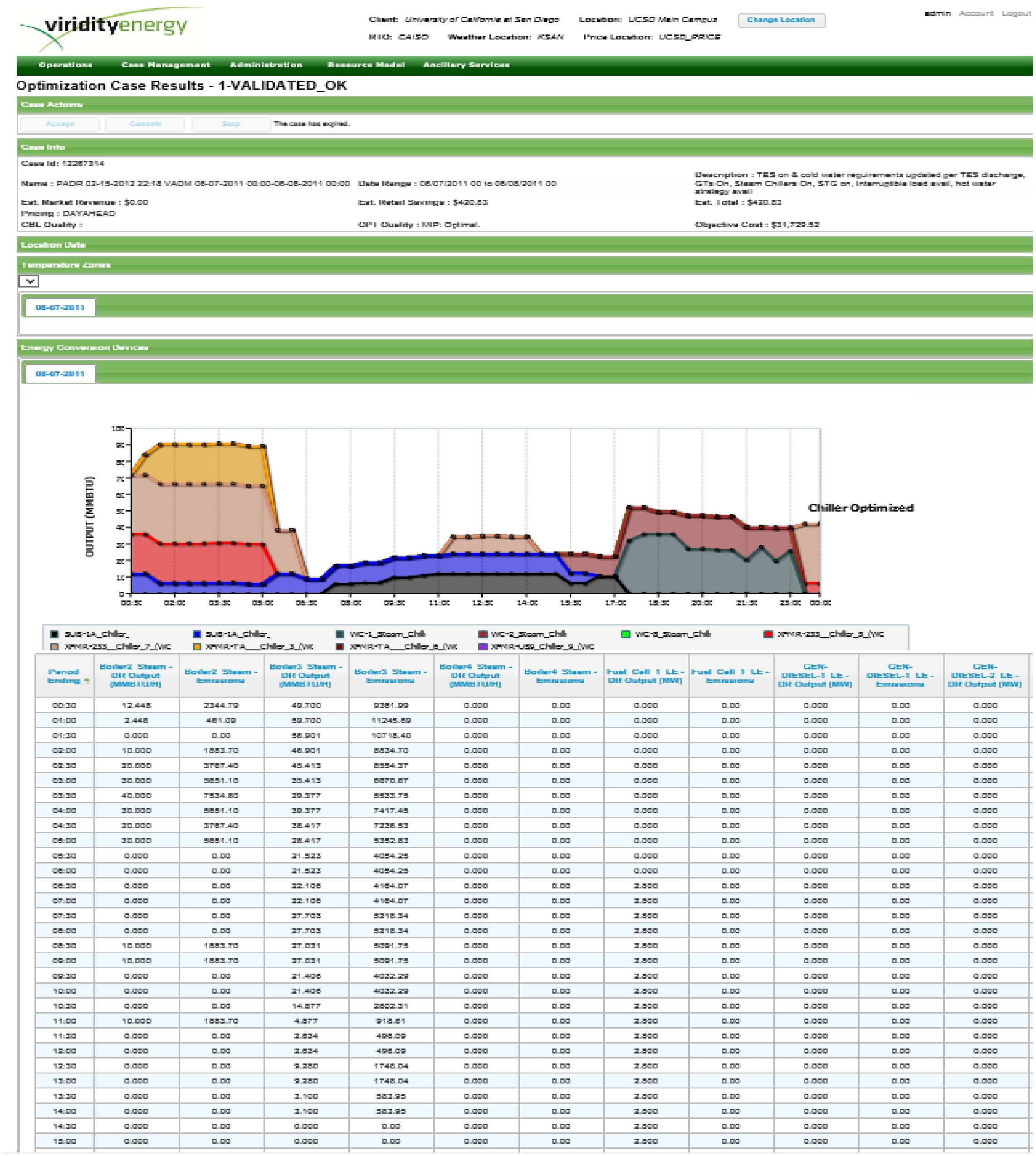
Approach

Model validation

As described in the sections above, challenges with gathering and analyzing data from multiple campus resources delayed the ability to validate the VPower model using historical performance data. Efforts began to compare the historical performance characteristics, collected by telemetry and cost data, found in campus invoices and bills, to the schedules and costs predicted by the VPower model. Mismatches might indicate where the model needed further tuning, or where improvements in the software might be required.

The models were compared to the data sets from the baselining task. Additional validation came through the comparison of operating under scenarios that included the contribution of various resource groups to meeting the campus obligations. These scenarios looked at the schedules resulting from the inclusion, or non-inclusion of cogeneration, thermal energy storage tank, hot water strategy, interruptible load, etc. The costs associated with serving the campus under the various scenarios were compared to each other and to the actual costs incurred on campus.

For the devices whose historical performance was known, those historical values were used as manually set, fixed dispatch amounts, to observe the behavior of the resources as modeled in VPower. VPower was executed, and while the decisions about quantities to expect in the schedule were already made, VPower predicted the schedule of non-fixed devices and the resulting costs of all resources, including the fixed-dispatch resources (Figure 14).



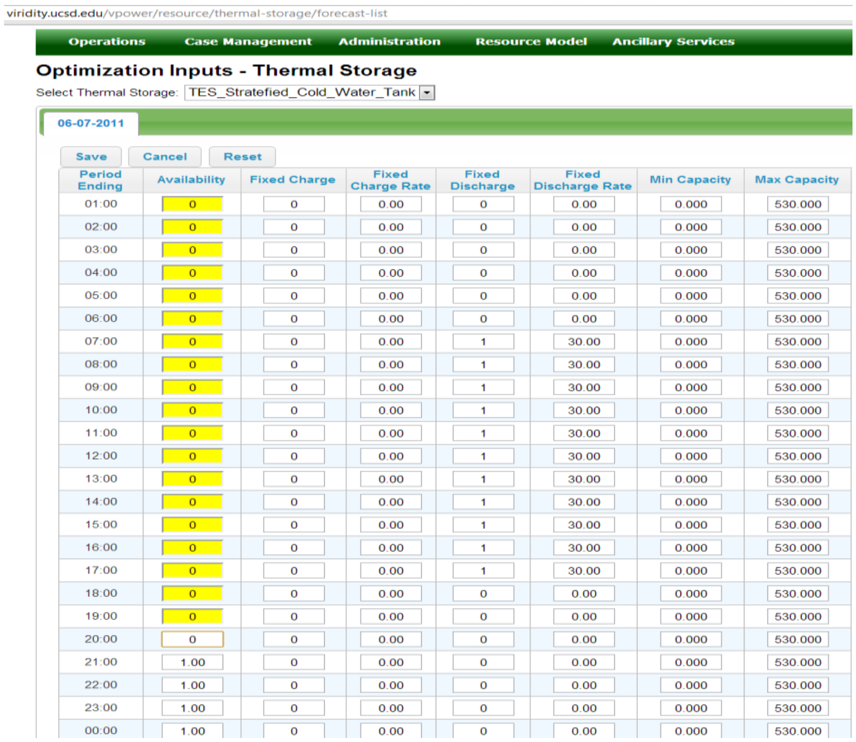
Period Ending	Boiler2 Steam - DH Output (MMBTU/H)	Boiler2 Steam - Emissions	Boiler3 Steam - DH Output (MMBTU/H)	Boiler3 Steam - Emissions	Boiler4 Steam - DH Output (MMBTU/H)	Boiler4 Steam - Emissions	Fuel Cell 1 LE - DH Output (MW)	Fuel Cell 1 LE - Emissions	GEN-DIESEL-1 LE - DH Output (MW)	GEN-DIESEL-1 LE - Emissions	GEN-DIESEL-2 LE - DH Output (MW)
00:30	12.448	2344.79	49.700	9351.99	0.000	0.00	0.000	0.00	0.000	0.00	0.000
01:00	2.448	461.09	59.700	11245.89	0.000	0.00	0.000	0.00	0.000	0.00	0.000
01:30	0.000	0.00	56.901	10715.40	0.000	0.00	0.000	0.00	0.000	0.00	0.000
02:00	10.000	1883.70	46.901	8824.70	0.000	0.00	0.000	0.00	0.000	0.00	0.000
02:30	20.000	3767.40	45.413	8554.37	0.000	0.00	0.000	0.00	0.000	0.00	0.000
03:00	30.000	5651.10	35.413	6670.67	0.000	0.00	0.000	0.00	0.000	0.00	0.000
03:30	40.000	7534.80	29.377	5533.75	0.000	0.00	0.000	0.00	0.000	0.00	0.000
04:00	30.000	5651.10	39.377	7417.45	0.000	0.00	0.000	0.00	0.000	0.00	0.000
04:30	20.000	3767.40	38.417	7236.53	0.000	0.00	0.000	0.00	0.000	0.00	0.000
05:00	30.000	5651.10	28.417	5352.83	0.000	0.00	0.000	0.00	0.000	0.00	0.000
05:30	0.000	0.00	21.523	4054.25	0.000	0.00	0.000	0.00	0.000	0.00	0.000
06:00	0.000	0.00	21.523	4054.25	0.000	0.00	0.000	0.00	0.000	0.00	0.000
06:30	0.000	0.00	22.106	4164.07	0.000	0.00	2.800	0.00	0.000	0.00	0.000
07:00	0.000	0.00	22.106	4164.07	0.000	0.00	2.800	0.00	0.000	0.00	0.000
07:30	0.000	0.00	27.703	5218.34	0.000	0.00	2.800	0.00	0.000	0.00	0.000
08:00	0.000	0.00	27.703	5218.34	0.000	0.00	2.800	0.00	0.000	0.00	0.000
08:30	10.000	1883.70	27.031	5091.75	0.000	0.00	2.800	0.00	0.000	0.00	0.000
09:00	10.000	1883.70	27.031	5091.75	0.000	0.00	2.800	0.00	0.000	0.00	0.000
09:30	0.000	0.00	21.406	4032.29	0.000	0.00	2.800	0.00	0.000	0.00	0.000
10:00	0.000	0.00	21.406	4032.29	0.000	0.00	2.800	0.00	0.000	0.00	0.000
10:30	0.000	0.00	14.877	2802.31	0.000	0.00	2.800	0.00	0.000	0.00	0.000
11:00	10.000	1883.70	4.877	918.61	0.000	0.00	2.800	0.00	0.000	0.00	0.000
11:30	0.000	0.00	2.634	496.09	0.000	0.00	2.800	0.00	0.000	0.00	0.000
12:00	0.000	0.00	2.634	496.09	0.000	0.00	2.800	0.00	0.000	0.00	0.000
12:30	0.000	0.00	9.280	1748.04	0.000	0.00	2.800	0.00	0.000	0.00	0.000
13:00	0.000	0.00	9.280	1748.04	0.000	0.00	2.800	0.00	0.000	0.00	0.000
13:30	0.000	0.00	3.100	583.95	0.000	0.00	2.800	0.00	0.000	0.00	0.000
14:00	0.000	0.00	3.100	583.95	0.000	0.00	2.800	0.00	0.000	0.00	0.000
14:30	0.000	0.00	0.000	0.00	0.000	0.00	2.800	0.00	0.000	0.00	0.000
15:00	0.000	0.00	0.000	0.00	0.000	0.00	2.800	0.00	0.000	0.00	0.000

Figure 14: Sample of VPower Optimized Dispatch Schedule

The resulting costs suggested by VPower were in the right order of magnitude, but it was determined that VPower's projected costs were lower than that observed in the campus utility invoices. This called into question whether VPower, or the VPower campus resource model was sufficiently accurate to be used for analyzing strategies in a simulation environment.

To further investigate the VPower campus model, VPower schedules and cost results were reviewed for the campus under various scenarios. This would perhaps establish a baseline of performance and would highlight the impact of various groups of resources.

1. **Import only:** in this scenario the electrical needs for the campus were met entirely by the electric utility's supply. The thermal needs for steam would be met with boilers separate from the gas turbines. Energy shifting resources such as the thermal energy storage tank, interruptible loads, and the hot water reduction strategy were made unavailable (see Figure 15 below).
2. **TES Tank:**   Same as the import only, but making the thermal energy storage tank available to shift some thermal load associated with chillers.
3. **TES Tank and CHP Available:** In addition to the TES tank, the cogeneration facilities were made available to the VPower optimization, this included the electrical generation, the steam generation, and the steam chillers.
4. **Load Shifting Resources made Available:** In addition to the above, the hot water temperature reduction strategy and the interruptible load were included.



Period Ending	Availability	Fixed Charge	Fixed Charge Rate	Fixed Discharge	Fixed Discharge Rate	Min Capacity	Max Capacity
01:00	0	0	0.00	0	0.00	0.000	530.000
02:00	0	0	0.00	0	0.00	0.000	530.000
03:00	0	0	0.00	0	0.00	0.000	530.000
04:00	0	0	0.00	0	0.00	0.000	530.000
05:00	0	0	0.00	0	0.00	0.000	530.000
06:00	0	0	0.00	0	0.00	0.000	530.000
07:00	0	0	0.00	1	30.00	0.000	530.000
08:00	0	0	0.00	1	30.00	0.000	530.000
09:00	0	0	0.00	1	30.00	0.000	530.000
10:00	0	0	0.00	1	30.00	0.000	530.000
11:00	0	0	0.00	1	30.00	0.000	530.000
12:00	0	0	0.00	1	30.00	0.000	530.000
13:00	0	0	0.00	1	30.00	0.000	530.000
14:00	0	0	0.00	1	30.00	0.000	530.000
15:00	0	0	0.00	1	30.00	0.000	530.000
16:00	0	0	0.00	1	30.00	0.000	530.000
17:00	0	0	0.00	1	30.00	0.000	530.000
18:00	0	0	0.00	0	0.00	0.000	530.000
19:00	0	0	0.00	0	0.00	0.000	530.000
20:00	0	0	0.00	0	0.00	0.000	530.000
21:00	1.00	0	0.00	0	0.00	0.000	530.000
22:00	1.00	0	0.00	0	0.00	0.000	530.000
23:00	1.00	0	0.00	0	0.00	0.000	530.000
00:00	1.00	0	0.00	0	0.00	0.000	530.000

Figure 15: VPower screen: Setting TES unavailable for use in optimization

Strategy and software functionality comparison

In parallel with the baselining analysis and model validation process, the team reviewed the study scenarios identified earlier. The scenarios were divided into three categories: peak load shifting (PLS), PV firming and grid support. PLS strategies seek to reduce peak load and UCSD energy costs while simultaneously providing incremental utility or societal benefits. The PV firming strategies address the intermittency challenges from UCSD's onsite solar PV using either UCSD resources or relying on the grid. In the final category, grid support, UCSD participates directly in CAISO wholesale markets to provide ancillary services. Based on remaining project schedule and budget, five target strategies were proposed for evaluation:

- Peak Shifting Strategy: Removing all hours demand charge
- Peak Shifting Strategy: Reducing duration of peak window
- PV Firming Strategy: Handle error with gas turbines
- PV Firming Strategy: Two-part rate
- Incentives for Grid Support: market products

Given the target strategies, three general methods to study the impact of the strategies were considered with VPower: (1) enter $/MW and hourly $/MWh prices/rates for energy and demand and observe how campus resources are dispatched differently, (2) enter $/MW and hourly $/MWh prices for market products that UCSD could bid into and observe whether or not to bid based on the optimization considering potential revenue and costs (simulated signals from the market would be used for testing), and (3) enter MW constraints for resources required to provide a specific service (e.g. spinning reserve, ramp product, etc.) and calculate the cost/impact associated with holding those MWs in reserve.

The team reviewed the target strategies and general methods against the existing VPower functionality, and found several key capabilities required to test the strategies were not available in VPower. These are described in further detail below in the Results section below and Appendix A.

Strategy analysis

In order to progress the evaluation of the target strategies while VPower changes were being evaluated and added, the excel spreadsheets used during the baselining process and the UCSD Dispatch Optimization Tool were enhanced and their scope expanded to help quantify the net benefits of the target strategies. The initial intent was to broadly test the feasibility of certain scenarios prior to running them through a more detailed optimization in VPower.

All target strategies share a common set of campus demands— electrical load (including the contribution of behind-the-meter solar generation), chilled water demand and hot water demand—which must be satisfied in the optimization. Each testing scenario category begins with a base case. The three base cases share the common input data but they differ from one another as a result of differences in how each category of strategies are modeled.

Each strategy is evaluated by its net cost, relative to its base case, defined as follows:

$$Net\ cost, strategy = [Total\ cost\ - revenue], strategy - [Total\ cost], base\ case$$

This change case less base case model isolates the impacts a strategy has on a common framework of assumptions. Using the net cost metric, the outputs from different strategies are compared with a shared base case to determine how input changes translate to costs or savings to the campus. Positive net costs indicate the strategy is not cost effective, relative to its base case; negative net costs indicate the strategy is cost-effective.

Base case development

The results of the baseline performance task were applied to develop an appropriate 'base case' for each of the renewables integration strategies evaluated. Many of the target strategies rely on operation of UCSD's flexible generation and thermal storage resources. The team sought to confirm that UCSD would be motivated economically to operate these systems (particularly its campus generation resources). The team also sought to understand the value proposition of moving beyond heuristics-based operations to an optimization-based approach

The optimization for each case was performed with the UCSD Dispatch Optimization Tool using data over the entire one year period of analysis (June 2011 – July 2012), with some dates removed due to inconsistent or problematic data. The data include both a winter and a summer month that were directionally consistent with the results for most months of the year.

As the optimization was performed to investigate the impact of the strategies the following questions were considered during the design of the tests, and informed the data collection and presentation.

- Does integrating additional resources in strategy dispatch decisions reduce costs or increase potential?
- Does the strategy reduce net the demand response facilities energy costs?
- Is the strategy cost-effective compared to alternatives at today's prices?

- If not currently cost-effective, is the strategy potentially cost-effective in the future?

If the answer to at least one of these questions was yes, then there is a possibility that the strategy is a good candidate. If the answer to all of these questions was no, then the strategy is not likely to be adopted as modeled.

