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FINAL PROJECT REPORT

DEMONSTRATION OF ONE-CYCLE CONTROL PEAK LOAD REGULATOR (OCC-PLR) SYSTEM

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Transportation

Demonstration of One-Cycle Control Peak Load Regulator (OCC-PLR) System is the final report for the ETDG I project (contract number PIR-09-020) conducted by One-Cycle Control, Inc.. The information from this project contributes to the Energy Research and Development Division's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

For more information about the Energy Research and Development Division's Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

State mandates promote of grid-tied Distributed Generation (DG) and recent mandates encourage the deployment of energy storage. Facility-located "on-site" DG can reduce facility electricity costs by providing peak-shaving and cogeneration of heat and power that can reduce grid delivery requirements, which is important during critical-usage events. However, many facilities do not have co-located DG and others have on-site renewable DG that can be intermittent and therefore impact the grid or not be available at times of peak grid stress. On-site energy storage enables local buffering of energy and adjustment of storage set points can reduce (or increase) local or regional demand during times of grid stress. Widely distributed small scale energy storage is a critical grid "reflex" that can be leveraged to autonomously mitigate rapid load or DG-source dynamics close to their sources and thus reduce otherwise imposed grid dynamics.

This project has demonstrated a One-Cycle Control (OCC) Peak Load Regulator (OCC-PLR) that employs a three-phase grid-tied Inverter (OCC-GTI) that enables bidirectional power flow in/out of a repurposed transportation lithium-ion battery pack for peak shaving. The OCC-PLR delivers 25kW of peak shaving capability with 20 minutes of run time, sufficient to enable reduction of 15-minute demand peaks.

This project demonstrated that second-life use of a transportation battery in a stationary application is a viable approach to extracting more value from the batteries prior to recycling. In facilities with dynamic demand profiles, the OCC-PLR can help reduce peak demand charges that typically account for 30 to 50 percent of the electricity cost in a commercial/industrial facility. The OCC-PLR has the potential to achieve a 3.5-year return on investment.

Key Words: One-Cycle Control, Peak Load Regulation, Grid-Tied Inverter, Four Quadrant Converter, Peak Shaving, Li-Ion Battery

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EXECUTIVE SUMMARY

Introduction

The purpose of the One-Cycle Control (OCC) Peak Load Regulator (OCC-PLR) demonstration is to show financial benefit for reducing peak loads for industrial customers. The target market is light-duty industrial (3-phase power) customers, in the Southern California Edison (SCE) service territory, on GS-1 (peak demand < 20 kilowatt (kW)) or GS-2 (peak demand between 20 kW and 200 kW) rate schedules. GS-1 customers do not pay peak demand charges, but risk being forced into GS-2 if their peak demand, during any 15-minute period, exceeds 20 kW for any 3 months out of 12. An OCC-PLR may prevent the customer from transitioning to GS-2 thus avoiding costly electricity bills. GS-2 customers pay peak demand charges between $12.15/kW during 8 months of the year and $29.20/kW during the four summer months. Therefore, reducing peak demand by 15 kW each month could save $3,210/year [$182.25/month for 8 months + $438/month for 4 summer months]. Additional financial return can be derived from demand response during critical peak pricing events. Peak load reduction alone has the potential to provide rapid return on investment (ROI).

Project Objectives

The quantifiable objectives of this project are:

(1) Interface One-Cycle Control BiDirectional Converter (OCC-BDC) to A123 Hymotion to create One-Cycle Control Peak Load Regulator (OCC-PLR) with a top-level control circuit that measures the customer load and adjusts power injection from the OCC-PLR to achieve the desired maximum peak load set by the user.

(2) Measure dynamic load conditions at two or more sites to determine best demonstration location.

(3) Install OCC-PLR and measure for 6-months including at least 2 summer months.

(4) Demonstrate OCC-PLR charge/discharge rates up to 15 kW

(5) Demonstrate full-power (15 kW) dynamic peak-load reduction with < 4 microsecond (ms) response

(6) Demonstrate peak-load reduction up to 15 kW at selected demonstration site

(7) Demonstrate ROI for demonstration site that is < 3 years

Project Outcomes

The actual results that correspond to each objective:

(1) The OCC-PLR included a One-Cycle Control Grid-Tied Inverter (OCC-GTI) with bidirectional current control rather than an OCC-BDC. The OCC-PLR top-level control circuit effectively measured the customer load and adjusted the power injection from the OCC-PLR to achieve the desired peak load.

(2) Analysis of electricity bills, rather than direct measurements, was sufficient to determine the best demonstration location.

(3) OCC-PLR was installed and operated for 22 months, including 7 summer months.

(4) OCC-PLR achieved charge/discharge rates up to 25 kW

(5) OCC-GTI achieved 200 microsecond response time from 36 kW charge to 36 kW discharge; however, response within 2 seconds is sufficient for managing 15-minute peaks.

(6) Peak load regulation at 13 kW, 10 kW, and 5 kW was demonstrated at the site; more aggressive than the original target of 15 kW.

(7) ROI is approximately 3.5 years based on the demonstration.

Conclusions

The primary conclusions of this project are:

(1) OCC-GTI coupled with (lithium-ion) batteries enables high-performance energy storage for peak load regulation

(2) Peak load can be regulated using repurposed Li-Ion transportation batteries that provide significant second-life.

(3) ROI is greater than originally expected, but can be improved by tapping into other value streams and by continued reduction in battery cost.

Recommendations

Based on the demonstrated performance of the OCC-PLR, the following next steps are recommended:

(1) develop a full-scale OCC-PLR that utilizes a larger battery pack and has scalable power rating by adding additional OCC-GTI modules in parallel.

(2) demonstrate a "constellation" of OCC-PLRs in a local geographic area, such as a commercial or industrial park to demonstrate: (a) improved local-grid stability through reduced load/DG-source dynamics so that penetration of renewables can be increased beyond the typical 15 percent, and (b) the aggregated benefits of distributed energy storage in existing high-value markets such as capacity bidding, so that value is delivered on both sides of the utility meter to accelerate the ROI.

(3) market and sell OCC-GTI and engineering services to enable accelerated deployment of energy storage systems by multiple companies. There are many types of energy storage and each has applications that can deliver value to customers.

Public Benefits to California

The results of this project demonstrate the effectiveness of peak load regulation using an OCC-GTI in combination with energy storage (in this case Li-Ion transportation batteries). The integration experience acquired during this project has enabled the OCC team to help accelerate the development of energy storage products by several companies. Peak demand charges typically account for 30 to 50 percent of the electricity bill for small to medium commercial/industrial facilities California. Providing cost-effective peak load regulation to these customers can enable reduction of electricity bills to improve the bottom-line financial strength of these businesses while also having a stabilizing effect on the grid. A 15 kW demand reduction for each of the 82,000 industrial customers in California could result in an annual financial benefit of $3,210 per facility, or a total financial impact of $263 million per year if all industrial companies converted to this technology. Furthermore, the deployment of large numbers of distributed OCC-PLR systems can enable increased penetration of renewables to achieve the California goals of 33 percent renewables by 2020 within the built-up areas where the power is needed so that transmission line upgrades can be postponed or eliminated. Increased renewables without transmission-line upgrades will deliver substantial benefits to California rate payers and society.