Peak Shifting Strategy: Removing all hours demand charge

Under existing tariffs, load shifting with the UCSD thermal storage tank is not as cost effective as it could be due to the campus demand charge structure. It includes an all-hours ('non-coincident') demand charge that frequently constrains the operation of the TES tank and/or the import of electricity in off-peak periods.

A scenario where the all-hours demand charge was eliminated, and the on-peak demand charge was increased to include both the all-hours and on-peak demand rates was analyzed.

Peak Shifting Strategy: Reducing duration of peak window

A scenario with a reduced peak window of just 4 hours instead of the SDG&E on-peak period of 7 hours was analyzed with the intent to determine if a shorter period would allow the TES to shift a reduced amount of load over a smaller peak period without increasing the all-hours demand charge during the off-peak period.

PV Firming Strategy: Handle error with Gas Turbines

How UCSD's own resources can be leveraged to integrate increasing levels of PV penetration was explored. One key is addressing the error between the day-ahead forecast of PV production, used to plan dispatch, and the actual PV production. This error can result in over-generation or unscheduled reliance on the grid to make up for a shortfall in energy. While this forecast error for the host microgrid is small relative to total resource flexibility, scaling up the amount of PV and corresponding uncertainty shows the benefit of flexible resources.

PV Firming Strategy: Two-part rate

This strategy assumes existence of a 2-part tariff, which consists of the current tariff along with a renewable integration penalty charge for error in forecasted PV production. All forecast error firmed with the grid incurs the penalty while exports to grid receive no compensation and increased imports from the grid incur the hourly cost of the energy.

Incentives for Grid Support Strategy: Market Products

Flexible resources may be incented to support grids with a higher level of intermittently available renewable generation capacity through the inclusion of DR and DER resources in markets for the following:

- Frequency regulation
- Load following/over-generation ramp
- Spinning/non-spinning reserve
- PV firming/backflow prevention

In the near future, there will soon be two options for non-generator resources to participate in frequency regulation markets.

- Regulation Energy Management in which the CAISO actively monitors the state of charge (SOC) for a storage resource or the dispatch operating target (DOT) for participating load.
- Load participating as a Dispatchable Demand Resource (DDR) in non-REM regulation.

The approach taken approximated the second alternative (DDR) assuming provision of a full hour of regulation for the MWs bid, and earning revenues in the energy market. The costs and benefits of providing frequency regulation was illustrated using step-wise cases, each with increasing complexity, to inform intuitive interpretation of the results.

- No regulation
- Fixed regulation
- Simple regulation

- Gas turbine based regulation
- All campus resources providing regulation

Results

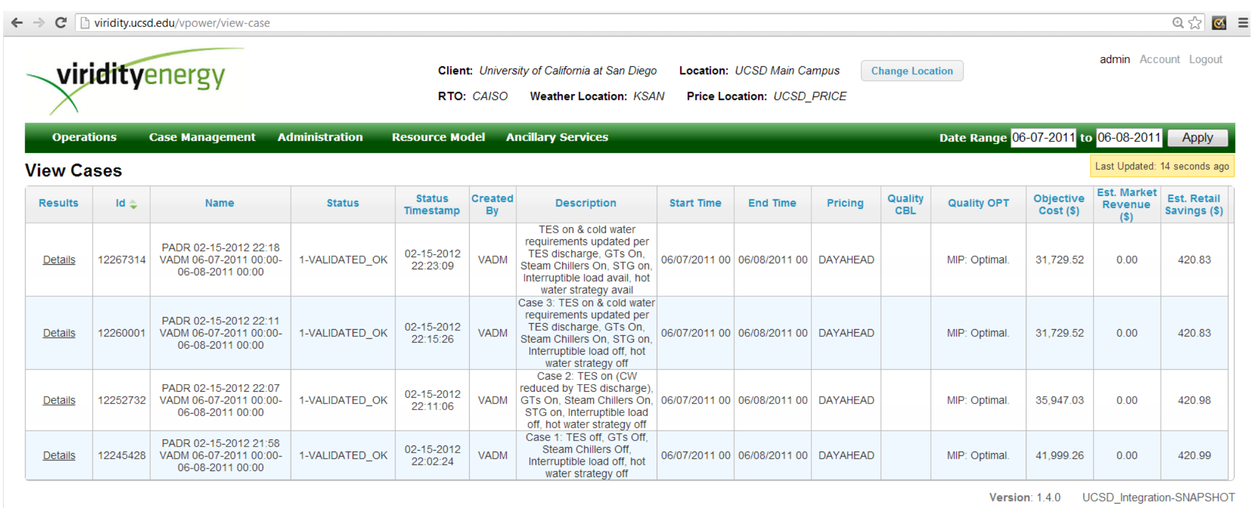
Model Validation

The VPower and UCSD Dispatch Optimization Tool were designed with a similar focus and the validation process was similar. Modeling challenges found in each tool were shared to the benefit of both tools, such as challenges in modeling demand charges and TES tank management.

VPower Model

Once the VPower static campus resource model was validated against baseline results and campus operator input, the resulting costs of the dispatch schedules were considered. Tests were run over study period of 24 hours, using historical data from June 7, 2011 as a validation data set.

Figure 16 shows a summary comparison screen of the costs ("objective cost") under the four test scenarios used to review VPower schedules and cost results (described above under the Approach/Model Validation section). Although each of the scenario costs seemed to make sense relative to the others, the costs still seemed to be underestimated by 10 – 25% as compared with campus utility invoices.



Results	Id	Name	Status	Status Timestamp	Created By	Description	Start Time	End Time	Pricing	Quality CBL	Quality OPT	Objective Cost ($)	Est. Market Revenue ($)	Est. Retail Savings ($)
Details	12267314	PADR 02-15-2012 22:18 VADM 06-07-2011 00:00-06-08-2011 00:00	1-VALIDATED_OK	02-15-2012 22:23:09	VADM	TES on & cold water requirements updated per TES discharge, GTs On, Steam Chillers On, STG on, Interruptible load avail, hot water strategy avail	06/07/2011 00	06/08/2011 00	DAYAHEAD		MIP: Optimal.	31,729.52	0.00	420.83
Details	12260001	PADR 02-15-2012 22:11 VADM 06-07-2011 00:00-06-08-2011 00:00	1-VALIDATED_OK	02-15-2012 22:15:26	VADM	Case 3: TES on & cold water requirements updated per TES discharge, GTs On, Steam Chillers On, STG on, Interruptible load off, hot water strategy off	06/07/2011 00	06/08/2011 00	DAYAHEAD		MIP: Optimal.	31,729.52	0.00	420.83
Details	12252732	PADR 02-15-2012 22:07 VADM 06-07-2011 00:00-06-08-2011 00:00	1-VALIDATED_OK	02-15-2012 22:11:06	VADM	Case 2: TES on (CW reduced by TES discharge), GTs On, Steam Chillers On, STG on, Interruptible load off, hot water strategy off	06/07/2011 00	06/08/2011 00	DAYAHEAD		MIP: Optimal.	35,947.03	0.00	420.98
Details	12245428	PADR 02-15-2012 21:58 VADM 06-07-2011 00:00-06-08-2011 00:00	1-VALIDATED_OK	02-15-2012 22:02:24	VADM	Case 1: TES off, GTs Off, Steam Chillers Off, Interruptible load off, hot water strategy off	06/07/2011 00	06/08/2011 00	DAYAHEAD		MIP: Optimal.	41,999.26	0.00	420.99

Figure 16: VPower baseline schedule cases for model validation

The comparison of scenarios highlighted the need for an improved model if the schedules were to be useable and credible as the basis of operations or for testing longer term pricing strategies. It was determined that as a minimum, demand charges and improvements in fuel consumption modeling would need to be added to VPower.

VPower does not directly include a power flow model and was dependent on the Master Controller (and Paladin) to perform a campus-wide power flow and verify that the equipment was operating within tolerances. In those cases where following the candidate schedule would have resulted in violated limits, optimization constraints (e.g. feeder capacity limitations, resources offline), were returned to VPower which would, when included in the optimization, alleviate the violated limits. However, without the benefit of the real time data link, the Paladin load models were not being dynamically updated to reflect actual conditions. In the absence of real-time data, Paladin based its analyses on default load distribution profiles, which meant that constraints were quite likely not often needed. Occasionally the VPower schedule included some manual dispatch values that were outside acceptable limits just to facilitate testing of the interface.

Further validation of the VPower model and software continued in a standalone environment off campus. This allowed the team full control over installing software and model changes without impacting master controller operations on campus.

UCSD Dispatch Optimization Tool

The UCSD Dispatch Optimization Tool modeling framework is based on the CUP energy flows shown in Figure 4 and uses a mixed integer linear program to develop dispatch schedules for the CUP systems to meet the campus electrical, hot water and chilled water demands in a manner that minimizes total costs, including demand charges. The tool and results are described in more detail in the "Task 6, 7, 8: Strategies and Incentives for integration of renewable generation using distributed energy resources" report. The cost benefit model uses historical hourly campus demands from June 2011 to May 2012 and historical natural gas and electricity prices across all cases. The model does not optimize any of the systems outside of the CUP, such as other HVAC systems, backup generators or auxiliary equipment. Focusing on one year of historical data, the model considers changes in variable operating costs only. The fixed cost of existing equipment is considered sunk, and no capital investment in new resources on campus is contemplated.

The model incorporates operating constraints in the form of upper and lower operating capacities, startup costs, and minimum run times for CUP equipment. The optimization engine must determine schedules that meet UCSD's electrical and thermal requirements while satisfying these operating constraints. A key feature of the model is TES tank management: the model determines discharge and charge schedules subject to charge/discharge rates, such that monthly demand charge is minimized.

The model optimizes over two different time frames, minimizing for either daily total cost or monthly total cost. The monthly approach was important for capturing demand charges accurately, which requires knowledge of demand over the entire month. Because the optimization model has perfect foresight over the period being solved (for example, the electrical demand 12 hours away), using two different time frames allowed for a balance between more or less forward looking results.

For the monthly minimization, due to computational limits, the temporal and resource resolution was reduced. Rather than developing hourly schedules, bi-hourly schedules were developed; chillers were aggregated and minimum run times were not imposed on these systems. Bi-hourly campus demands were generated from hourly data.

The daily minimization, which runs for consecutive days, requires constraints to be satisfied each hour of the day and passes the operating state of each resource (e.g. whether a resource is on, and for how many hours it has been running) and maximum demand level from one day to the next. The daily time frame affords greater time resolution at the expense of suboptimal results for the demand charge and TES tank management. The monthly time frame does not offer the same temporal granularity, but produces optimal solutions for demand charges. These two approaches can be integrated by feeding month long optimization results into the daily optimization.

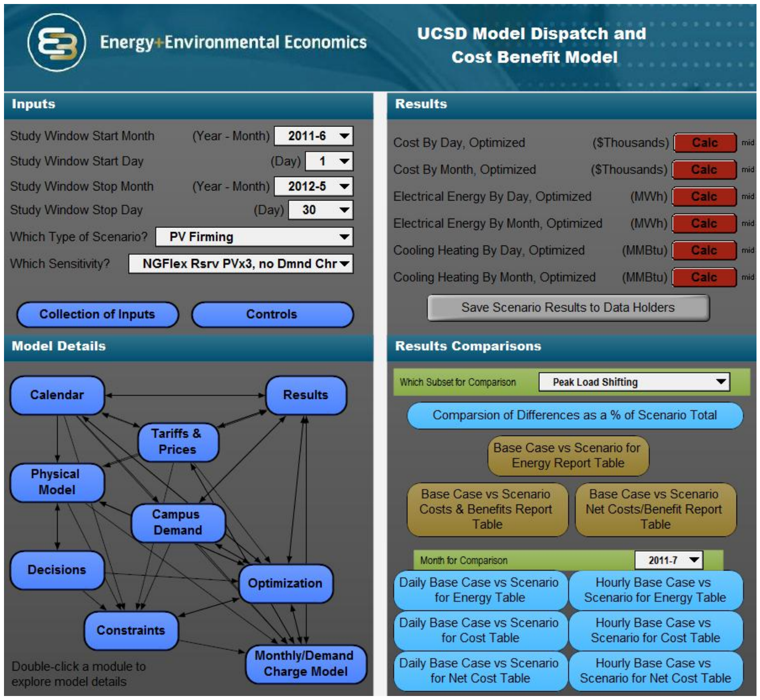


Figure 17: Screen shot of UCSD Dispatch Optimization Tool

The following approximations were made to reduce solving time and to maintain the number of variables and constraints within the software limits:

- Chiller, generator and boiler efficiencies are represented as constant values, rather than a function of the output
- Steam production is assumed to be constant from the natural gas generators between minimum and maximum electrical output operating levels; this assumption is based on UCSD's operational experiences
- The boilers are represented as an aggregated single unit rather than as three independent units
- The TES must be fully recharged at the end of the period of total cost minimization

For the month long model additional approximations are required:

- A bi-hourly time step, with hourly campus needs and prices averaged over every two hours into a single time steps
- Only gas turbine minimum run times are included

- Individual chillers are aggregated into composite chillers, steam and electric, with weighted average efficiencies

Strategy and Software Functionality Comparison

As the project team evaluated the target strategies, it was clear that additional VPower software enhancements were required. Without the real time data feed, the capability to perform studies over longer periods with large amounts of varying inputs and to graph results was limited. Viridity decided to streamline the development effort through their core software development team rather than the project team.

Ultimately, this resulted in two actions which supported meeting project objectives. First, the UCSD Dispatch Optimization Tool would be leveraged to perform the bulk of analysis until the relevant capabilities were available in VPower. Second, Viridity VPower core product development team priorities were established to produce the needed system enhancements.

The VPower release made available in April 2013, has the capabilities to optimize and analyze opportunities on a longer term basis. However, limited time was available within the grant schedule to fully develop and execute simulations leveraging the new capabilities and include those results in this report. As a result, the details of the enhancements and some initial results are included in Appendix A.

Strategy Analysis

The results from the UCSD Dispatch Optimization Tool are summarized below for each strategy category in three ways.

- First, an example week of resource dispatch, showing how the dispatch of campus resources changes with each successive case. This illustrates how the strategy impacts the dispatch of campus resources, and how changing constraints or available resources alters that dispatch.

- Second, the change in net cost from the base case for each type of cost for the campus is shown: electricity import costs, demand charges, natural gas costs, incremental revenues (if any) and the net impact of all four summed together.

- Finally, the net cost impact for a summer and winter month is shown.

Although the optimization for each case was performed over the entire one year period of analysis (June 2011 – July 2012), a subset of results is presented below for two reasons. First, it is far easier to effectively represent and highlight impacts over the weekly or monthly time frame than it is for a full year of hourly data. Second, due to computational limitations, the model did not solve consistently for all the days and months of the year. In all cases, more that 93% of the days/hours solved in the optimization, giving a good representation of performance across the year and varying conditions. A winter and a summer month were chosen that were directionally consistent with the results for most months of the year.

Examples of the hourly dispatch results in the month of August that illustrate the value of utilizing different levels of UCSD DERs are shown in Figure 18, with the three graphs showing the full import, full import with TES and cogeneration with TES dispatches. These three graphs show how the addition of resources changes the campus dispatch due to lower costs.

The figure shows that campus electrical load is met by imports alone, and the electrical chillers run consistently throughout the day except for a few hours with high energy prices. In these few hours the steam chillers provide cooling, effectively fuel switching to natural gas.

The middle panel shows how the dispatch changes with the addition of the TES system. The electrical chillers turn off during some afternoons where the model discharges stored chilled water to avoid increasing the on-peak demand rate and high priced energy.

The final panel shows the cogeneration with TES case. The cogeneration substantially decreases the level of imports, and its steam to drive chillers, together with the TES, means the electric chillers are not needed.

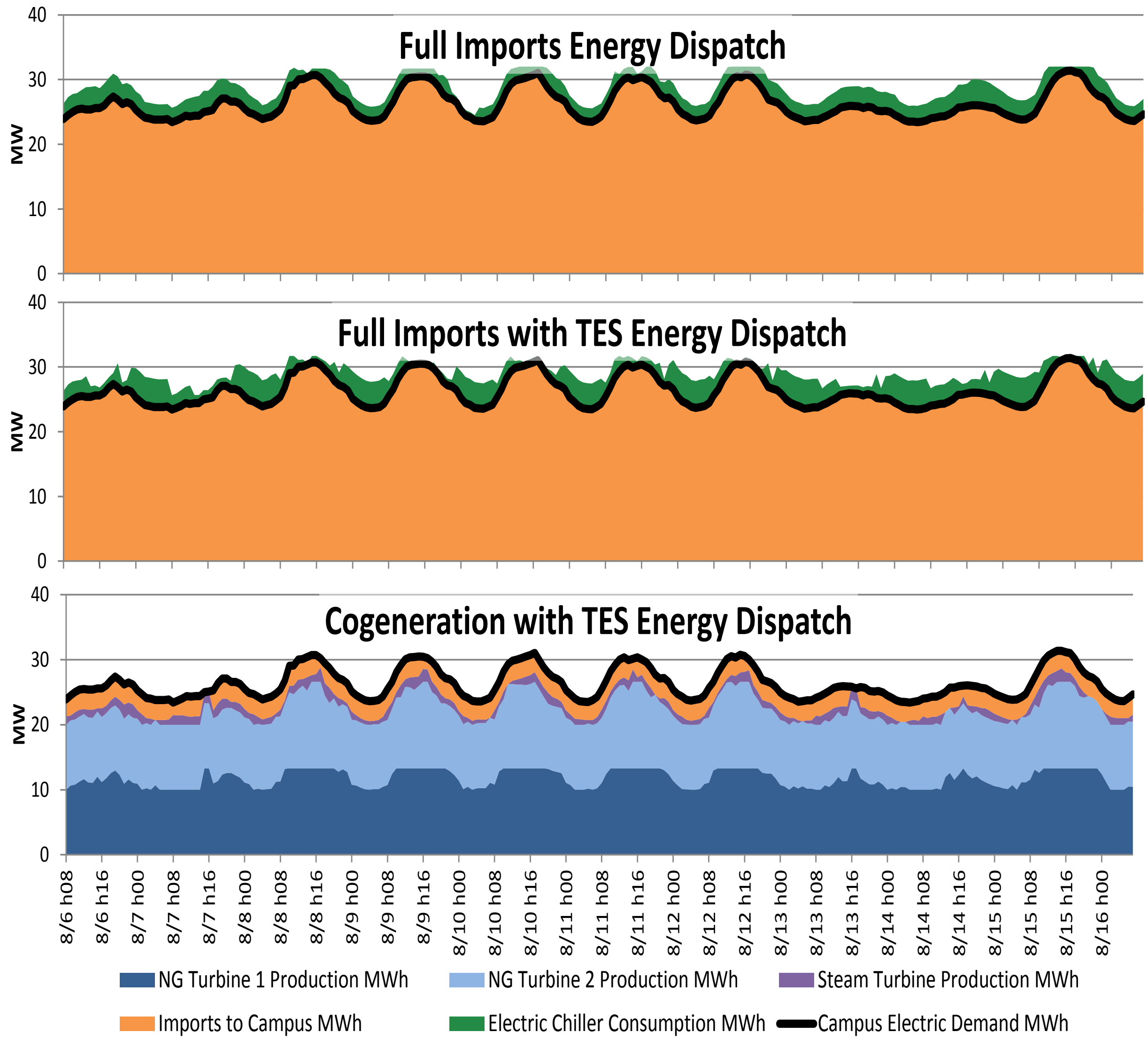


Figure 18: Examples of hourly dispatch for the stepwise analysis, where cases have progressively more DERs in each graph

Peak Shifting Strategy: Removing all hours demand charge

Analysis of historical campus loads and resources showed that the all-hours demand charge frequently limits off-peak charging of the TES tank. In some cases, fully recharging the TES during off-peak hours would cause an increase to the maximum demand billing determinant for the month; that is the UCSD off-peak demand would exceed their previously set on-peak demand MW for the month. This leads to a counter-productive result for a customer with load-shifting capability wherein UCSD is prevented from reducing peak loads to the full extent possible.