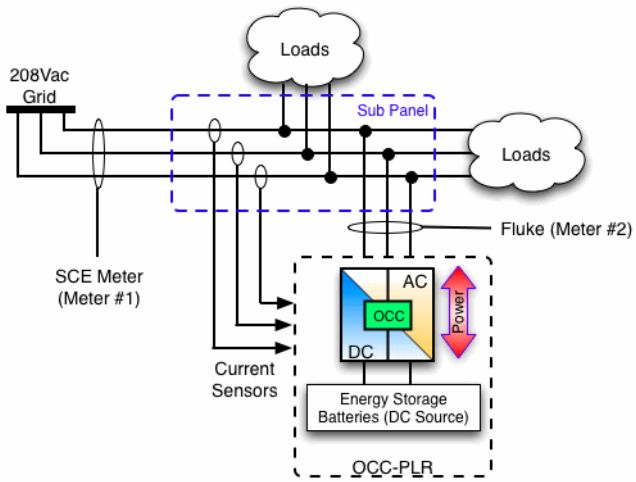
CHAPTER 1: Introduction

The purpose of the OCC-PLR demonstration is to show financial benefit of reducing peak loads for industrial customers. The target market is light-duty industrial (3-phase power) customers, in the SCE service territory, on GS-1 (peak demand < 20kW) or GS-2 (20kW < peak demand < 200kW) rate schedules. GS-1 customers do not pay peak demand charges, but risk being forced into GS-2 if their peak demand, during any 15-minute period, exceeds 20kW for any 3 months out of 12; an OCC-PLR may prevent the customer from transitioning to GS-2 thus avoiding costly electricity bills. GS-2 customers pay peak demand charges between $12.15/kW during 8 months of the year and $29.20/kW during the four summer months. Therefore, reducing peak demand by 15 kW each month could save $3,210/year [$182.25/month for 8 months + $438/month for 4 summer months]. Additional financial return can be derived from demand response during critical peak pricing events. Peak load reduction alone has the potential to provide rapid return on investment (ROI).

The OCC-PLR (

Figure 1) incorporates an OCC-GTI (brochure in Appendix B), a Li-Ion battery pack (from A123 Systems), and a custom top-level-control (developed by OCC) that monitors facility load. This latter unit commands the charge or discharge of the battery into the facility's 208 Vac grid to regulate the peak load to the power "thermostat" (target maximum peak demand) setting. The OCC-GTI incorporates OCC hardware-based control that delivers substantial speed and simplicity, a unique feature of the OCC-PLR. The Li-Ion battery is the Hymotion Pack originally marketed to convert a Toyota Prius to a plug-in hybrid; two Hymotion Packs are used in the OCC-PLR.

Figure 1: OCC-PLR Function Block Diagram (left); photo of OCC-PLR (right)



Figures & Photo Credit: OCC, Inc.

At the time the project started most energy storage systems were large and focused on centralized utility-scale deployment. During the project execution, several companies have realized the market potential of smaller-scale energy storage systems and a number of products are coming to the market; some product developers are incorporating the OCC-GTI as a component.

CHAPTER 2:
Project Objectives

The quantifiable objectives of this project are:

(1) Interface OCC-BDC to A123 Hymotion to create OCC-PLR with a top-level control (TLC) circuit that measures the customer load and adjusts power injection from the OCC-PLR to achieve the desired maximum peak load set by the user.

Integration of the OCC power converter, battery, and TLC was necessary to create the operational OCC-PLR system. Originally an OCC-BDC was thought to be the desired power converter, but as the team initiated the project, they realized that the OCC-GTI provided the preferred current-source / sink capability with direct control of current. This change simplified the execution, since the OCC-BDC would have provided indirect control of current by adjusting the DC voltage output.

(2) Measure the dynamic load conditions at two or more sites to determine best demonstration location.

The team included assessment of two or more sites to enable determination of a location that possessed rapid dynamic power demand variability that could best exercise the OCC-PLR and show its value.

(3) Install OCC-PLR and measure for 6-months including at least 2 summer months.

The extended measurement enabled assessment over multiple months with data from summer months to see if benefits were greater during the summer, since a primary objective is to determine the potential ROI.

(4) Demonstrate OCC-PLR charge/discharge rates up to 15 kW

This is a necessary function of the OCC-PLR in order to ensure it is able to mitigate peaks of significance to help accelerate the ROI.

(5) Demonstrate full-power (15 kW) dynamic peak-load reduction with < 4ms response

Initially, speed of response was considered essential; however, if the objective is to only mitigate 15 minute peaks, then slower response is acceptable.

(6) Demonstrate peak-load reduction up to 15 kW at selected demonstration site

This was to ensure that not only could the OCC-PLR realize power excursions of 15kW, but could in fact impose a 15kW demand reduction.

(7) Demonstrate ROI for demonstration site that is < 3 years

This is a key aspect of the project, since a rapid ROI could mean accelerated deployment of OCC-PLR products and accelerated market benefits.

CHAPTER 3:
Project Approach

This section is organized according to the tasks proposed in the original grant application. For each task, the approach, methods and materials used for each task are outlined. Relevant visual aids, diagrams and photos are included in this section but no data is included in this section.

3.1 Task 1.1: Attend Kick-Off Meeting

The project started on 9/2/2010, and the Kick-Off Meeting was held by telephone on Dec 8, 2010. The OCC team and PM discussed the progress report format, the invoicing procedures for the program, and other programmatic / contractual matters.

3.2 Task 1.2: CPR

On February 17, 2011 (Month 6), the project manager traveled to OCC, Inc. to view progress and see a demonstration of manual control of OCC-PLR power flow in and out of the battery to the grid.

3.3 Task 2: Design/Build/Test OCC-PLR

The OCC team quickly executed the Design/Build/Test phase of the OCC-PLR (progress shown in Figure 2). The team initiated computer aided design (CAD) design in September 2010 (Month 1), and completed the CAD mechanical design and procured the Li-Ion battery packs by November 2010 (Month 3). The team completed testing of the OCC-GTI power converter and started the OCC-PLR mechanical build in December 2010 (Month 4). To minimize footprint of the system, the mechanical design included vertical mounting of the pair of Hymotion packs. By Feb 2011 (Month 6), the OCC team had completed assembly of user interface (UI) hardware into the OCC-PLR rack and tested to full power ~36 kW with bidirectional flow at full power with rapid dynamics. The team collected data and submitted with the Lab Test report in June 2011 (Month 9).

Figure 2: Hymotion batteries, CAD Models, Batteries in Rack, Assembled OCC-PLR

Photos and CAD-Images Credits: OCC, Inc.

3.4 Task 3: Design/Build/Test User Interface (UI)

The OCC team procured the UI hardware in Dec 2010 (Month 4), and initiated the UI software development (Figure 3). Following development of preliminary programmable logic controller (PLC) software in Jan 2011 (Month 5), the OCC team decided to implement some functions in hardware to improve performance and designed/built/tested the new boards within 2 months. In April 2011, the OCC team completed the first demonstration of closed loop operation using the sensed OCC facility load (Figure 4) and achieved fully autonomous operation in May 2011, and the first full-day operation in June, only 9 months after project start. The team operated the OCC-PLR in autonomous mode for the months of July, Aug, and Sep, then implemented full metering according to the metering and verification (M&V) plan in late September. Metering continued for another 13 months until October 2012. The OCC-PLR continues to mitigate peak load and save money on the OCC, Inc. electricity bill.

Figure 3: Top Level Control hardware with HMI Panel

Photo Credits: OCC, Inc.

Figure 4: OCC-PLR User Interface Panel with Facility-Load Simulation Screen (left) and the Physical Setup of the Facility-Load Simulation that uses the Actual Building Load (right)

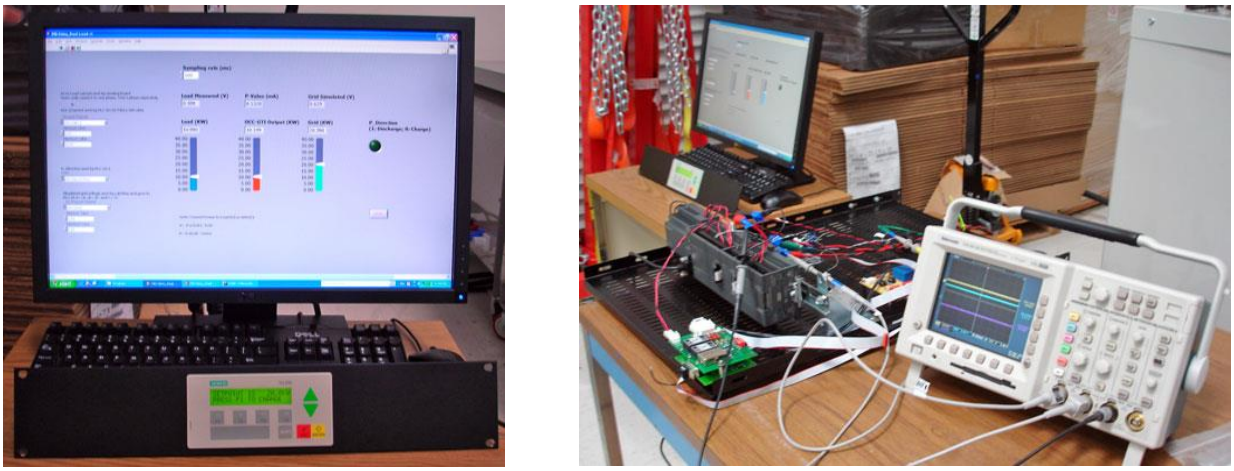


Photo Credits: OCC, Inc.

3.5 Task 4: Complete Demonstration Site Selection

OCC moved quickly to complete site selection (candidates are shown in Figure 5). In month 1 the team secured utility-meter data from one candidate site (IEPC, Inc.) and the OCC facility. The OCC facility showed dynamic load with 15-minute peaks above 20 kW, whereas the IEPC facility had no 15-minute utility data, since peaks generally below 10 kW and on a GS1 [1] rate schedule. It was clear that the IEPC facility would not be the best site for testing the OCC-PLR. OCC also met with SCE to seek assistance on identifying a suitable field test site for the OCC-PLR; however, it proved difficult to identify any alternatives to those already known to OCC. Ultimately, data were secured from four candidate sites: IEPC Inc., a Taco Bell restaurant, a small-scale manufacturer, and the OCC facility. These data provided input to the Site-Survey Report that the team submitted in November 2011. The Maul Manufacturing and IEPC sites had only monthly peak-demand data available and the peak load at IEPC was typically too low to result in any peak charges. The Taco Bell restaurant had some interesting peaks, but not very large. Ultimately the OCC-PLR was kept at OCC for the field trial measurements, where close supervision and proper data availability were conducive to program success.

While preparing data for the Site-Survey report, the OCC team developed a set of Excel spreadsheets to facilitate estimation of electricity-bills based on expected peak-reduction that could be achieved. These spreadsheets enable financial assessment by reviewing the historical data at the site and estimating the peak-reduction capability of the OCC-PLR. From the historical data, one can determine an estimate of ROI potential of a given site and the size of energy storage and power that would be needed to provide measurable benefit to the customer.

Figure 5: Candidate Sites Clockwise from top left: Maul Mfg; Taco Bell; IEPC Corp.; OCC, Inc.

Photo Credits: OCC, Inc.

3.6 Task 5: Establish M&V with SCE

During the first month of the project, OCC received verbal confirmation that SCE would support the project with M&V commentary/recommendations. In May 2011, SCE forwarded formal written approval/support of the OCC-PLR M&V plan. The SCE M&V support letter was included as a deliverable on the program and therefore submitted to the Energy Commission. With M&V approval in place, the OCC team completed the draft test plan in September 2011 and submitted the final version of the Test Plan report in Nov 2011.

3.7 Task 6: Complete Demo Install

Upon receiving approval of the Test Plan, M&V approach, and the site survey report, OCC completed the Demo Install at OCC and submitted the formal Demo Install letter to the California Energy Commission in November 2011.

3.8 Task 7: Measure/Report Performance

The OCC team conducted long-term measurements of the OCC-PLR performance in the OCC facility over a 22-month period.

Figure 1, shows the function diagram with metering points; Meter #1 is the utility (SCE) meter and Meter #2 is a Fluke Power Quality Analyzer for data logging. Measuring at two points enables reconstruction of the facility load by adding the two measurements. The OCC team also operated Meter#2 at a fast sampling rate for some period of time to resolve the dynamic charging and discharging of the OCC-PLR. Representative data are described in the next section and an entire appendix of raw data is provided in Appendix A.