Peak Shifting Strategy: Reducing duration of peak window

The shorter summer peak period strategy results in a minor change in dispatch as compared to the base case as shown in Figure 19. While imports consistently remain low over all hours for both the shorter peak and base case, the gas turbines are dispatched at a marginally lower level in some hours in the shorter peak strategy.

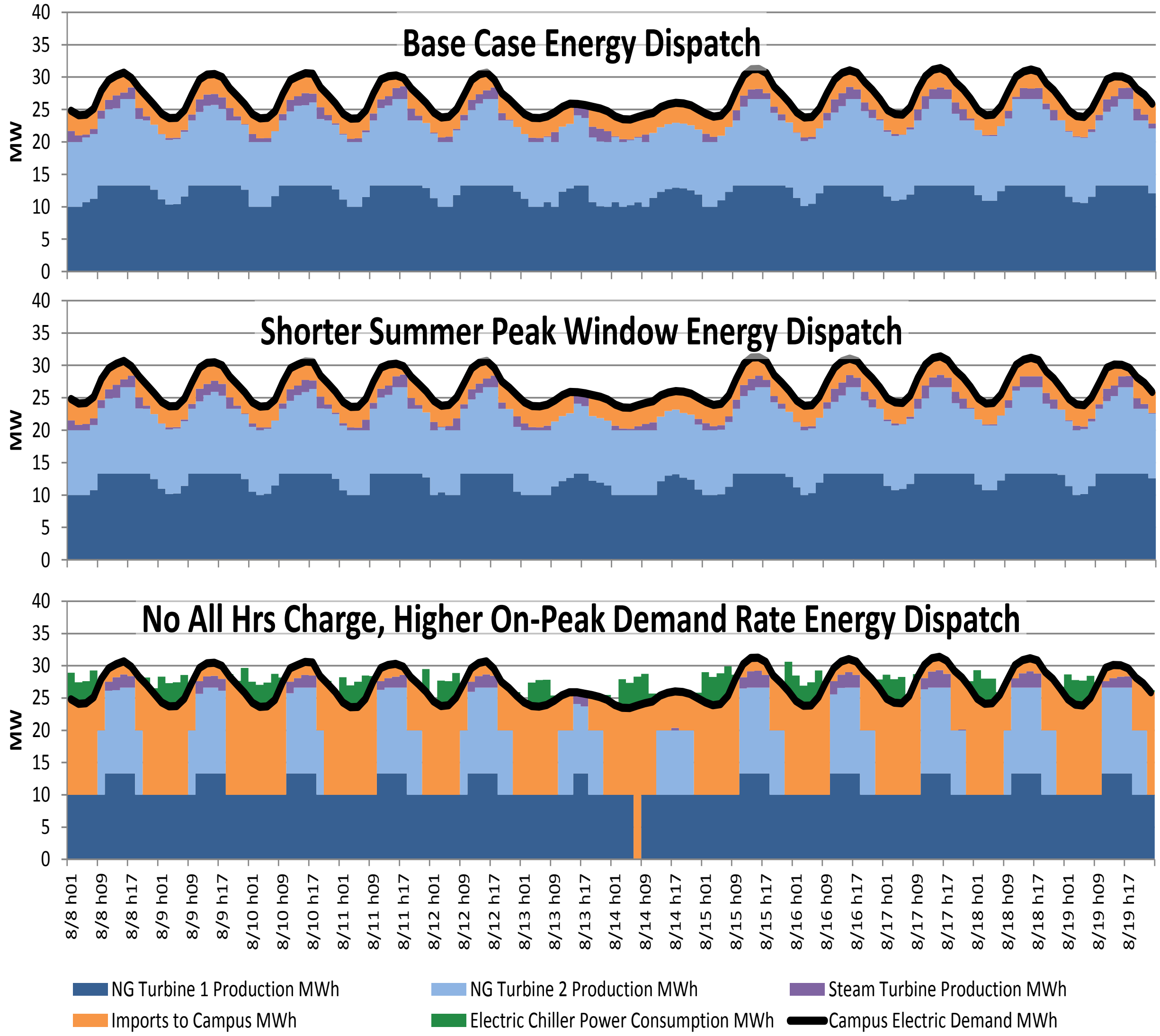


Figure 19: Examples of hourly dispatch for the Peak Load Shifting

PV Firming Strategy: Handle error with Gas Turbines

The natural gas generation firming strategy shows savings in electricity imports relative to the base case, but those savings are overwhelmed by increased natural gas costs making total costs increase in both months.

PV Firming Strategy: Two-part rate

All the PV firming strategies have positive net costs but with varying levels. The 2 part tariff strategy incurs about 1% higher electricity import costs, which include penalty payments and negligible increases in natural gas costs for both months. The increase in electricity imports is higher for the grid leaning strategy than the other strategies (Figure 20).

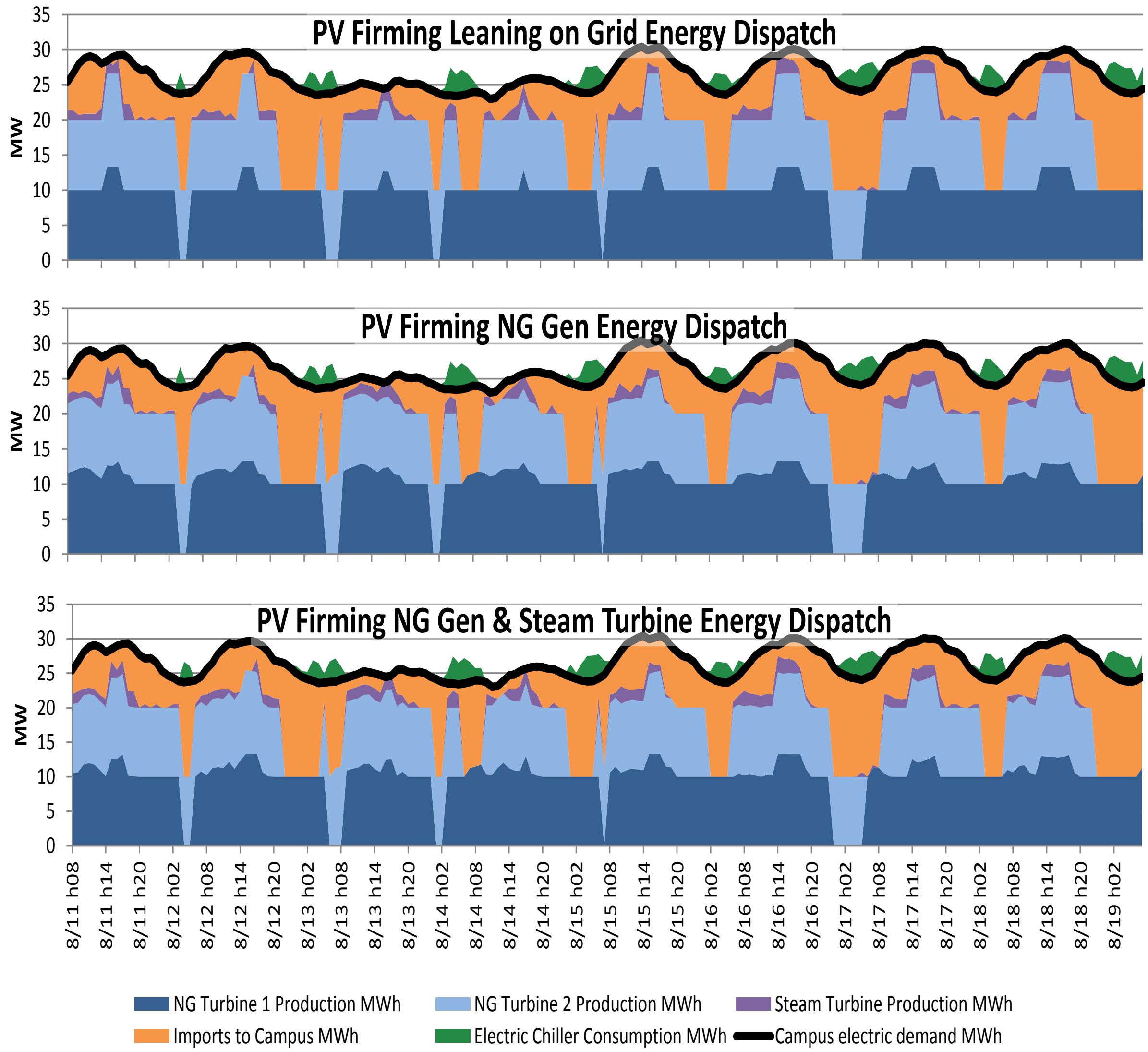


Figure 20: Examples of energy dispatch for three different formulations for firming campus PV

Incentives for Grid Support Strategy: Market Products

The dispatch of campus resources three regulation cases (natural gas generators bid the same up and down MWs; gas generators bid separate up and down MWs; and all resources bid separate up and down MWs) are shown in Figure 21. The dispatch is similar in all cases, with some additional imports for electric chiller consumption in the last case. Although the quantity of regulation offered in each case changes, the dispatch of campus resources does not. With increasing flexibility in market rules and the resources offering regulation, the optimizer takes further advantage of the opportunity to earn revenues in the regulation market (Figure 22), but does not alter the dispatch of campus resources to do so. There is a dramatic difference in costs and revenues between the two cases that require the same quanity to be bid in both directions, and the two cases that allow different quantities in the up and down direction. Offering the same quantity in both directions requires the generator to operate near the mid-point of 23.3 MWs to provide regulation. Under normal operation, the generators will operate predominately at 20 or 26. 6 MWs, or one generator will shut down entirely. The optimizer is generally choosing to offer regulation when the generators would otherwise operate at 20 MW. Therefore, the overall level of generation is increased, reducing imports and increasing natural gas consumption.

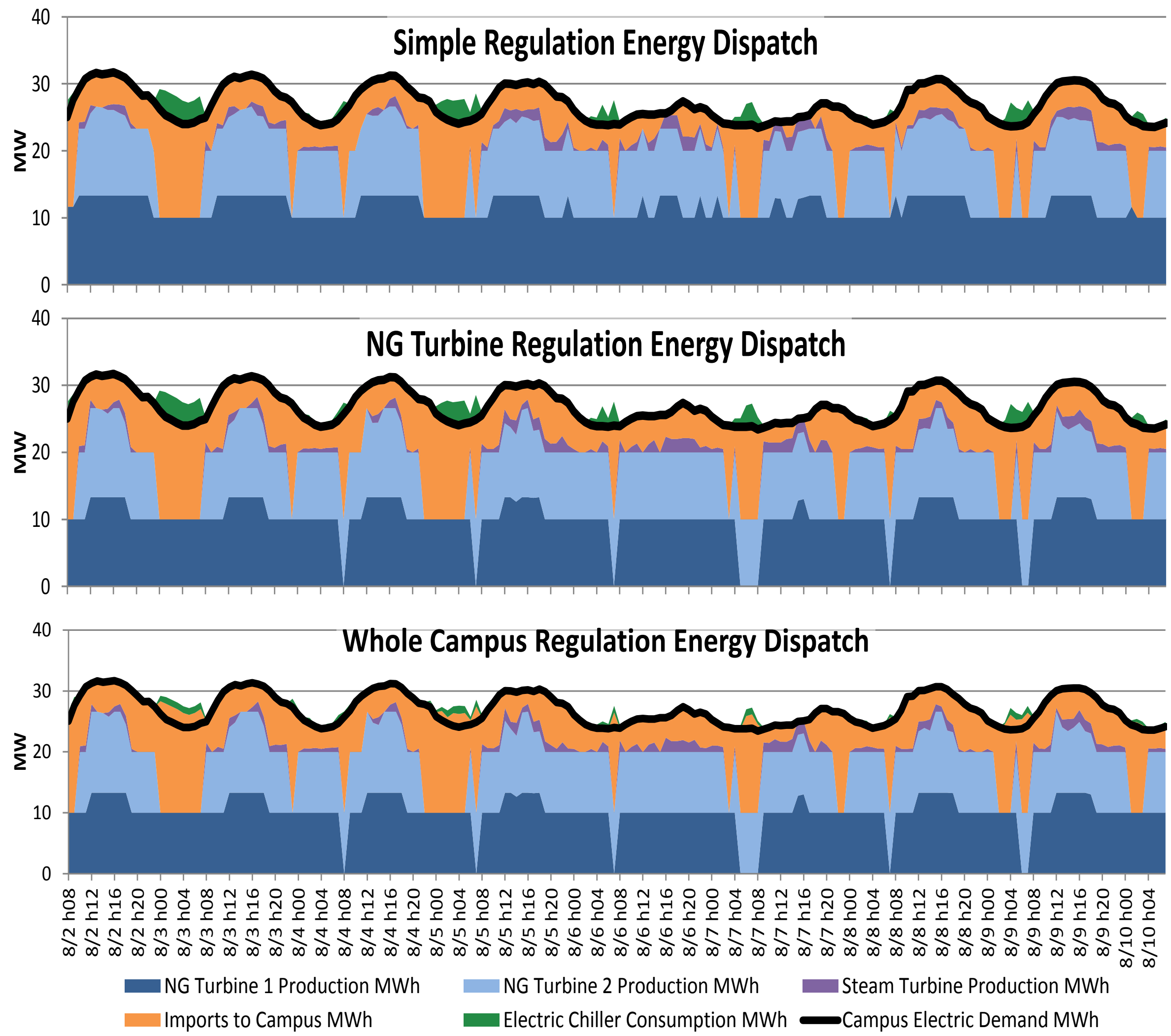


Figure 21: Examples of energy dispatch for different regulation bidding strategies

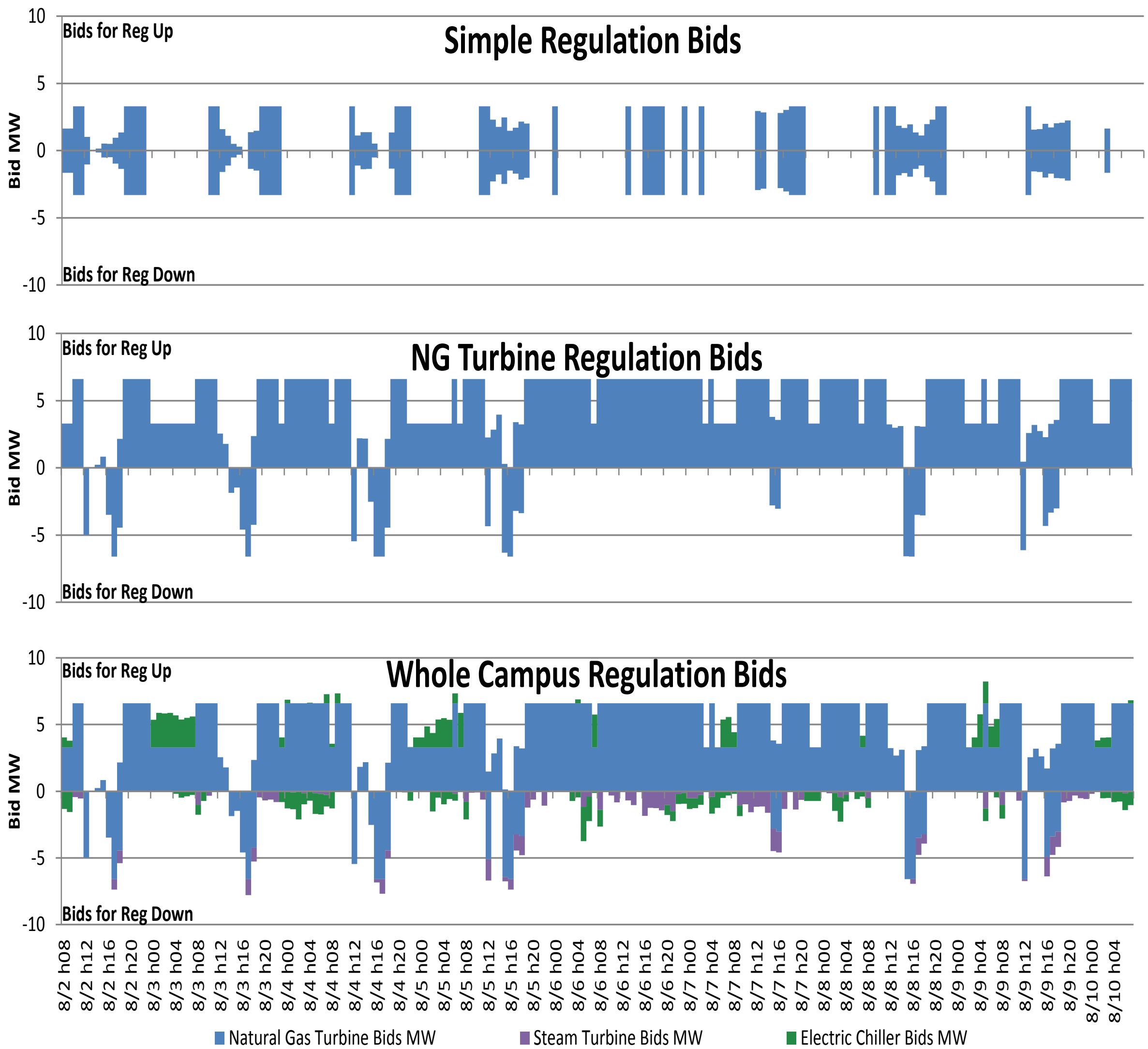


Figure 22: Regulation bids, up and down, for three different strategies for providing regulation

Public Cost Benefit Tool

For reasons described earlier, the UCSD Dispatch Optimization Tool was developed beyond the scope initially envisioned for this project to perform detailed dispatch optimization of UCSD resources over an entire year. This significant expansion of the functionality of the UCSD Dispatch Optimization Tool consumed significant additional time and budget. Because resources were diverted to fully developing the optimization approach, and because the model became significantly more complex as a result, a simplified public interface for the tool as envisioned in Task 8 was not developed.