3.9 Task 8: Technology Transfer

Starting in January 2011, the OCC team was proactive to disseminate the knowledge gained from the OCC-PLR project to various stakeholders and to the public. In fact, through this public disclosure OCC also managed to secure a number of customers who were developing energy storage systems that needed power electronics and in some cases, engineering support to complete integration. The OCC-PLR stands as proof that the OCC team is quite adept at integration of energy storage and this gives customers the confidence to select the OCC team as its power electronics partner. Technology transfer has included three full-power demonstrations, twenty-three public invited talks, and attendance at a Trade Show. Tables 3.10.1 and 3.10.2 summarize the Technology Transfer activities during this program. In addition, OCC created dedicated web pages for the OCC-PLR and OCC-GTI on the OCC website (Figure 6) and designed/implemented 2-page OCC-PLR and OCC-GTI brochures (see Appendix B). The OCC-GTI web page and brochure are used to market the OCC-GTI to OEMs interested to create an energy storage product and the OCC-PLR brochure demonstrates OCC capability for energy-storage system integration.

Figure 6: OCC-PLR and OCC-GTI Dedicated Web Pages

Web pages Credit: OCC, Inc.

3.10 Demonstrations and Presentations

3.10.1 Stakeholder Demonstrations

Date	Title	Stakeholders
03/24/2011	OCC-PLR Stakeholder Demo	SDGE, A123 Systems, UC Irvine, Cal State Univ. Long Beach,.
06/10/2011	OCC-PLR Stakeholder Demo	USC, Sun-Doul-Os, GreenTech Automotive, Automotive Tech Group, Top Gallent Energy, A123 Systems. (see Figure 7)
06/20/2011	OCC-PLR Stakeholder Demo	Top Gallant Energy, Auto. Tech Group, Sun-Doul-Os, Coulomb Technologies, QGC, Inc..

Figure 7: Autonomous Demo: OCC-PLR (left) and Stakeholder Group (right)

Photo Credits: OCC, Inc.

3.10.2 Invited Presentations

Date	Title	Location / Event
11/06/2010	"Green Technologies" How do we connect more to the GRID?	3rd Symposium Global Emerging Environmental Challenges & Government Responses, Invited Talk, Southern California Chinese American Environmental Protection Association, Cerritos, CA.
11/08/2010	OCC-Peak Load Reduction (OCC-PLR)	Emerging Technologies Coordinating Council (ETCC) 2010 Summit, Invited Talk, Sacramento, CA
03/10/2011	Reactive Power Supply Inverter for Distributed Energy	APEC 2011, Invited Talk SP1.5.2, Fort Worth, TX
06/07/2011	PIER-Venture Capital Forum – OCC Commercialization	CEC Venture Capital Forum, Sacramento, CA
07/13/2011	OCC Power Converters – Smart Grid Enablers	Invited Talk, UCLA SMart grid Energy Research Center (SMERC), Los Angeles, CA
09/14/2011	OCC Power Converters Mitigate Grid	Invited Talk, UCLA SMERC, Los Angeles, CA

Date	Title	Location / Event
	Dynamics	
09/16/2011	Distributed Dynamic VARS / ESS	Invited Talk – SDGE, San Diego, CA
10/26/2011	OCC-Peak Load Reduction (OCC-PLR)	SCE – Emerging Technology Open Forum, Rosemead, CA
11/14/2011	OCC Intro + First Steps into China	Orange County Business Council – Introduction to Export Meeting, Irvine, CA
11/30/2011	Intro to OCC è “Green” Shanghai Applications	Orange County Business Council Presentation – Shanghai Delegation Visit, Irvine, CA
12/01/2011	Intro to OCC è First Steps into China	Global Trade Summit, Anaheim, CA
02/15/2012	From UCI to Market	Reactor Café, Invited Talk, UC Irvine, Irvine, CA
03/21/2012	Power Electronics Enable the Future Grid	IEEE Distinguished Lecturer, Cal State University Long Beach, Long Beach, CA
04/16/2012	Power Electronics: Enabling the Future Grid	USC, Invited Talk, Los Angeles, CA
09/18/2012	Enabling a Smart Grid	CleanTech OC Conference, Invited Talk, Irvine, CA
09/21/2012	Intro to OCC & OCC-PLR	Cal Poly Pomona, Pomona, CA
11/19/2012	Power Converters that Enable Buildings to Support the Grid	IEEE Green Energy Forum, Invited Talk, Cal State University Long Beach, Long Beach, CA
01/23/2013	Intro to OCC & OCC-PLR	EON Reality, Irvine, CA
03/16/2013	Grid Stability	PSMA –EPRI Workshop: Are you Smart enough for the Smart Grid? Invited Talk.
03/19/2013	Power Electronics Enable the Future Grid	UCLA, SMERC, Smart Grid Training Workshop, Invited Talk
03/20/2013	Power Management in the Smart Grid	APEC 2013, Invited Talk, Industry Session, IS2.3
05/08/2013	Power Electronics Enable the Future Grid	EECS-294 Colloquium, Invited Talk, UC Irvine, Irvine, CA
05/15/2013	Power Electronics enable Secure, Reliable, Stable Grid	CleanTech OC, The Smart Grid – A Revolution in Progress, UC Irvine, CA

3.10.1 Trade Shows and Gold Key Service with the US Dept. of Commerce

10/26/2011 Booth, Eco Expo Asia, Hong Kong (see Figure 8)

10/24/2011 DOC Gold Key Intros & Business Development, Guangzhou, China (Day 1)

10/25/2011 DOC Gold Key Intros & Business Development, Guangzhou, China (Day 2)

05/30/2012 Booth, Silicon Valley Energy Storage Symposium, Mountain View, CA

Figure 8: Booth at Eco Expo Asia 2011

Photo Credit: OCC, Inc.

3.11 Task 9: Production Ready Plan

In preparation for production of the OCC-PLR, the OCC mechanical team created a fully-documented Production Readiness Plan that included a detailed bill of materials (BOM) and design report with assembly instructions. Most of the Production Readiness Plan is confidential and is mentioned here to highlight that the OCC team invested effort on Production Readiness for the OCC-PLR.