Conclusion

Several conclusions can be drawn from this project. They are presented here in three categories: Modeling, Operations, and Tariff and incentives.

Modeling insights

Modeling insights come from the efforts to implement VPower and the UCSD Dispatch Optimization tools and working with UCSD operators to parameterize the cost benefit optimization model. Working closely with the UCSD energy manager proved instrumental in validating modeling results and identifying where focused detail is needed and where reasonable approximations can be made.

Modeling and testing a microgrid for either simulation or real time mode is complex and requires the availability of subject matter experts: The complexity of modeling and testing the operational parameters for the variety of resources and their interactions within a microgrid is a detailed and time-consuming task. Having subject matter experts that are dedicated as part of the project team is key to working through challenges. UCSD staff was extremely responsive and helpful, but given their other responsibilities could not support the time required to work with the team to address some of the data and model issues encountered.

Integrating thermal resources in optimization is required for robust results: Good integration of thermal resources and their interactions with other resources in optimization proved crucial to winning operator confidence in the results. Integration studies tend to focus on electrical impacts, but heating and cooling are key additional primary end-uses. The two threshold issues for campus operators are: 1) are the results credible and intuitive and 2) do they include the downstream impacts in hot and cold water production.

Separate approaches are needed for monthly and daily period of analysis for demand charge costs: As is true for many large C&I customers, the monthly demand charge is a large cost driver for UCSD. Performing a full optimization over one month was not feasible in VPower nor the UCSD Campus Dispatch Optimization Tool model due to computational limitations. It was found to be most expedient to adopt the two stage approach presented in this study: a one month optimization, with approximations as needed for computational efficiency, to determine maximum demand for demand charges and TES dispatch; and a more detailed optimization over one to several days at a time to perform hourly or sub-hourly dispatch optimization.

Operational insights

Modeling efforts and insights produced results that offer some useful observations on UCSD resource operation. The scenarios are modeled results and as such they do not fully capture the detailed considerations and uncertainties faced by UCSD microgrid operators. However modeling hourly dispatch for a full year has offered insights into how the strategies examined here could work with actual campus operations.

Integrated optimization and dispatch of campus resources can reduce costs while providing flexibility: Modeling optimal dispatch of campus resources proves effective in identifying strategies that can reduce costs or increase flexibility relative to standard operation. Currently, UCSD applies heuristics to dispatch resources, which are operated in a pseudo-steady state manner. Characterizing and optimizing campus resources demonstrates the capacity to perform additional services while meeting campus demands and achieve additional cost savings.

Incorporating additional resources in dispatch strategies does meaningfully reduce costs or increase flexibility: In both the PV firming strategies and grid support strategies, adding resources such as the steam generators or electric chillers to the available portfolio reduces the comparative campus costs and increases the quantity of service provided.

PV firming with campus resources appears feasible, but more expensive than current estimates of grid renewable integration costs: Using renewable integration cost estimates of $8/MWh generated or $31/MWh of forecast error – on the high end of renewable integration cost estimates – it was determined that using the campus resources to firm PV is not cost-effective. This follows the generally accepted wisdom that a diverse portfolio of resources over a wider geographic area will be more efficient in managing variability. Including additional campus resources (such as building loads or electric chillers) could reduce the campus costs. Furthermore, to the extent that there are higher local integration costs, DER's could still prove an economic resource for renewable integration.

Current prices for regulation are cost-effective for campus but revenues are small compared to total costs: Campus resources can provide frequency regulation in the CAISO market at today's prices cost-effectively. However, net revenues are only ~2% of the total campus energy cost. Regulation revenue can help justify investments in new resources, but will be supplemental rather than a main driver of the decision. Because regulation can be a demanding service with increased risk and O&M costs, additional incentives or alternative strategies (such as pooled provision of regulation by aggregated networks of distributed resources) will be necessary to encourage wider adoption.

Tariff and incentive insights

Operational insights often arose together with insights about how changes in the cost UCSD faced or the addition of incentives could have substantial positive impacts on the integration strategies. Modeling shows the strategies in this work can be operationally possible and further work may show they are operationally feasible, but tariffs and incentives will be the final determinant of whether these integration strategies can be deployed.

Off-peak demand charge significantly constrains on-peak dispatch of campus resources: The SDG&E all-hours demand charge proves to be a significant constraint to the peak load shifting dispatch for UCSD. Because UCSD has significant load shifting capacity relative to peak net loads, load shifting frequently increases monthly peak demand, though it occurs in the off-peak period. Simply implementing alternative tariffs for recovering fixed costs could increase the peak load shifted by over 1 MW. While the all-hours demand charge was not modeled with the other strategies, it is expected that it will also prove to be a disincentive many strategies for using DER for renewable integration.

Two-part rates will be needed to encourage DER provision of renewable integration services: Retail tariffs are relatively blunt instruments and impose significant risks and potential costs for customers seeking to provide renewable integration services. It is unrealistic to expect dynamic rates alone to provide sufficient incentives. In fact, as is seen in the PLS strategies, time differentiated rates can lead to counter-productive incentives when it comes to renewable integration. Supplemental tariffs and incentives that can be layered on top of retail rates without compromising utility fixed cost recovery will be necessary to engage the full potential of DER's for renewable integration.

Direct participation in wholesale markets do not provide sufficient incentives for campus provision of integration or ancillary services: Campuses like UCSD have a diverse and large portfolio of resources, but emissions, economic and end-use considerations limit the relative quantity of capacity available for providing grid support. These services can be cost effective from the grid perspective, but participation results in revenue that is a small percentage of total campus costs. Additional research or product development is needed to develop strategies to effectively engage to large C&I customer DERs in wholesale markets.

Findings

Implementing optimization tools at UCSD revealed unexpected challenges. The operation of sophisticated, multi-resource combined energy and thermal systems like the UCSD Microgrid is extremely complex. An experienced team approached this project with no illusions about the modeling, optimization and system integration challenges entailed. Even so, several issues prevented the implementation and operation of VPower as planned, and forced the team to develop an alternative approach. Compared to most campuses, acquiring, processing and cleaning data from multiple sources proved time consuming, even for a well metered campus. The historian and telemetry need for real-time and near real-time campus data were still being configured during the course of the project. Static data models supported VPower modeling, but the nature of the interfaces did not easily support strategy testing. The team determined that evaluating scenarios would require longer duration and more flexible analyses and therefore, an alternative approach. Separate, computationally efficient optimization approaches, were developed for hourly dispatch over daily and monthly/annual periods. Neither tool fully accounts for uncertainty or increased operational costs or risks from complex operational strategies.

Security requirements need to be considered and addressed as part of implementing the management and optimization tools. There were several cases where changes in campus cyber security policies affected the project. The VPower installation was removed a few times and needed to be reinstalled and re-authenticated. Security restrictions at some of the off campus sites that were considered for participation in the project, limited the team's ability to gather data needed for modeling. Security could also restrict the external monitoring and control functions necessary for rapid customer responses to pricing and dispatch signals.

Value and cost estimates for local, distribution grid support and integration services are needed, but not readily available. There is little, if any, public cost estimates for local and distribution level impacts, which are frequently the primary limiting concerns for utility operators when it comes to high PV penetration and EV charging. These services are potentially more valuable and lucrative than wholesale grid markets. Identifying, developing and monetizing high value services for local grid support is crucial for increased customer, vendor and service provider engagement.

A public and transparent framework to explicitly compare central, distributed, load and market based renewable integration and GHG reduction strategies is needed. Although several initiatives and proceedings are examining long-term planning and procurement for flexible resources and renewable integration, there remains no framework to readily evaluate and compare the diverse portfolio of alternative strategies available to utilities and policy makers. A guiding framework for evaluating the relative costs and benefits of resources like CTs, energy storage, demand response and the CAISO Flexi-ramp product in meeting identified system needs would be instrumental in identifying and developing high value, low cost strategies in each category.

The limited value of net AS market revenues relative to total energy costs reinforces the importance of non-price strategies to engage the substantial resources of large C&I customers for integration and ancillary services. In eastern ISO markets, DER's now provide up to 10% of the total MW's enrolled in centralized capacity markets. Participation in reserve and AS markets is much more limited. This project's analysis suggests that access to wholesale markets alone is insufficient to motivate participation by UCSD and by proxy, other large C&I customers. These findings, together with the experience in eastern ISO markets, suggests that customer engagement and outreach will be important elements in encouraging DER to provide renewable integration.

Recommendations

Support an implementation study of DER integration strategies using UCSD as a pilot site: To enable the large existing pool of DER to engage in strategies to enable greater renewable integration the work that has been done for UCSD will need to adapted to range of applications and disseminated. While this work models the dispatch of UCSD resources under proposed renewable integration strategies a vital next step in realizing these strategies is piloting their actually operation at the campus. The modeling conducted in this analysis does not address the uncertainty and nuances facing by system operators. An effort to operationalize these strategies for UCSD would leverage this work and produce a great deal of information on how modeled strategies translate to real world operation.

Restructure all-hours demand charge for PLS customers: The current all-hours demand charge paradoxically reduces the incentive for UCSD to shift load and increase off-peak generation at a time when system operators are claiming an increased need for both renewable integration and to replace local capacity lost due to the San Onofre Nuclear Generating Station outage. Restructuring the all-hours demand charge together with the on-peak demand charge for UCSD and other customers with significant load shifting capacity could meet both objectives at little or no cost to utilities or ratepayers.

Allow utilities to negotiate terms specific to individual, large C&I customers: UCSD is an example of a large, underutilized resource for SDG&E. The all-hours demand charge is counter-productively limiting peak load shifting, and established baseline rules base on 10 historical days are too inaccurate and risky for UCSD to enroll in established DR programs. There is established precedent for utilities to negotiate special rates for customers considering bypass. A similar policy of allowing utilities to negotiate customized terms to facilitate the maximum participation by local distributed resources should be considered.

Public benefits to California

The results of this project are relevant beyond UCSD and could promote DER adoption and the use of DER for renewables integration. Although the project did not meet the original goal of demonstrating specific strategies at UCSD in a live environment, the results provide useful insights for customers and policy makers that can provide economic and environmental benefits in the near-term.

Technical potential. C&I loads have significant technical potential to provide renewables integration strategies in California. College campuses total 500 MW of load; industrial customers total over 2000 MW of load[7] and have many controllable end-use loads (pumps, fans, motors); there are ~ 8500 MW of combined and heat and power systems at ~ 1,200 sites in California[8].

Simple policy changes. Analysis during this project shows that a simple policy change — 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 ~$1.0 Million/year using 2013 avoided capacity costs. (Capacity value in Local Capacity Requirement (LCR) area such as San Diego are not publicly available but generally estimated to be much higher.)

Integration at the distribution level. Analysis during this project suggests UCSD can firm its solar PV using its own resources at a cost comparable to relying on the grid, even using relatively high estimates of renewables integration costs. However, local integration costs are uncertain and could be higher than average integration costs, which increases the value of using DER to provide firming. The two-part that is described when firming with the grid can be implemented with smart meters.

Insights on grid support. Analysis during this project of grid support suggests it is economical for UCSD to provide grid support based on regulation prices but the net

[7] Itron 2007, Assistance in Updating the Energy Efficiency Savings Goals for 2012 and Beyond Task A4 . 1 Final Report : Scenario Analysis to Support Updates to the CPUC Savings Goals Main (2007), at 37.

[8] ICF International, 2012. Combined heat and power: Policy analysis and 2011-2013 market assessment. Report prepared for the California Energy Commission. Report CEC-200-2012-002

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 provides insights, tools and strategies that can be used by California colleges to support efforts in reducing energy consumption, costs and GHG emissions. For example, achieving the GHG emissions reductions called for in the University of California's Policy on Sustainable Energy Practices (which encourages carbon neutrality as soon as possible) presents numerous challenges and will require new analysis tools and innovative strategies such as those described in this study.

References and Companion Reports

References

CAISO. (2012). Flexible Ramping Products: Draft Final Proposal. Folsom, California: CAISO.

Itron (2007). Assistance in Updating the Energy Efficiency Savings Goals for 2012 and Beyond Task A4.1 Final Report : Scenario Analysis to Support Updates to the CPUC Savings Goals.

PG&E, SCE, SDG&E. Joint IOU Supporting Testimony. July 1 2011, CPUC Long Term Procurement Proceeding, R. 10-05-006. http://www.cpuc.ca.gov/NR/rdonlyres/070BF372-82B0-4E2B-90B6-0B7BF85D20E6/0/JointIOULTPP_TrackI_JointIOUTestimony.pdf

Companion Reports

The following reports were produced as part of this project. They are available at **http://www.calsolarresearch.ca.gov/solicitation2-viridity.html**

Task 2: Strategies for Integrating High Penetration Renewables Report

Task 3: Tariffs and Incentives for Integrating High Penetration Renewables Report

Task 4.1: Deliverable (Final)-VPOWER Installation Report

Task 4.2: Expansion of DER Model CSI 2 Grant

Task 4.3: VPower Enhancements Report CSI 2 Grant

Task 5: Report on baseline performance for UCSD DER operation under current rates and incentives

Task 6, 7, 8: Strategies and Incentives for integration of renewable generation using distributed energy resources

Appendix A – VPower Enhancements

VPower Enhancements

Initial Modifications to VPower

- **Thermal Energy Production:** VPower was enhanced to specifically model the production of thermal outputs such as steam, chilled water, or hot water. This was essential since UCSD must supply from the same set of resources electrical demand as well as hot and cold water to the HVAC system. This enhancement allowed VPower to economically balance the schedules for steam to the steam turbine generator, the steam chillers, and the heat exchangers.
- **Thermal Energy Storage:** VPower was enhanced to specifically model the storage of thermal outputs. This allowed VPower to more accurately model the chilling of water during the off peak period, which can then later be scheduled along with on-line chilling to meet the period to period chilled water demand. Additionally it enabled some flexibility in the hot water requirements, allowing a temporary reduction in temperature to reduce system loading during peak periods.
- **Enhanced Load Curtailing:** VPower was enhanced to model the campus HVAC control system as a unitary curtailable load. USCD uses a Johnson Control System provided building management system that can switch the controls between three modes: occupied, standby, and unoccupied. By switching from occupied mode to unoccupied, the campus load can drop by up to 1.5 MWs for a few hours. This enhancement improved curtailable load modeling in VPower for those installations where VPower is not integrated with the building management system directly.
- **Multiple Inputs/Outputs:** VPower's model of generation resources that utilize multiple inputs and produce multiple outputs was enhanced. An example of resources with multiple outputs could be a fueled generator which produces electricity that additionally produces steam from its heat recovery steam generator (HRSG). An example of a resource with multiple inputs could include a generator which uses a mix of two types of fuel, or a resource model in which the water used for cooling along with the fuel needed to be modeled as an explicit input.
- **Input/Output Ratios:** With the VPower enhancements, during modeling time the analyst can configure VPower to schedule the consumption of multiple inputs either automatically in a way that is economically optimal, assuming the resources are so-capable. Or they can be set to consume the inputs in a fixed ratio. Likewise the outputs associated with a multiple output resource can schedule the outputs in

whatever ratio determined to be economically optimal, or they can be assigned a fixed ratio.

- **Thermal Energy Topology:** Additional enhancements were made to the connection modeling between thermal resource outputs and the destination of the thermal product. The connection model allows a generator of steam, or chilled water, to feed that output to a specified device (or devices). Once again, the enhancement allows the destination of outputs to be specified as a fixed ratio, or to be determined as part of the optimization.
- **Weather and Price:** To support the UCSD resource analysis, a commercial grade weather service was configured to import the latest forecasts for San Diego. Additionally during the CSI project, VPower was extended with modules to download and process both locational marginal prices from the real-time and day ahead energy markets.
- **VPower GUI Enhancements:** The user interfaces were extended during the project to provide a better global picture to the VPower Operator. Enhancements included resource specific, period by period estimates of emissions (e.g., carbon dioxide); summary of the period-by-period steam production being modeled; and additional information pushed to the dashboard UI in Power Analytics Paladin application.

Additional improvements identified mid-project

During the process of base-lining the campus and reviewing the UCSD collected data, some areas of improvement were identified where the VPower modeling and optimization could more accurately account for the observed operations of the campus resources. Among these areas for improvement were:

- Inclusion of demand charges
- Multipoint fuel consumption/efficiency curves
- Support for fuel prices that vary over time

Additional improvements not specifically designed for UCSD include the ability to model fuel markets and resale of fuel in physical markets; modeling fuel contract quantities and costs for resources, such as natural gas amounts and costs for natural gas turbines, or diesel fuel for diesel generators.