CHAPTER 4:
Project Outcomes

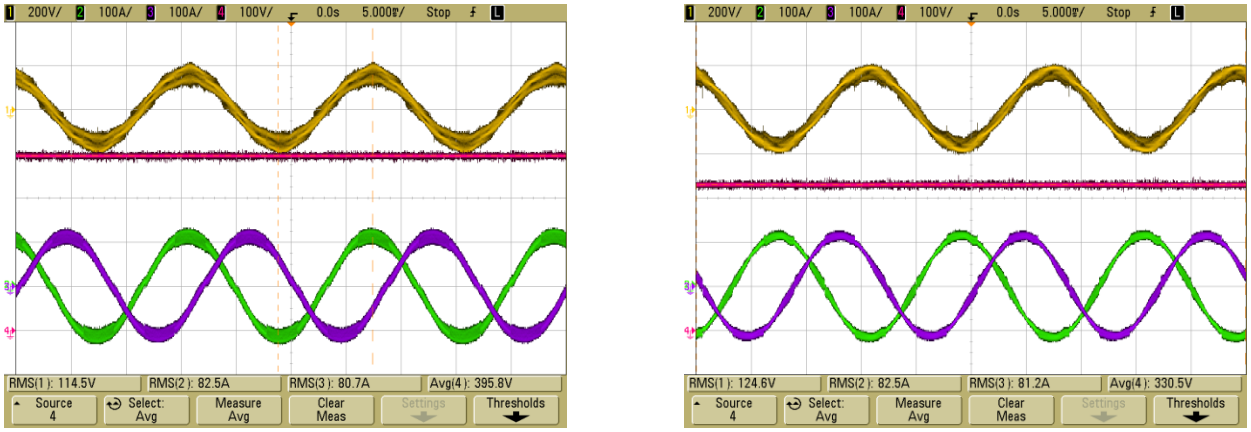
The outcomes of this project are described below; note, the original objectives are repeated here to provide a framework for the discussion:

4.1 Interface OCC-BDC to A123 Hymotion to Create OCC-PLR with a Top-Level Control (TLC) Circuit that Measures the Customer Load and Adjusts Power Injection from the OCC-PLR to Achieve the Desired Maximum Peak Load Set by the User

The OCC team integrated the OCC power converter, Hymotion battery packs, and the TLC to create a functional OCC-PLR system. In the original proposal, the OCC team indicated that an OCC-BDC was the appropriate power converter for the OCC-PLR, but, as the team initiated the project, it became clear that the OCC-GTI provided direct control of current to realize the preferred current-source/sink capability to/from the battery pack. The OCC-BDC would require indirect control of the current by varying the DC voltage set point of the OCC-BDC, thus slowing the response time of the overall system. Changing the OCC-BDC to the OCC-GTI significantly simplified the execution and ultimately improved the performance.

Waveforms in Figure 9 show the steady-state OCC-PLR performance with bidirectional current flow to/from the battery pack. Note that during charging, the Phase A current (Green) and Phase A voltage (Yellow) are in phase; during discharging, the current and voltage are 180 degrees out of phase, indicating that current is flowing to the grid from the battery.

Figure 9: OCC-PLR 80 Arms Charge (left) and 80 Arms discharge (right)

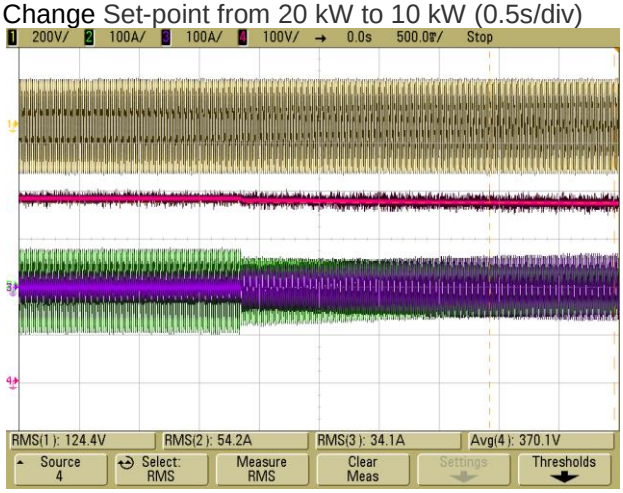


{Top to bottom: Va (yellow), Vdc (pink-battery voltage), Ia (green), Ib (purple)}
Figure Credits: OCC, Inc.

Dynamic peak-load mitigation is shown in Figure 10, by changing the OCC-PLR set point while operating to mitigate a large facility peak load. The charts below highlight the case where the set point is first changed from 20 kW to 10 kW, and then back to 20 kW. The observations are explained below. Note: Ch1: Vb-grid (Yellow); Ch2: Ib-grid (Green); Ch3: Ib-PLR (Purple); and Ch4: Vdc (Red).

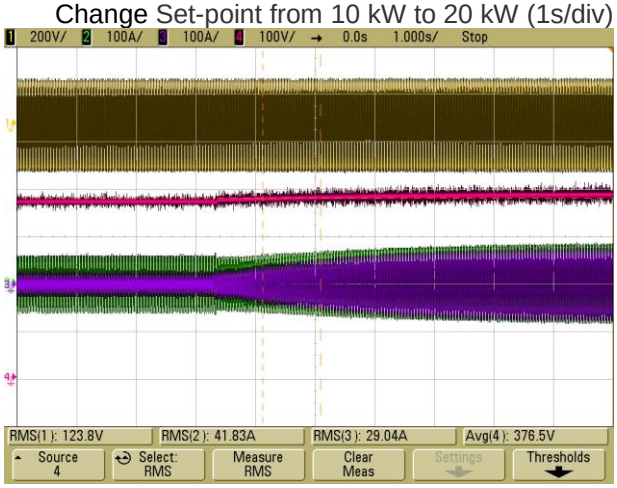
Figure 10: Waveform Response to Step Changes in OCC-PLR Setpoint

Change Set-point from 20 kW to 10 kW (0.5s/div)



The OCC team changed the set-point from 20 kW to 10 kW using the User Interface (UI), while the OCC-PLR was discharging. Note that grid power decreased immediately after the set-point changed and then gradually reached the new set-point. At the same time, the OCC-PLR injected more power to the grid to reduce the grid power to the new set-point. The transition takes about 2 to 3 seconds.

Change Set-point from 10 kW to 20 kW (1s/div)



The OCC team changed the set-point from 10 kW to 20 kW using the User Interface (UI), while the OCC-PLR was charging. Note that grid power increased after the set-point changed and then gradually reached the new set-point. At the same time, the OCC-PLR absorbed more power from the grid to charge the battery at a higher rate. The transition takes about 2 to 3 seconds.

Figure Credits: OCC, Inc.

4.2 Measure Dynamic Load at Two or More Sites to Determine Best Demo Location

The team included assessment of four sites (see Figure 5), to select a location that possessed rapid dynamic power demand variability that could best exercise the OCC-PLR and show its value. In these cases, utility data enabled sufficient analysis of the sites without the need for on-site measurements. The OCC site has significant dynamics making is a well-suited site for peak load regulation demonstration.

4.3 Install OCC-PLR and Measure for 6-Months including at least 2 Summer Months

The extended measurement enabled assessment over multiple months with data from summer months to see if benefits were greater during the summer, since a primary objective is to determine the potential ROI. The OCC team connected the OCC-PLR to the OCC facility grid for 22 months and monitored continuously, spanning 7 summer months. In general, benefits during the summer would be greater on the standard GS2 rate schedule [2] where peak summer

demand is charged at a much higher rate than peak winter demand. The OCC facility is on the GS2-TOU-A rate schedule that has a flat $12.15 per peak kW flat rate for the entire year.