Demand Charges

Background

As VPower was developed as a decision support tool to schedule resources over the coming day or two, its model focused on costs which would be included within the window of scheduling. It did not explicitly include longer term costs, such as demand charges which are set over the preceding month(s). As the VPower models were tuned and the costs compared to the UCSD actual costs, it was noticed that the demand charges were quite substantial. The results were not an apple to apple comparison and not having the demand charges meant that VPower was lacking one of the potential levers whose action may be important in balancing responsive microgrid resources, intermittent generation, and reliance on utility supply imports.

General Overview of Demand Charges

In order to assess the costs and benefits that additional PV brings to an installation, it is helpful to understand the impact of (and full costs associated with) utilizing their flexible resources to firm intermittent generation. If a customer has no additional capacity to call upon when the PV generation drops, the next MW may be served through the electric utility. While the energy price per MW may not be onerous, the implication of increasing the maximum peak monthly or annual demand charge can be very substantial.

While a customer's electrical energy can vary over time, the grid equipment that facilitates the distribution of electrical services to customers must be sized based on the largest (or peak) demand conditions. It is common practice for electric utilities to include a significant charge in the customer's bill related to the peak demand observed during the service period, or even during a longer period prior to the service period, for example the previous year. The order of magnitude of the peak demand-based charges can approach the energy charges covering the same duration. The energy charges are primarily driven by the energy price (which may vary over time) and the kilowatt-hours consumed. Thus it is important to consider the demand charge when attempting to compare a customer's total energy costs to the costs predicted by a planning and optimization tool, such as VPower.

For a microgrid, VPower's schedule optimizer models thermal and electrical consumption, generation, and the import of electrical supply. Limiting the electrical supply provided from the utility (import MWs), to some maximum amount, can help manage the size of the demand charges imposed. Thus, a microgrid with self-generation resources, can use an optimized schedule to both minimize operational costs, while meeting the load requirements, and effect some control over the demand charges to be incurred.

Demand charge constraint

VPower's optimization utilizes resource models that describe a resource's ability to produce or consume various forms of energy, connections between those devices, an economic objective formulation, and numerous constraints. If the customer has determined a priori the import limit which balances the demand charge with the cost of their other goals, that can be specified as a constraint on the import MWs. Depending on the structure of the utility charges, there may be different constraints corresponding to various time categories (e.g., all-hours, off peak, on peak, etc.).

The determination of the appropriate balance between minimizing energy charges and demand charges might be accomplished through experience, or determined through the use of an analysis tool. Inclusion of the demand charges directly in the objective formulation to perform a month-long (or similar) period using load and price forecasts can determine the target import limit which provides the best mix of flexibility and economics.

Configuring VPower to utilize demand charge limits entering a time category (e.g., on-peak, off-peak, all-hours, etc.) the demand charge price associated with that time category, and indicating the "control-to" peak import limit. Once those elements are in place, each hour ending of the day is mapped to the demand charge time category. Some customers having multiple energy suppliers may configure demand charges for each point of coupling to the "grid". For UCSD, a single set of demand charges was modeled in VPower.

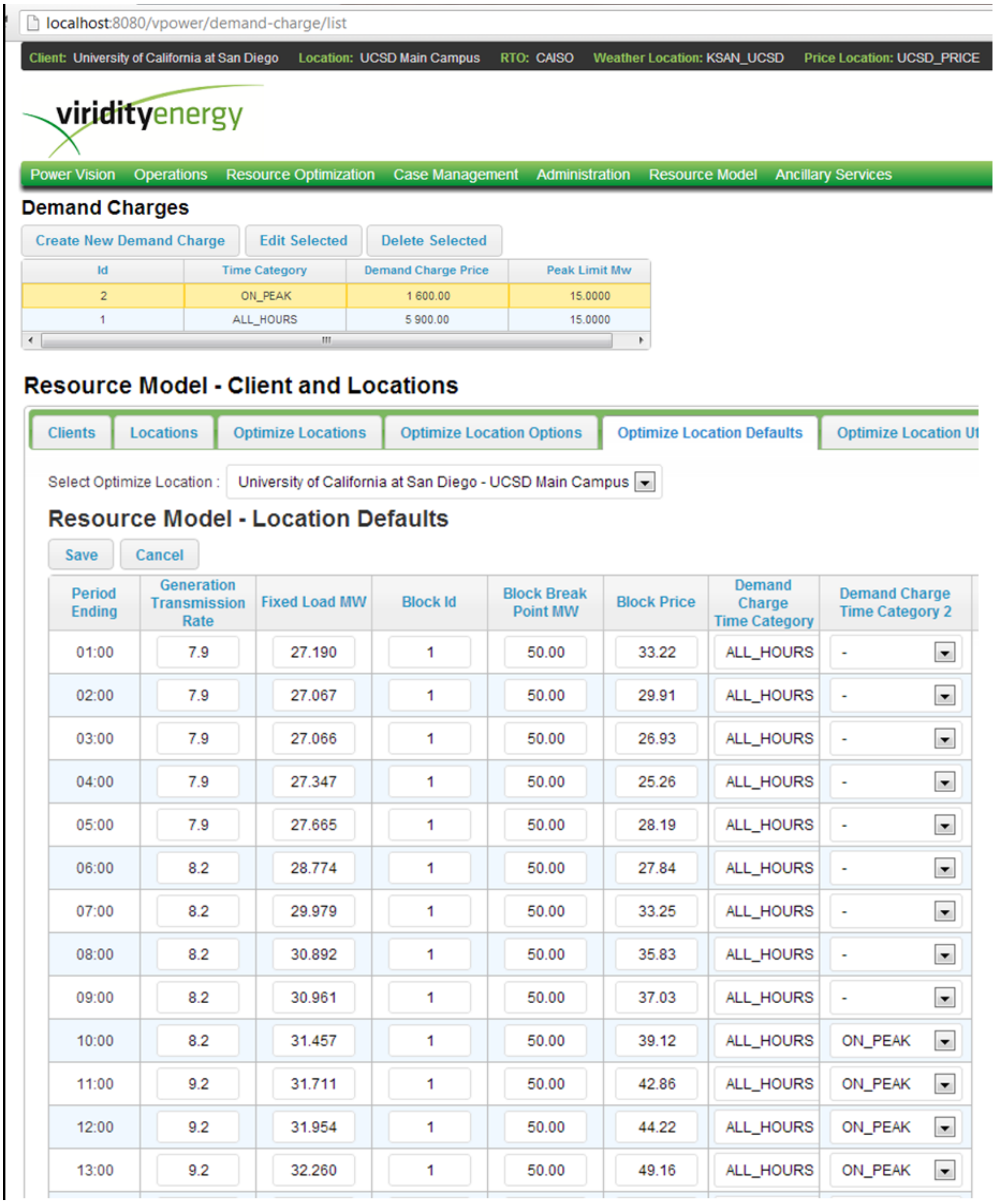


Figure A-1: VPower GUI for user to define demand charge information

Fuel Efficiency Curves

During the course of the baseline effort, it was found that using a single parameter over the entire range of operation for some resources did not accurately reflect the input/output data relationship. For a single point or for a small range of operation surrounding that point, this was a first approximation, but the further the schedule deviated from that point, the greater the mismatch would become. It was for this reason that VPower was updated to utilize efficiency curves which describe the fuel consumption for power output levels at various points of operation.

The following curves show that the original single parameter model would have been off by more than 80 MMBTU at zero MW output which would be encountered briefly during startup. At 10 MWs, the stated economic minimum generation limit for this particular gas turbine, the mismatch would have been in the range of 10-12 MMBTU per hour.

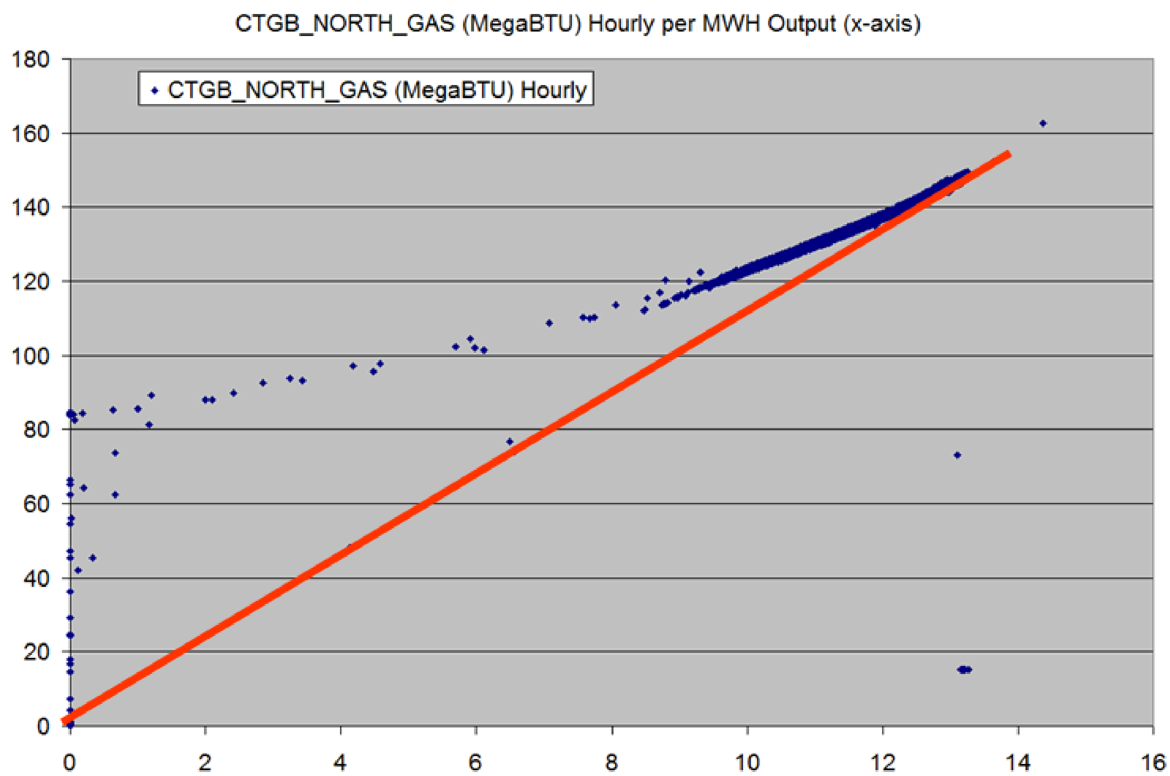


Figure A-2: Simple linear fuel consumption model (MMBTU/hour) (vertical axis) vs electrical output (MW) (horizontal axis)

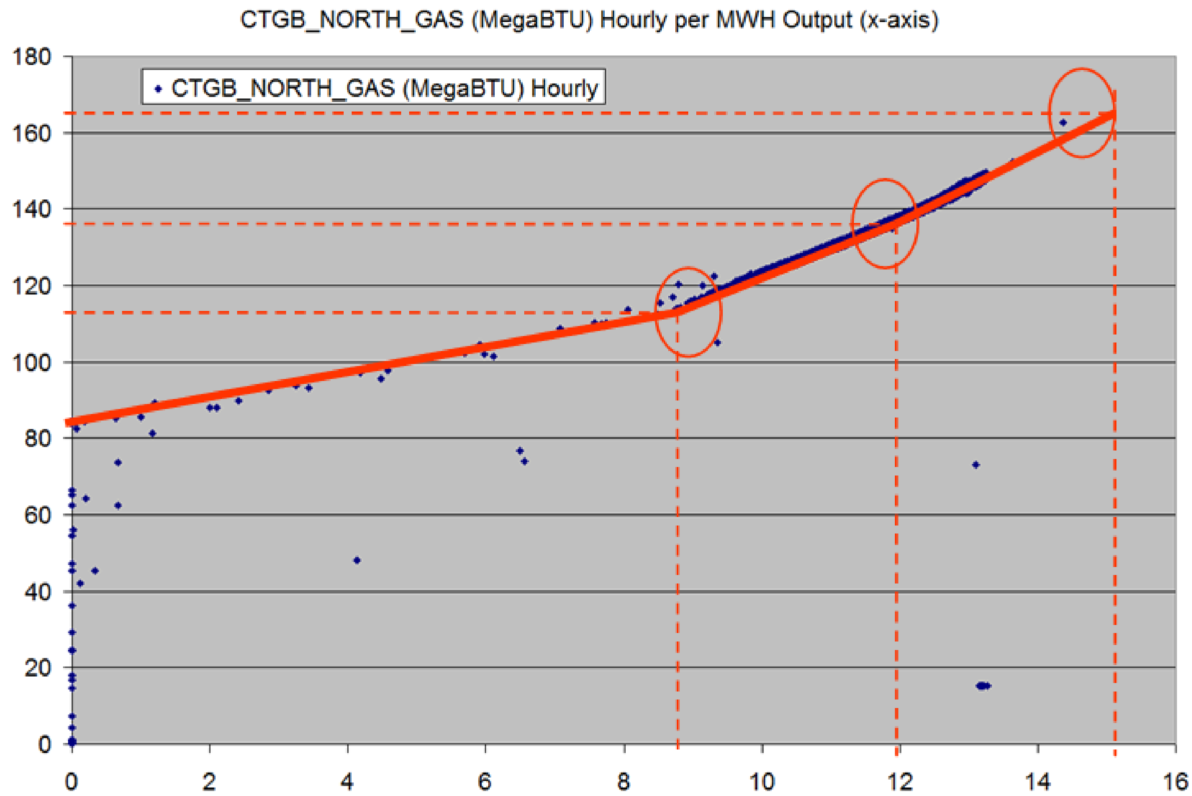


Figure A-3: Improved model of fuel consumption (MMBTU/hour) (vertical axis) vs electrical output (MW) (horizontal axis)

At the same time as support for the multiple point piecewise linear fuel efficiency curves were being added, support for interval based fuel price was added to VPower. Separate prices can be supported for each generation device, or can be modeled as various types of fuel supply contracts with resources using the fuel mapped to the contract.

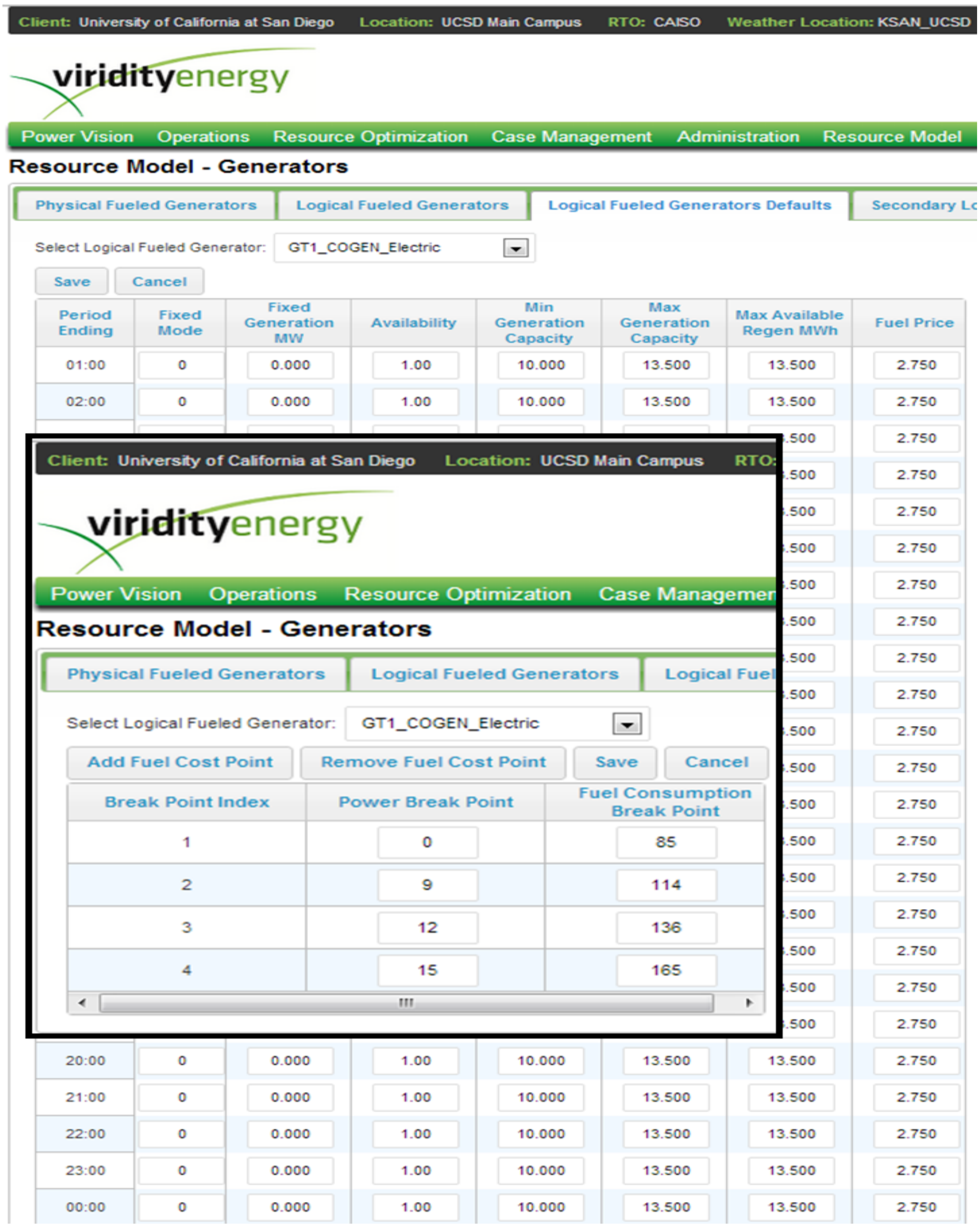


Figure A-4: VPower Fuel Consumption Curve User Interface and Fuel Price by Interval

VPower as a What-if Analysis Tool

While VPower was not utilized directly for the longer term analyses described in the strategies and outcomes sections of this document, there were a number of cases used to test the features that were added.

Example VPower Cases

This section describes six single-day cases that were analyzed in the Viridity Energy optimizer, a component of VPower. The resource model on which the simulations described here leveraged the VPower UCSD model, expanded to take advantage of enhanced optimizer capabilities. Specifically, the enhancements include: the addition of demand charge calculations into the objective function and the replacement of linear fuel curves with multi-segmented, piecewise-linear fuel curves.

The six cases were developed to investigate the impact of demand charge MW limits, and more realistic fuel curves on total utility costs. Each of the five cases was run twice: first in the business-as-usual model to replicate as closely as possible macro-standard operating procedures for the UCSD microgrid. The output of this simulation is termed the Customer Baseline Load (CBL). The second run was the optimization of the grid resources constrained by the operating envelope of the microgrid and the individual resources.

Demand Charge Limits: Four cases explored the impact of demand charge MW limits on utility costs. Since the generating resources of the microgrid are capable of meeting the entire load of the microgrid during the dates utilized, three cases were used to explore a spectrum of business-as-usual operating conditions. The first case of this set, a baseline case, assumed that the entire combined heating and power plant and all diesel generators are not part of business-as-usual operating procedures. While this is not a realistic assumption, it forms a useful starting point for analysis. In the second case one gas turbine and the steam turbine were included in the business-as-usual operating conditions. In the third case both gas turbines and the steam turbine were considered part of business-as-usual condition. The fourth case is the third case with all demand charge prices and Demand Charge MW Limits removed. The diesels were never considered to be part of business-as-usual conditions.

Fuel Consumption Curves: The fifth case, examining the impact of simple linear fuel curves, included the calculation of a CBL based on the business-as-usual conditions of one gas turbine and the steam turbine operating. For both the CBL and optimization runs, the multi-segmented, piecewise linear fuel curves were replaced by simple linear fuel curves.

Demand Charge MW Limits: The demand charge used in the model is $5900/MW for All Hours and $1600/MW for On-Peak Hours.

The table below details the case specifics of resource availability for these cases, where 1 = Available for operation and 0 = Unavailable for operation. Case UC-C4-D01-08 is identical to case UC-C4-D01-03 except that for Case UC-C4-D01-08 there are no demand charges and no Demand Charge MW Limits imposed.

	CBL				**Optimization**			
Case	**GT-1**	**GT-2**	**ST**	**All Diesel**	**GT-1**	**GT-2**	**ST**	**All Diesel**
UC-C4-D01-01	0	0	0	0	1	1	1	1
UC-C4-D01-02	1	0	1	0	1	1	1	1
UC-C4-D01-03	1	1	1	0	1	1	1	1
UC-C4-D01-08	1	1	1	0	1	1	1	1

Table A-1: Case settings for customer baseline and optimization executions

When calculating the CBL, the optimization parameters are set to identify the optimal demand charge MW limit. This limit is then used in the optimization run to restrict the total imports allowed.

Demand Charge Results

The summary import, generation, and demand charge costs for these three cases are listed below.

Case	Total Import + Generation Costs	Demand Charge MW Limit	Demand Charge Cost	Import+Generation+ Demand Charge
UC-C4-D01-01	$24,061.40	25.93	$194,497.76	$218,559.16
UC-C4-D01-02	$24,009.77	9.43	$70,747.76	$94,757.53

UC-C4-D01-03	$24,040.97	0.00	$0.00	$24,040.97
UC-C4-D01-08	$24,010.72	N/A	0	$24,010.72

Table A-2: Summary Results from Test Cases

In the table above the demand charge cost is a monthly cost extrapolated from the one-day results. All other costs are daily total costs. As the case results indicate, including demand charges in the model significantly reduce total energy costs even if the demand charge costs are divided by 30 to represent a single day. It is important to remember that the Demand Charge MW Limits were determined by the optimizer during the CBL run for each case. The cases have different numbers of resources available to meet demand as indicated in the previous table. As the number of resources available to meet demand increase, the optimizer calculates a smaller Demand Charge MW Limit. This new demand charge optimization feature represents a significant advancement in optimizer capability. Ignoring demand charges in optimization has the potential to earn a client revenue in the energy markets while increasing their supply costs even more if extensive load shifting is performed within the optimization.

The graphs compare the results from Case UC-C4-D01-01, Case UC-C4-D01-03 and Case UC-C4-D01-08.

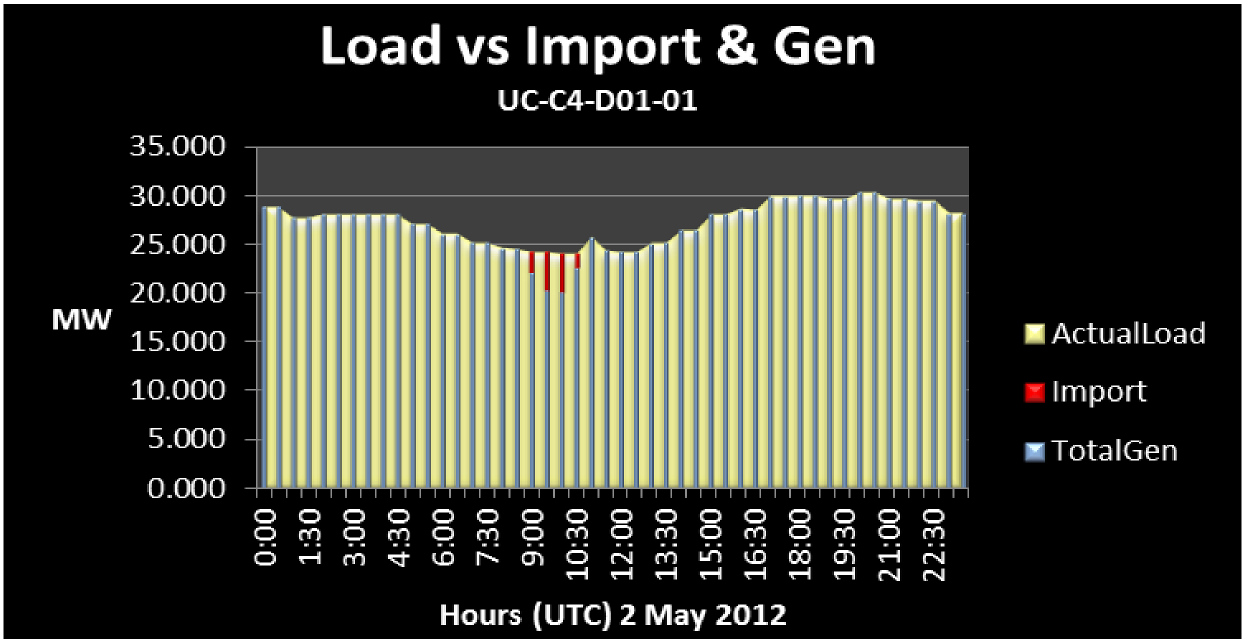


Figure A-5: Load vs Import and Generation for UC-C4-D01-01

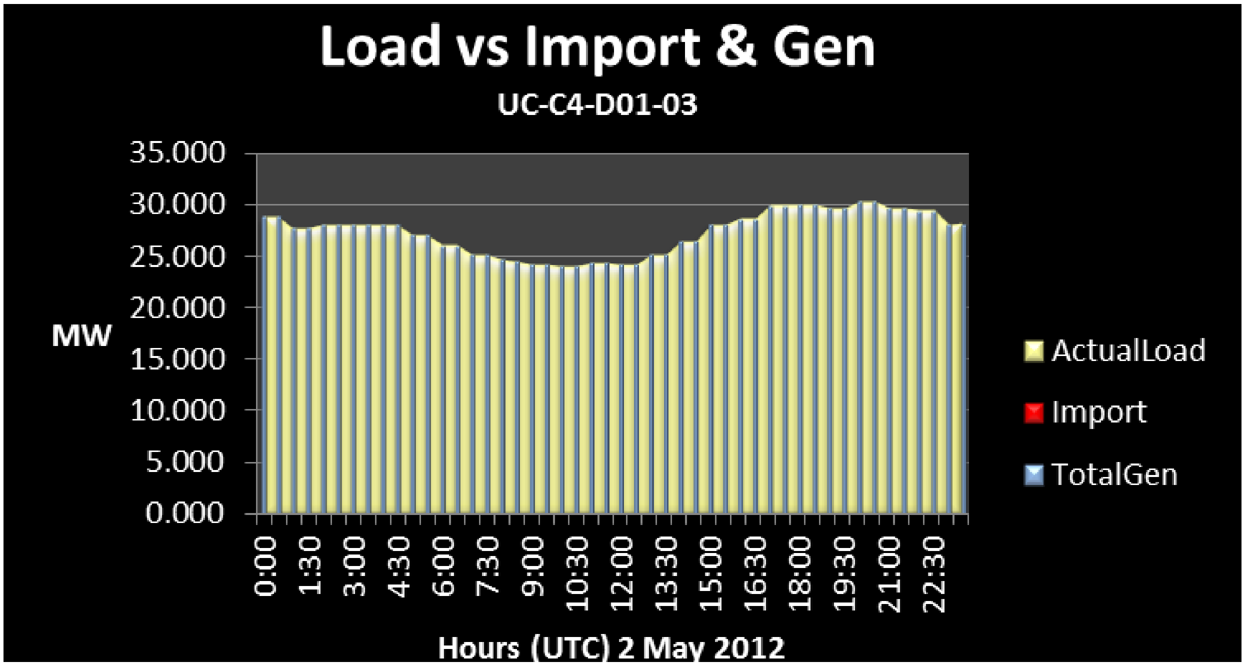


Figure A-6: Load vs Import and Generation for UC-C4-D01-03.

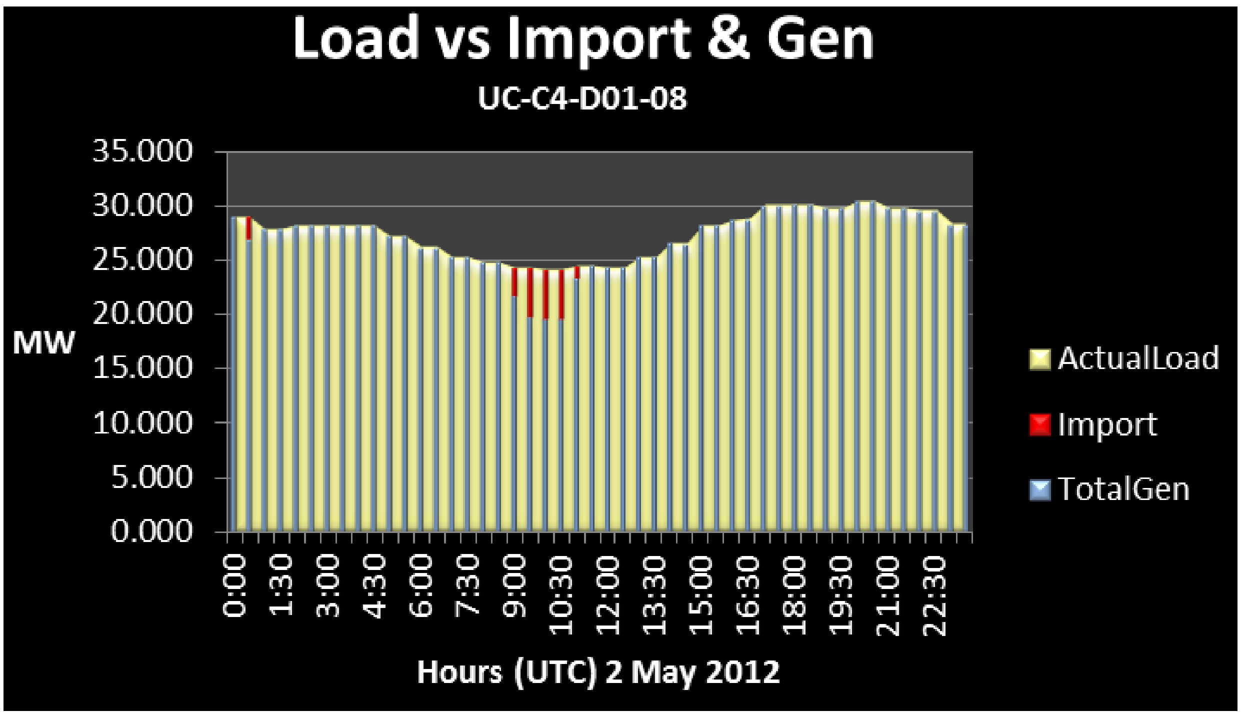


Figure A-7: Load vs Import and Generation for UC-C4-D01-08.

In Case UC-C4-D01-01 there are no on-site resources available for meeting demand and the optimizer calculates the large Demand Charge MW limit in order to allow sufficient power to be imported to meet demand. Although the Demand Charge MW Limit is large, the optimizer only imports about 4 MW for a few hours because in the optimization run all resources are available to meet demand. In Case UC-C4-D01-03 all resources are available in the CBL run to meet demand and the Demand Charge MW Limit is 0—no imported power is allowed. Case UC-C4-D01-08 is Case UC-C4-D01-03 with a demand charge price of $0.00/MW and no Demand Charge MW Limit. In this case the optimizer imports some power but the total import and generation cost for this case are less than for Case UC-C4-D01-03. This case reflects the fact that minus demand charges imported power may be less expensive than generated power but demand charges may require more expensive generated power to be used to avoid demand charges.

Enhanced Fuel Curve Model Results

Cases UC-C4-D01-02 and UC-C4-D01-05 illustrate the impact of upgrading the linear fuel curves to multi-segmented piecewise linear fuel curves (the curve points were displayed on figures earlier in this appendix). Case UC-C4-D01-05 is case UC-C4-D01-02 with the advanced fuel curves replaced with simple linear fuel curves. The Table below summarizes the fuel consumed by the generators for these two cases.

Case	Generation Cost
UC-C4-D01-02	$23,753.72
UC-C4-D01-05	$23,343.01

Table A-3: Generation Cost for Case UC-C4-D01-02 and UC-C4-D01-05.

As expected, the results show that the simple linear fuel curves underestimate the cost of fuel consumed. The difference in fuel cost is not more dramatic due to the operating point of the gas turbines for the two cases. Even though the cost of operation for the gas turbines in the two cases are different, the combined gas turbine output for the two cases, averaged over the 24-hour operating period, are within one percent of each other. By operating at near maximum output in both cases, the linear fuel curves and advanced fuel curves approximate each other closely. If the gas turbines were to operate at a part-load condition, the difference in generation costs would be more significant. It is in part-load operation conditions that the multi-segmented fuel curves will improve the accuracy of optimizer fuel consumed calculations significantly. The chart below depicts the fuel cost by hour for these two cases.

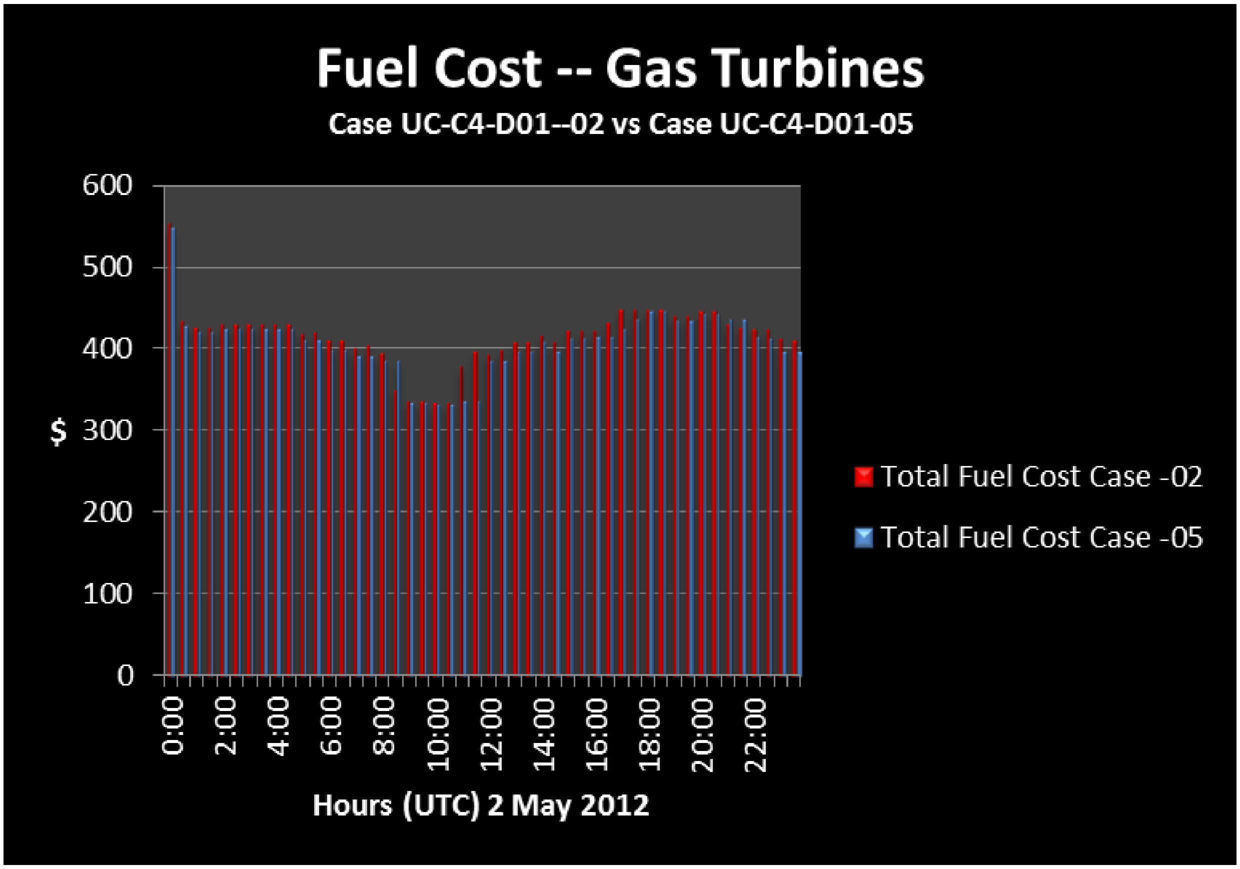


Figure A-8: Single day gas turbine fuel cost simple vs piecewise linear cost curve

As can be seen, the fuel cost for Case UC-C4-D01-02 is generally higher than for Case UC-C4-D01-05 because Case UC-C4-D01-02 has the multi-segmented piecewise-linear fuel curves whereas Case UC-C4-D01-05 has the simple linear fuel curves.