4.4 Demonstrate OCC-PLR Charge/Discharge Rates Up to 15 kW

This is a necessary function of the OCC-PLR in order to ensure capability to mitigate peaks of significance to help accelerate the ROI. Note that this capability is presented in Figure 9 above, where the battery is charged and discharged at 80Arms, so charge and discharge power is (80Arms x 208Vac x sqrt(3)) = 28.8 kW, clearly demonstrating capability beyond the target of 15 kW. In normal operation, the OCC-PLR is limited to 70Arms (25 kW).

4.5 Demonstrate Full-Power (15 kW) Dynamic Peak-Load Reduction with < 4ms Response

Data below show a 2-3 second response time. Peak reduction of 25 kW shown is in Section (6).

4.5.1 Response Time (2-3 seconds):

Initially fast response (e.g. 4 ms) was considered essential; however, when the objective is to mitigate 15-minute peaks, then slower response is acceptable. The OCC team completed testing of the automated operation of the OCC-PLR. Figure 11, shows the test setup within the OCC facility and a set of waveforms from a dynamic load transition (200 msec/div). In this case, the PLR is set to 20 kW and the team started the facility air conditioner to increase the load above the set point. The waveforms are top to bottom: Grid Voltage (yellow); Battery Voltage (red); Grid Current (Green); OCC-PLR current (Purple). Note that when the air conditioner starts, it pulls high peak current from the grid; the OCC-PLR increases its output current (Purple) to compensate and shaves the facility power draw to ~20 kW within approximately 2-3 sec.

Figure 11: OCC-PLR Test Setup with Various Loads (left) and a Dynamic Load Measurement (right)

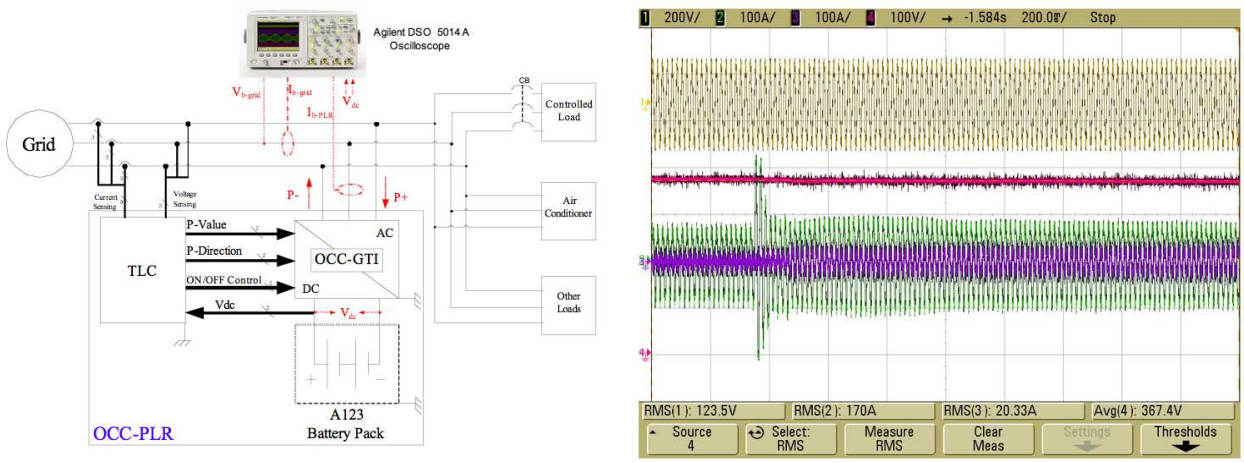


Figure Credits: OCC, Inc.

4.6 Demonstrate Peak-Load Reduction Up to 15 kW at Select Demo Site

Figure 12 (left), shows high-resolution data from Meter#2 (30 second intervals) of a major peak event at about 09:15 that required aggressive discharge of the OCC-PLR at near its maximum rating (25 kW). After about 10 min, the peak subsided and allowed a brief recharge for about 8 min; however, since the OCC-PLR is set to 13 kW, the maximum charging rate is limited by the facility loads, so it charged at about 13 kW for approximately 1 min, then due to a facility load increase, the OCC-PLR charging rate reduced to approximately 6 kW for the remainder of the 8 min. The dynamic up and down peak event continued for about 34 minutes until the battery was fully discharged; however, since the facility load remained >13 kW, the OCC-PLR was not allowed to recharge and OCC-PLR output dropped to 0 kW. When the peak event ended at approximately 10:20 the OCC-PLR immediately initiated recharging at 6 kW for the next 90 min to achieve full charge (approximately 9 kWh of energy storage). The event clearly indicates the ability of the OCC-PLR to provide 25 kW of peak load regulation when needed.

Figure 12: OCC-PLR during Peak Usage Event & Subsequent Recharge (left); 15min Average with SCE Meter (Meter#1) Data and Reconstructed Facility Load (PLR Power + SCE Power)

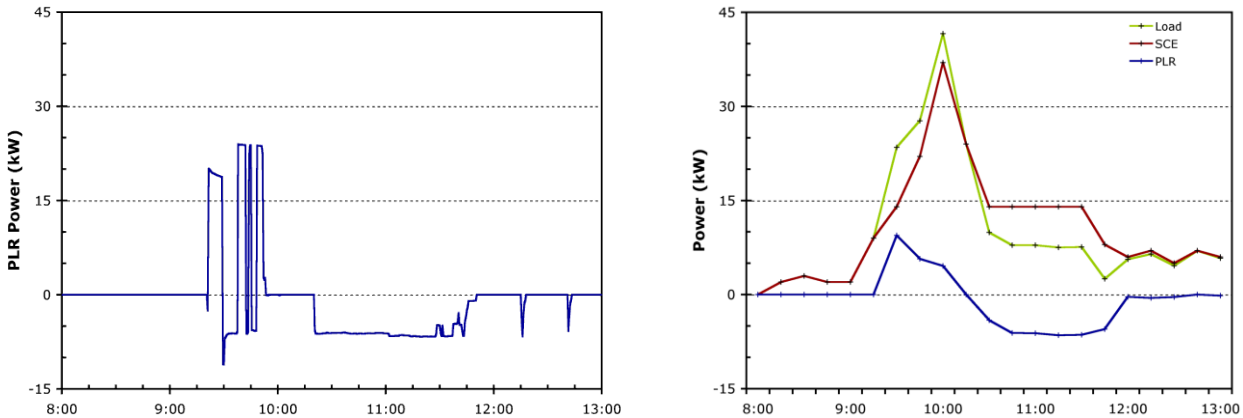


Figure Credits: OCC, Inc.