VPower Screenshots / Graphic Interfaces

Following are selected screenshots from the application installed at UCSD. Within the screenshots are depicted some of the data used to model the UCSD microgrid resources.

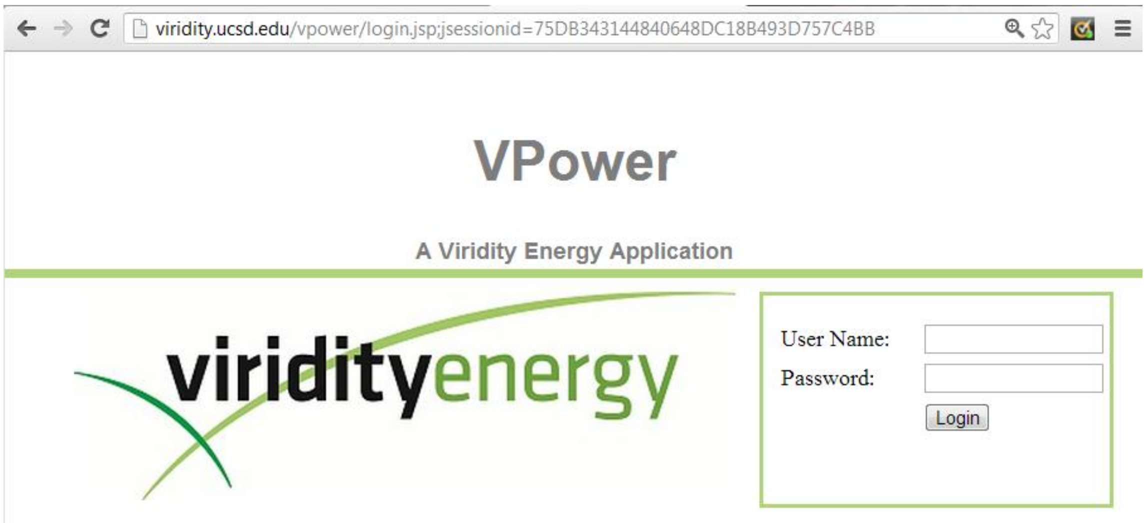


Figure A-9: VPower Login Screen.

Accessed via browser, VPower includes username and password authentication, and role-based access control.

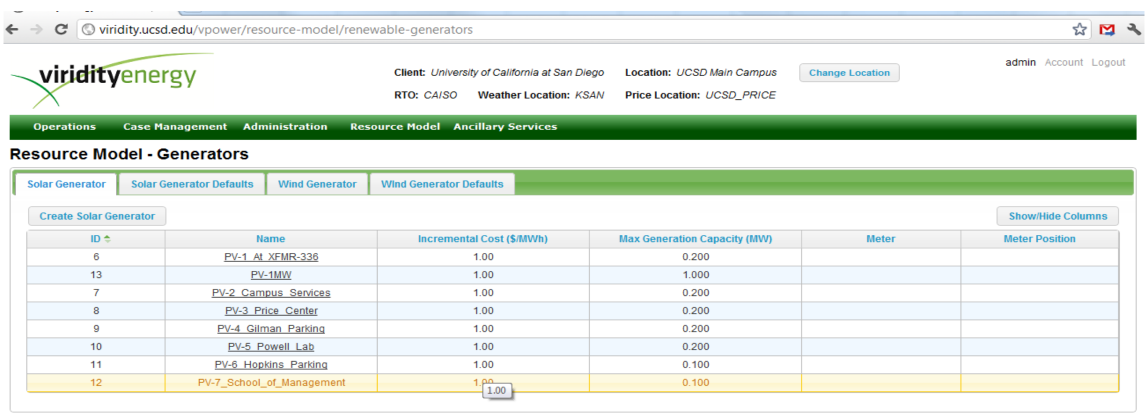


Figure A-10: VPower Resource Modeling – Solar Generator User Interface.

VPower models solar photovoltaic devices installed at UCSD. Weather data including irradiance, cloud cover is collected every hour from a service which is used to drive the expected output. Interfaces to the campus OSI Soft PI repository through Paladin support using campus produced solar KWH forecasts.

Setup New Generator

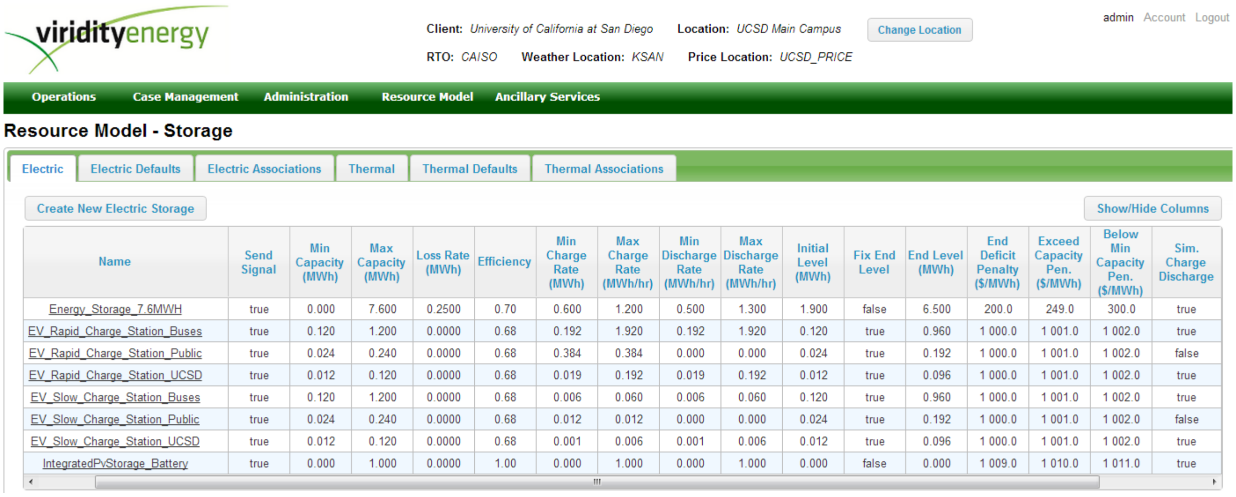
ID	Name	Input Energy Feeds *Name | Energy Type*	Output Energy Feeds *Name | Energy Type*	Logical Fueled Generators *Name | Input Name | Input Mix Ratio | Output Name | Output Mix Ratio*
14	Boiler	Boiler | THERMAL	Boiler | THERMAL	Boiler_Steam | Boiler | 100 | Boiler | 100
23	Fuel_Cell_1	Fuel_Cell_1 | THERMAL	Fuel_Cell_1 | ELECTRIC	Fuel_Cell_1_LE | Fuel_Cell_1 | 100 | Fuel_Cell_1 | 100
21	GEN-DIESEL-1	GEN-DIESEL-1 | THERMAL	GEN-DIESEL-1 | ELECTRIC	GEN-DIESEL-1_LE | GEN-DIESEL-1 | 100 | GEN-DIESEL-1 | -100
22	GEN-DIESEL-2	GEN-DIESEL-2 | THERMAL	GEN-DIESEL-2 | ELECTRIC	GEN-DIESEL-2_LE | GEN-DIESEL-2 | 100 | GEN-DIESEL-2 | -100
18	GEN-DIESEL4kV-1	GEN-DIESEL4kV-1 | THERMAL	GEN-DIESEL4kV-1 | ELECTRIC	GEN-DIESEL4kV-1_LE | GEN-DIESEL4kV-1 | 100 | GEN-DIESEL4kV-1 | -100
19	GEN-DIESEL4kV-2	GEN-DIESEL4kV-2 | THERMAL	GEN-DIESEL4kV-2 | ELECTRIC	GEN-DIESEL4kV-2_LE | GEN-DIESEL4kV-2 | 100 | GEN-DIESEL4kV-2 | -100
20	GEN-DIESEL4kV-3	GEN-DIESEL4kV-3 | THERMAL	GEN-DIESEL4kV-3 | ELECTRIC	GEN-DIESEL4kV-3_LE | GEN-DIESEL4kV-3 | 100 | GEN-DIESEL4kV-3 | -100
15	GT1_COGEN	GT1_COGEN | THERMAL GT1_COGEN | THERMAL	GT1_COGEN | THERMAL GT1_COGEN | ELECTRIC	GT1_COGEN_Electric | GT1_COGEN | 100 | GT1_COGEN | -100 GT1_COGEN_Steam | GT1_COGEN | 100 | GT1_COGEN | -100
16	GT2_COGEN	GT2_COGEN | THERMAL GT2_COGEN | THERMAL	GT2_COGEN | THERMAL GT2_COGEN | ELECTRIC	GT2_COGEN_Electric | GT2_COGEN | 100 | GT2_COGEN | -100 GT2_COGEN_Steam | GT2_COGEN | 100 | GT2_COGEN | -100
60	Heat_Exchanger Physical	Heat_Exchanger Physical | THERMAL	Heat_Exchanger Physical | THERMAL	Heat_Exchanger | Heat_Exchanger Physical | 100 | Heat_Exchanger Physical | 100
74	Hot Water Strategy Physical	Hot Water Strategy Physical | THERMAL	Hot Water Strategy Physical | THERMAL	Hot Water Strategy | Hot Water Strategy Physical | 100 | Hot Water Strategy Physical | 100
100	STEAM_HEADER	STEAM_HEADER | THERMAL	STEAM_HEADER | THERMAL	STEAM_HEADER_LS | STEAM_HEADER | 100 | STEAM_HEADER | 100
17	Steam_Turbine_ST1	Steam_Turbine_ST1 | THERMAL	Steam_Turbine_ST1 | ELECTRIC	Steam_Turbine_ST1_LE | Steam_Turbine_ST1 | 100 | Steam_Turbine_ST1 | 100

Figure A-11: VPower Resource Modeling, Electric and Thermal Generators Screen

VPower models devices that produce electricity, steam, hot water and cold water. Physical devices that can produce multiple outputs, or that consume multiple inputs are committed together, and may have output that is defined with fixed output ratios, or by separate fuel consumption curves.

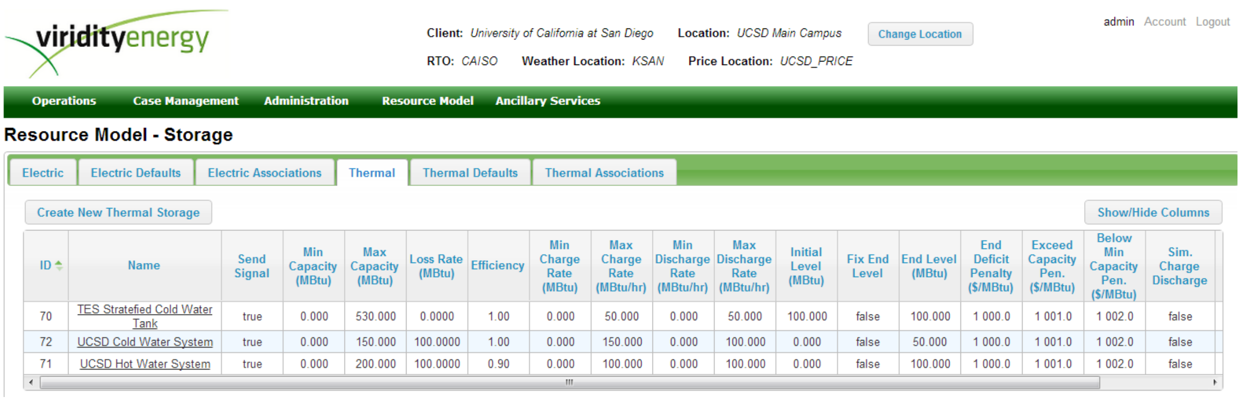
ID	Name	Emission Rate (lb/fuel)	Fuel Consumptio Rate (fuel/MWh)	Incrementa Cost ($/MWh)	Min Down time (hr)	Min Run Time (hr)	Operation Cost ($/hr)	Ramp Down Rate (MW/hr)	Ramp Up Rate (MW/hr)	Startup Cost ($)	Startup Time (hr)	Max Run Time (hr)	Shutdown Time (hr)	Nameplate Capacity (MW)	Sync Reserve Available
24	Boiler_Stear	0.00	1.00	19.00	0.0	0.0	0.00	20.000	20.000	0.00	0.0	999.0	2.0	48.50	false
35	Fuel_Cell_1	0.00	45.00	25.00	0.0	0.0	5.00	2.800	2.800	500.00	4.0	999.0	0.5	2.80	false
33	GEN-DIESEL-1_LE	22.50	16.92	45.00	0.0	0.0	0.00	1.000	1.000	0.00	0.0	30.0	0.0	1.00	false
34	GEN-DIESEL-2_LE	22.50	14.00	45.00	0.0	0.0	0.00	1.000	1.000	0.00	0.0	30.0	0.0	1.00	false
30	GEN-DIESEL4kV-1_LE	0.00	45.00	25.00	0.0	0.0	5.00	2.800	2.800	500.00	4.0	999.0	0.5	2.80	false
31	GEN-DIESEL4kV-	22.50	25.38	45.00	0.0	0.0	0.00	1.500	1.500	0.00	0.0	30.0	0.0	1.50	false

Figure A-12: VPower Resource Modeling, Generator Detail User Interface.



Name	Send Signal	Min Capacity (MWh)	Max Capacity (MWh)	Loss Rate (MWh)	Efficiency	Min Charge Rate (MWh)	Max Charge Rate (MWh/hr)	Min Discharge Rate (MWh/hr)	Max Discharge Rate (MWh/hr)	Initial Level (MWh)	Fix End Level	End Level (MWh)	End Deficit Penalty ($/MWh)	Exceed Capacity Pen. ($/MWh)	Below Min Capacity Pen. ($/MWh)	Sim. Charge Discharge
Energy_Storage_7.6MWH	true	0.000	7.600	0.2500	0.70	0.600	1.200	0.500	1.300	1.900	false	6.500	200.0	249.0	300.0	true
EV_Rapid_Charge_Station_Buses	true	0.120	1.200	0.0000	0.68	0.192	1.920	0.192	1.920	0.120	true	0.960	1 000.0	1 001.0	1 002.0	true
EV_Rapid_Charge_Station_Public	true	0.024	0.240	0.0000	0.68	0.384	0.384	0.000	0.000	0.024	true	0.192	1 000.0	1 001.0	1 002.0	false
EV_Rapid_Charge_Station_UCSD	true	0.012	0.120	0.0000	0.68	0.019	0.192	0.019	0.192	0.012	true	0.096	1 000.0	1 001.0	1 002.0	true
EV_Slow_Charge_Station_Buses	true	0.120	1.200	0.0000	0.68	0.006	0.060	0.006	0.060	0.120	true	0.960	1 000.0	1 001.0	1 002.0	true
EV_Slow_Charge_Station_Public	true	0.024	0.240	0.0000	0.68	0.012	0.012	0.000	0.000	0.024	true	0.192	1 000.0	1 001.0	1 002.0	false
EV_Slow_Charge_Station_UCSD	true	0.012	0.120	0.0000	0.68	0.001	0.006	0.001	0.006	0.012	true	0.096	1 000.0	1 001.0	1 002.0	true
IntegratedPvStorage_Battery	true	0.000	1.000	0.0000	1.00	0.000	1.000	0.000	1.000	0.000	false	0.000	1 009.0	1 010.0	1 011.0	true

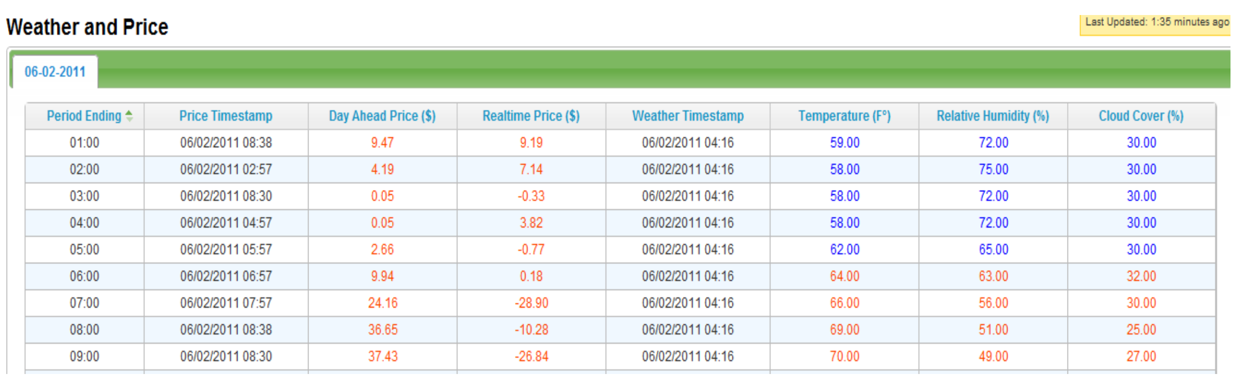
Figure A-13: VPower Electrical Storage Device Parameters



ID	Name	Send Signal	Min Capacity (MBtu)	Max Capacity (MBtu)	Loss Rate (MBtu)	Efficiency	Min Charge Rate (MBtu)	Max Charge Rate (MBtu/hr)	Min Discharge Rate (MBtu/hr)	Max Discharge Rate (MBtu/hr)	Initial Level (MBtu)	Fix End Level	End Level (MBtu)	End Deficit Penalty ($/MBtu)	Exceed Capacity Pen. ($/MBtu)	Below Min Capacity Pen. ($/MBtu)	Sim. Charge Discharge
70	TES Stratefied Cold Water Tank	true	0.000	530.000	0.0000	1.00	0.000	50.000	0.000	50.000	100.000	false	100.000	1 000.0	1 001.0	1 002.0	false
72	UCSD Cold Water System	true	0.000	150.000	100.0000	1.00	0.000	150.000	0.000	100.000	0.000	false	50.000	1 000.0	1 001.0	1 002.0	false
71	UCSD Hot Water System	true	0.000	200.000	100.0000	0.90	0.000	100.000	0.000	100.000	0.000	false	100.000	1 000.0	1 001.0	1 002.0	false

Figure A-14: VPower Thermal Storage Device Parameters

Parameters associated with resources that produce steam, hot water, cold water and electricity may include those parameters typically found with unit commitment and scheduling tools. Examples include emission rates, fuel consumption, hourly costs, and ramping constraints, startup and shutdown constraints, etc.