Figure 12 (right), shows the data from Meter#1 (15-min utility data; SCE), Meter#2 (15-min averaged; PLR), and the computed facility load (15-min average; Load) during the same event. Note that 15-min averaging of Meter#2 data substantially smoothes the dynamics of the OCC-PLR power, but the general appearance of a discharge followed by a recharge is clearly visible. During the event, Meter#1 recorded a peak of ~38 kW, and the reconstructed facility load reached a peak of ~41 kW. During recharge of the PLR, Meter#1 registered a flat 14 kW while the PLR made small adjustments to accommodate facility load changes and maintain the 14 kW maximum utility load (measured by Meter#1). It is worth noting that the OCC-PLR was set to 13 kW during this period, but rounding / measurement difference between the Top-Level Control (TLC) of the OCC-PLR and the utility meter (Meter#1), account for the difference between the setpoint (13 kW), and the maximum measured utility load (Meter#1) of 14 kW.

The extended peak event measured here reveals a note-worthy aspect of the OCC-PLR. Since the system has a peak power rating of ~25kW, it could charge at ~25kW if the set point were

high enough to allow it. The 13 kW set point used here is significantly less than 25 kW, so the OCC-PLR is forced to operate at a slower charging rate than what its maximum power rating would otherwise allow. It appears that the optimal set point for this OCC-PLR is probably >30kW in order to fully utilize the power rating for charge and for discharge; of course, actual kW and kWh needs will vary with each application, so the power rating and the amount of energy storage may need adjustment to suit a particular facility.

4.7 Demonstrate ROI for demonstration site that is < 3 years

This is a key aspect of the project, since a rapid ROI could mean accelerated deployment of OCC-PLR products and accelerated market benefits. ROI calculation is presented below through comparison of the facility peak-demand during a period of time prior to installation of the OCC-PLR to the peak-demand following installation of the OCC-PLR.

4.7.1 Utility Data (Meter#1)

The research team acquired utility data from SCE meter on the OCC, Inc. facility for this study from August 2010 through October 2012. The project team installed the OCC-PLR at the OCC facility in July 2011, started autonomous operation, and recorded only Meter#1 data from July 3 to Sept 19, 2011. The project team installed Meter#2 on Sept 20, 2011 and started recording charge and discharge of the OCC-PLR so that data from the two meters could be used to reconstruct the facility load and assess the OCC-PLR ability to respond to facility load changes. Example data from these meters and the reconstructed load data were discussed in the previous section.

The maximum peak loads for each month, taken from the monthly 15-minute peak data in Appendix A, are presented in Figure 13. Note that the first two months following OCC-PLR installation involved setup and evaluation of the system. The team set the OCC-PLR set point ("power thermostat") to either 10 kW or 13 kW as indicated on the chart. If the facility peak load can be maintained below 20 kW for 12 consecutive months, the OCC facility could apply for a change to the GS1 rate schedule [1] and no longer need to pay peak demand charges. Once GS1 is established, two monthly demands greater than 20 kW are allowed during each 12-month period; if monthly demand exceeds 20 kW a third time during a 12-month period, the utility will automatically switch the facility back to GS2 [2] and demand charges will be assessed monthly.

During the 11 months prior to OCC-PLR installation, the demand exceeded 20 kW 5 times. During the 16 months after OCC-PLR installation the demand exceeded 20 kW only 3 times (Peaks 1, 3, and 5 numbered in Figure 13). Peaks 1 and 3 occurred following complete discharge of the OCC-PLR during extended high-power converter testing at OCC and Peak 5 occurred while the OCC-PLR was turned OFF during a specific high-power converter test. So, an operational and connected OCC-PLR was able to reduce the number of >20 kW events from 5 out of 11 months (45%) to 2 out of 16 months (13%). Furthermore, OCC-PLR decreased the average peak demand from 20.2 to 17.7 kW.

4.7.2 Analysis of Peaks

Figure 13, shows five labeled peaks that are 5 kW or more above the "Power Thermostat" set points and are selected for further analysis in Figure 14. Peak #1 is omitted from Figure 14, since it was evaluated in the "Metering and OCC-PLR Behavior" above.

Figure 13: OCC Monthly Peak Load (grey = no PLR); (orange, green = with PLR)

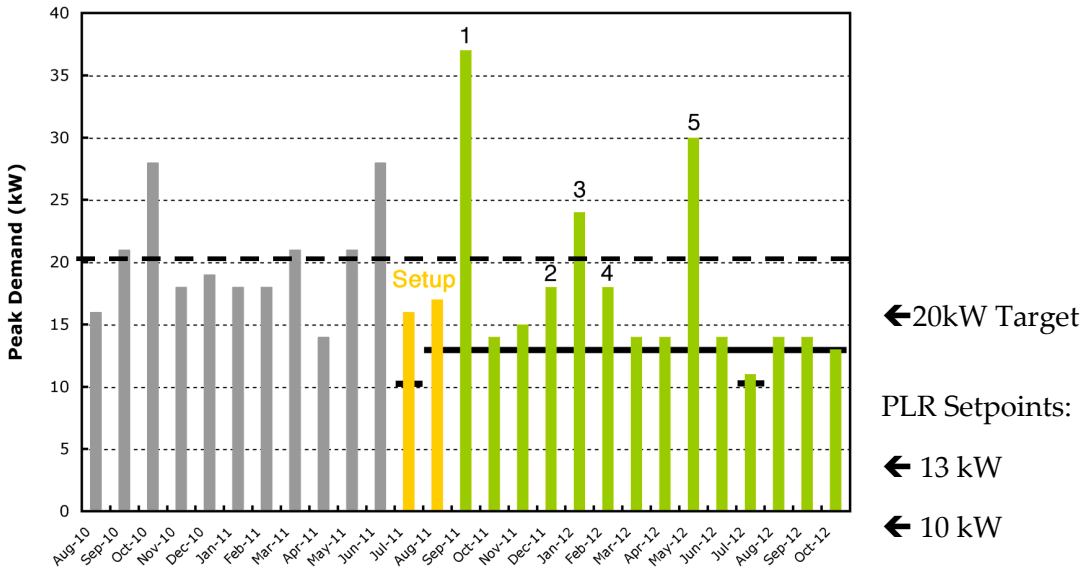


Figure Credit: OCC, Inc.