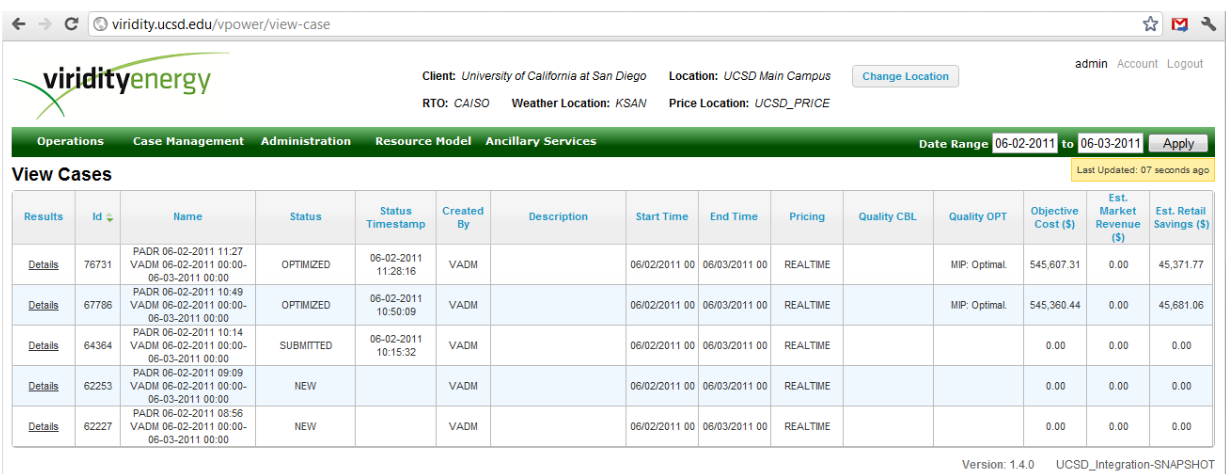
Period Ending	Price Timestamp	Day Ahead Price ($)	Realtime Price ($)	Weather Timestamp	Temperature (F°)	Relative Humidity (%)	Cloud Cover (%)
01:00	06/02/2011 08:38	9.47	9.19	06/02/2011 04:16	59.00	72.00	30.00
02:00	06/02/2011 02:57	4.19	7.14	06/02/2011 04:16	58.00	75.00	30.00
03:00	06/02/2011 08:30	0.05	-0.33	06/02/2011 04:16	58.00	72.00	30.00
04:00	06/02/2011 04:57	0.05	3.82	06/02/2011 04:16	58.00	72.00	30.00
05:00	06/02/2011 05:57	2.66	-0.77	06/02/2011 04:16	62.00	65.00	30.00
06:00	06/02/2011 06:57	9.94	0.18	06/02/2011 04:16	64.00	63.00	32.00
07:00	06/02/2011 07:57	24.16	-28.90	06/02/2011 04:16	66.00	56.00	30.00
08:00	06/02/2011 08:38	36.65	-10.28	06/02/2011 04:16	69.00	51.00	25.00
09:00	06/02/2011 08:30	37.43	-26.84	06/02/2011 04:16	70.00	49.00	27.00

Figure A-15: VPower Weather and Price Data User Interface

The weather and price user interface shows a subset of the weather data available to VPower. Values are color coded to show whether they represent historical actual values, or forecast values (up to two weeks in advance with hourly data). The following values are retrieved for the weather station closest to the customer location from the weather service:

- temperature
- humidity
- cloud cover
- wind speed
- wind direction
- irradiance
- heat index,
- dew point
- wind chill

The screenshot above shows the day ahead market and realtime market prices. CAISO Price data is retrieved once daily for day ahead market prices, and periodically throughout the day of operations for the Hour Ahead/Real-Time markets/indicative markets.



Results	Id	Name	Status	Status Timestamp	Created By	Description	Start Time	End Time	Pricing	Quality CBL	Quality OPT	Objective Cost ($)	Est. Market Revenue ($)	Est. Retail Savings ($)
Details	76731	PADR 06-02-2011 11:27 VADM 06-02-2011 00:00-06-03-2011 00:00	OPTIMIZED	06-02-2011 11:28:16	VADM		06/02/2011 00	06/03/2011 00	REALTIME		MIP: Optimal.	545,607.31	0.00	45,371.77
Details	67786	PADR 06-02-2011 10:49 VADM 06-02-2011 00:00-06-03-2011 00:00	OPTIMIZED	06-02-2011 10:50:09	VADM		06/02/2011 00	06/03/2011 00	REALTIME		MIP: Optimal.	545,360.44	0.00	45,681.06
Details	64364	PADR 06-02-2011 10:14 VADM 06-02-2011 00:00-06-03-2011 00:00	SUBMITTED	06-02-2011 10:15:32	VADM		06/02/2011 00	06/03/2011 00	REALTIME			0.00	0.00	0.00
Details	62253	PADR 06-02-2011 09:09 VADM 06-02-2011 00:00-06-03-2011 00:00	NEW		VADM		06/02/2011 00	06/03/2011 00	REALTIME			0.00	0.00	0.00
Details	62227	PADR 06-02-2011 08:56 VADM 06-02-2011 00:00-06-03-2011 00:00	NEW		VADM		06/02/2011 00	06/03/2011 00	REALTIME			0.00	0.00	0.00

Version: 1.4.0 UCSD_Integration-SNAPSHOT

Figure A-16: VPower View Cases User Interface

Users can review descriptions and summary information for the cases which have been created and/or optimized. Users can drill down to the interval based results by clicking on the “Details” hyperlink.

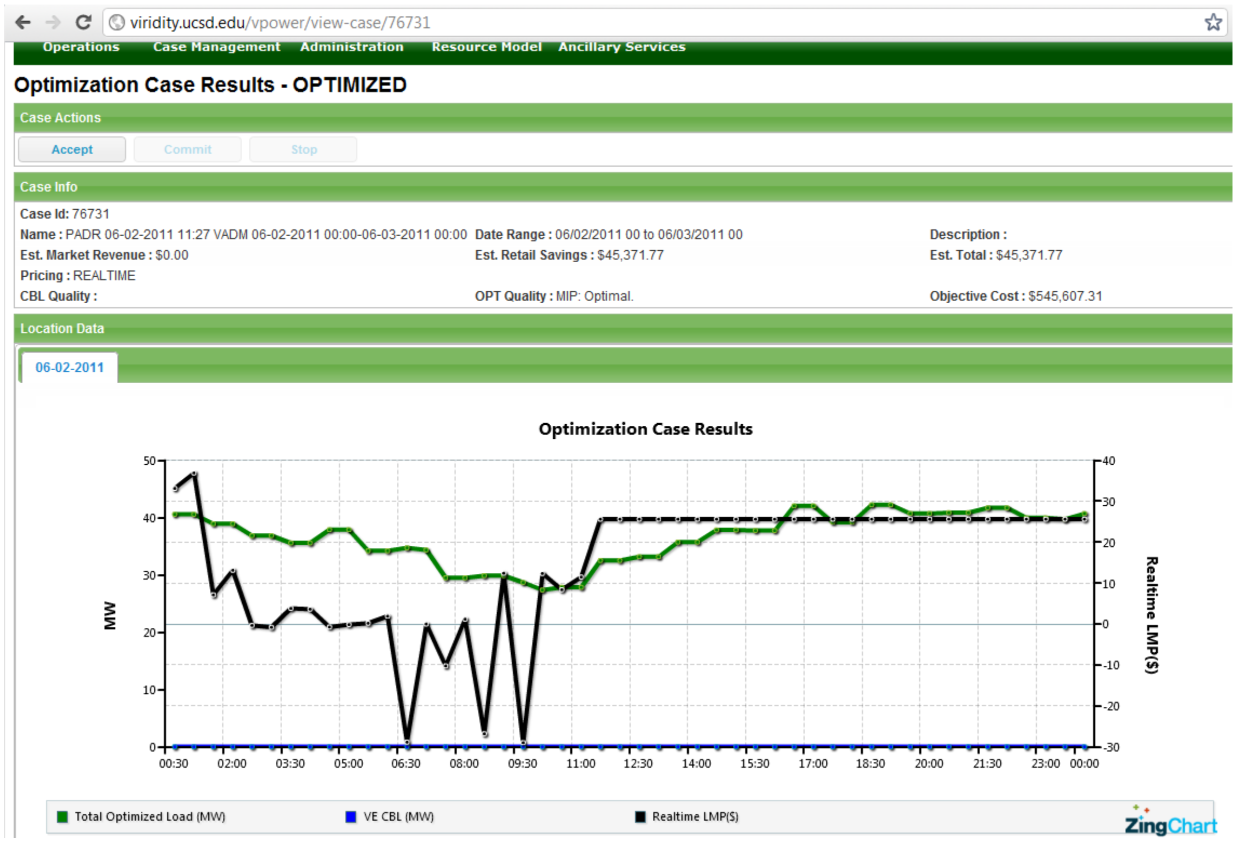
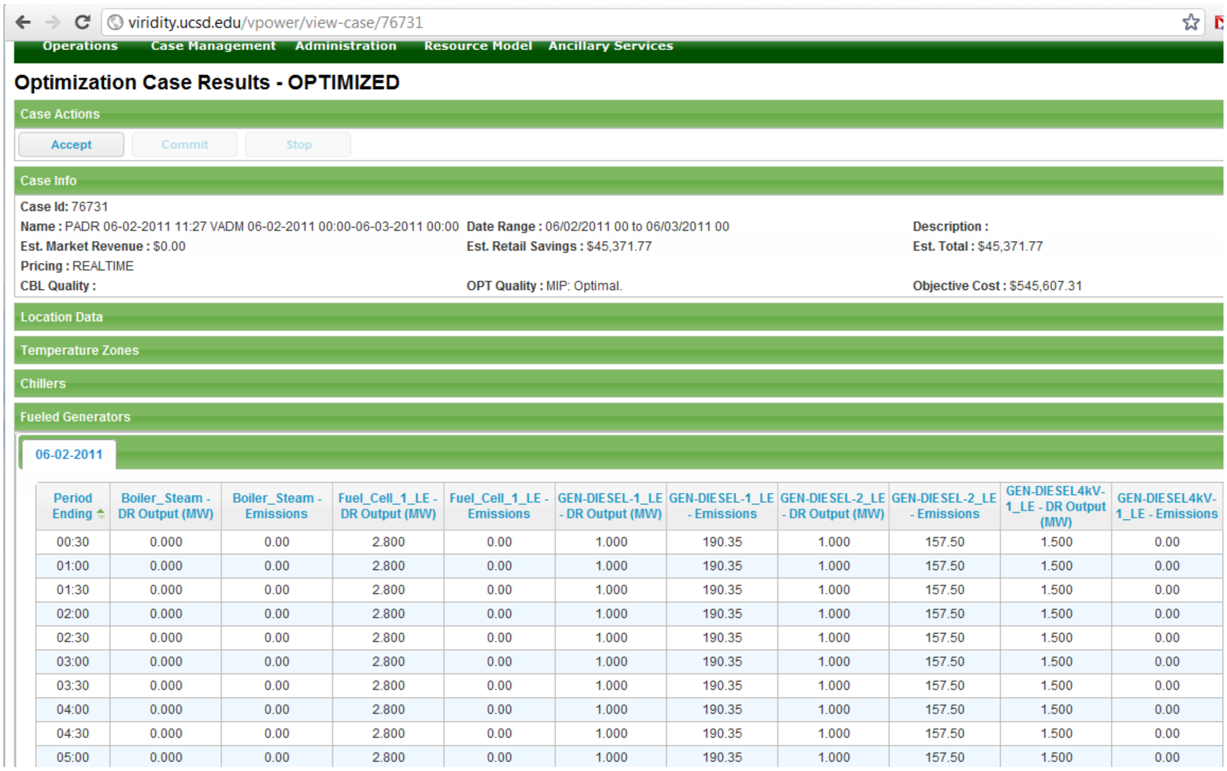


Figure A-17: Overview of Case Results

The user can review summary data for the entire set of modeled resources. If the case includes both a customer baseline and an optimization for economics run, the savings achieved as compared to the base case will be displayed. The user can view the total MWs by interval and the locational marginal prices (LMPs) for the case (this can be actual values if available, or forecasted values).


viridity.ucsd.edu/vpower/view-case/76731

Operations Case Management Administration Resource Model Ancillary Services

Optimization Case Results - OPTIMIZED

Case Actions

Accept Commit Stop

Case Info

Case Id: 76731

Name : PADR 06-02-2011 11:27 VADM 06-02-2011 00:00-06-03-2011 00:00 Date Range : 06/02/2011 00 to 06/03/2011 00 Description :

Est. Market Revenue : $0.00 Est. Retail Savings : $45,371.77 Est. Total : $45,371.77

Pricing : REALTIME

CBL Quality : OPT Quality : MIP: Optimal. Objective Cost : $545,607.31

Location Data

Temperature Zones

Chillers

Fueled Generators

06-02-2011

Period Ending	Boiler_Steam - DR Output (MW)	Boiler_Steam - Emissions	Fuel_Cell_1_LE - DR Output (MW)	Fuel_Cell_1_LE - Emissions	GEN-DIESEL-1_LE - DR Output (MW)	GEN-DIESEL-1_LE - Emissions	GEN-DIESEL-2_LE - DR Output (MW)	GEN-DIESEL-2_LE - Emissions	GEN-DIESEL4kV-1_LE - DR Output (MW)	GEN-DIESEL4kV-1_LE - Emissions
00:30	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
01:00	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
01:30	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
02:00	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
02:30	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
03:00	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
03:30	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
04:00	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
04:30	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00
05:00	0.000	0.00	2.800	0.00	1.000	190.35	1.000	157.50	1.500	0.00

Figure A-18: Overview of Case Results

The details of resource schedules are provided for each half-hour of the study-period, and include both the scheduled output, and the emissions expected to occur at that output level.

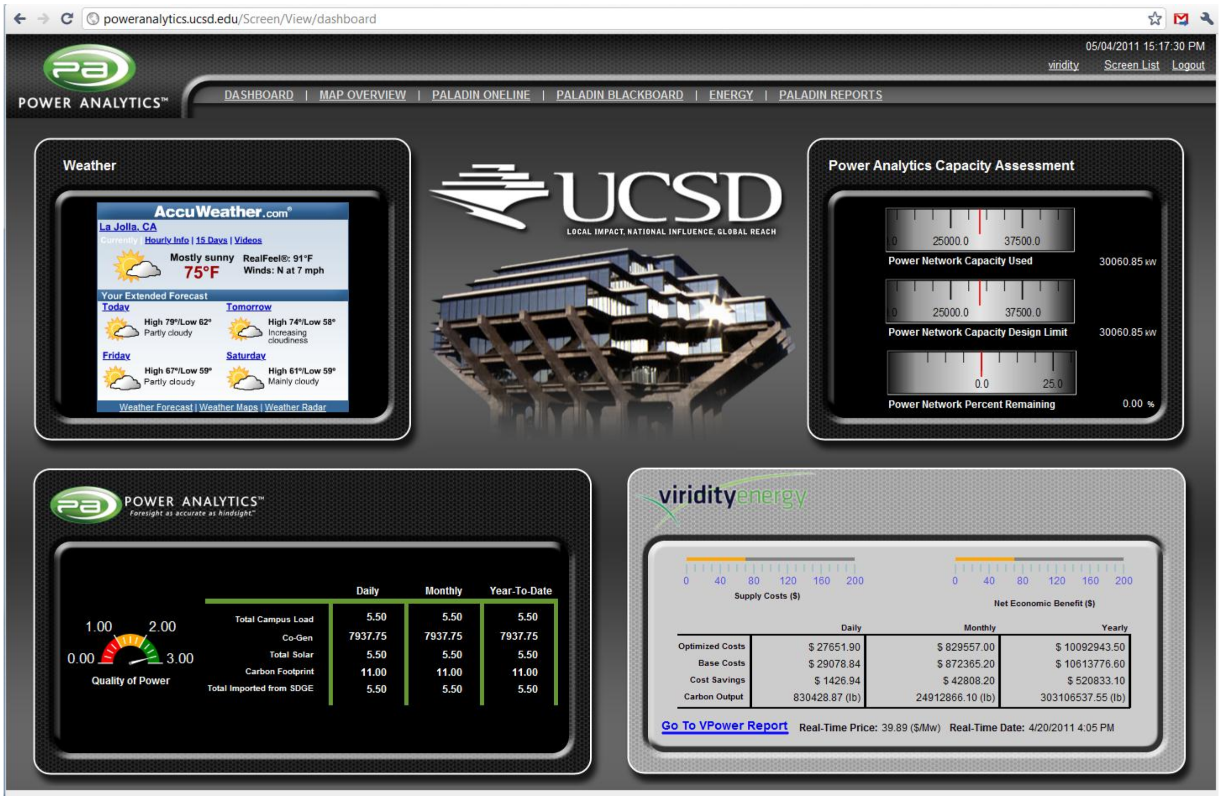


Figure A-19: Power Results on the Paladin Dashboard

The interface between VPower and Paladin supports the population of data on the dashboard. See the lower right hand panel for information that comes from VPower but which is populating a screen provided by Paladin.