Figure 14: 15-min Data (with explanation) of Peak Event Days #2 through #5 from Figure 13

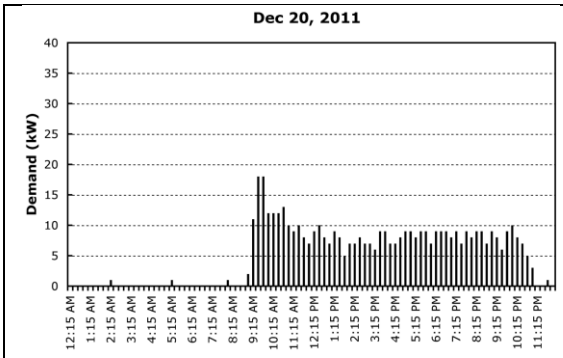
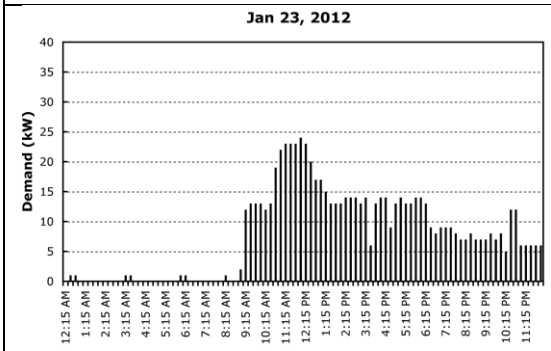
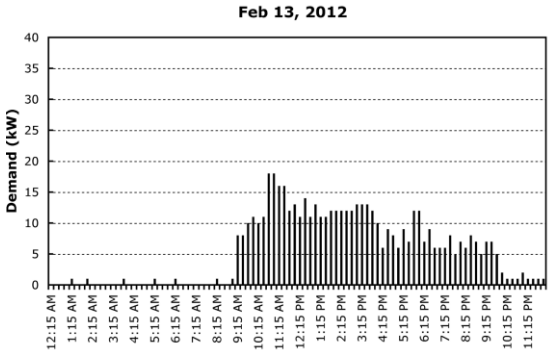
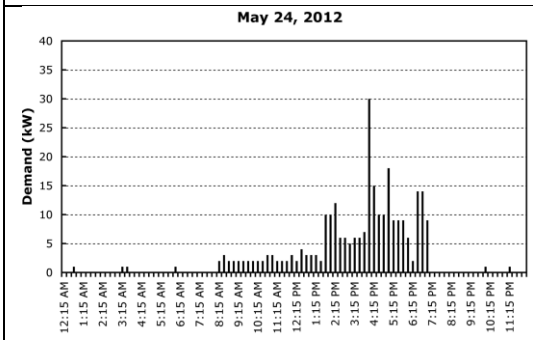
	Peak #2: 18 kW Peak OCC-PLR was OFF for other testing at OCC, so it did not regulate the peak to the 13 kW set point. This was a modest peak that could have been managed. Evidence of the PLR being OFF is shown by the rapid jump from 11 kW to 18 kW @ 09:30 without any attempt to mitigate to the 13 kW setpoint.
	Peak #3: 24 kW Peak OCC-PLR was ON and set to 13kW; evident by the peak mitigation in the early time intervals (09:15 to 10:15). High-power testing at OCC resulted in complete discharge of the OCC-PLR, ultimately revealing the sustained 23 to 24 kW peak. Mitigation of this peak would require significantly larger energy storage.
	Peak #4: 18 kW Peak OCC-PLR was OFF. The immediate jump from 11 kW to 18 kW demonstrates that the OCC-PLR was not actively mitigating to the 13 kW set point.
	Peak #5: 30 kW Peak OCC-PLR was OFF. The immediate jump from 7 kW to 30 kW @ 16:00 clearly demonstrates that the OCC-PLR was not actively mitigating to the 13 kW set point. Given the short duration of this peak, the OCC-PLR would have been able to mitigate to the 13kW set point.

Figure Credits: OCC, Inc.

4.7.3 Financial Analysis

The OCC facility is billed according to the GS2-TOU-A rate schedule [2], with a fixed demand charge of $12.15 per kW peak throughout the year. Since the OCC facility has a dynamic load profile (see Appendix A), with significant peaks above the baseline for short durations; a small OCC-PLR can enable peak charge reduction. However, the load is not only dynamic, but also highly irregular depending on the type of products being tested that can lead to large peaks that run for four hours or more causing depletion of the OCC-PLR. This irregularity makes it difficult to effectively size the energy storage element of the OCC-PLR to manage all scenarios. A more favorable environment for the best financial return on an OCC-PLR would have a dynamic load profile with significant repeatable peaks or large peaks that are of short duration.

This financial analysis focuses on peak cost based on the GS2 rate schedule [2] compared to acquired facility data prior to the installation of the OCC-PLR. For the sake of comparison, outlier peaks that occurred during the OCC-PLR being OFF are included and also removed to provide two potential financial scenarios.

Table 1: Peak Demand and Demand Cost without OCC-PLR

	2010					2011						
	Aug	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
No PLR (kW)	16	21	28	18	19	18	18	21	14	21	28	16
Total =	**238 kW_{peak} x $12.15 / kW_{peak} = $ 2,892**											

Table 2: Peak Demand and Demand Cost with OCC-PLR (all peaks & with removal of outlier peaks)

	2011					2012						
	Aug	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
PLR (kW)	17	37	14	15	18	24	18	14	14	30	14	11
Total =	**226 kW_{peak} x $12.15 / kW_{peak} = $ 2,746** (with all peaks)											
PLR (kW)	17	14	14	15	14	14	14	14	14	14	14	11
Total =	**169 kW_{peak} x $12.15 / kW_{peak} = $ 2,053** (remove outlier peaks)											

*Demand Cost = $12.15 per kW peak (SCE Rate Schedule: GS2-TOU-A) [2]

The calculations presented in Table 1 and 2, demonstrate potential savings of $146/year when all peaks are included or $839/year when all outlier peaks are removed. If all outlier peaks are removed, then the facility could transition to GS1 [1] and the annual savings based on the above would be $2,892/year since there would no longer be a peak demand charge.

4.7.4 ROI

Based on the analysis above, the potential monetary return is $146/year when outlier peaks are included, $839/year when outliers are removed, and $2,892/year assuming the facility is able to move to GS1 and no longer pay peak-demand charges. Under the most favorable scenario, a 5 year ROI would enable the 10kWh @ 25kW system to sell for $14,460. As battery prices continue to drop, this may become possible. At present, the California Self-Generation Incentive Program (SGIP) [3] helps to establish the market by providing a customer financial incentive. As of this writing, the SGIP incentive for Advanced Energy Storage from a California Supplier is $2.16/Watt based on a 2-hour run time, up to 60% of the total cost of the system. Since the OCC-PLR used in this study has approximately 9 kWh of energy storage, the rated power level for Self Generation Incentive Program (SGIP) is 4.5 kW, so the incentive would be 4,500 Watts x $2.16/Watt = $9,720. With a sales price of $20,000 the customer would pay $10,280 and the ROI would be approximately 3.5 years. This calculation demonstrates that with the SGIP incentive, the potential ROI is within reasonable reach. The key is to identify the target customers who can be transitioned from GS2 to GS1 so that they no longer need to pay for peak-demand.

CHAPTER 5: Conclusions

This project demonstrates that the OCC-PLR can regulate peak load to mitigate the peak-demand charges at a commercial/industrial facility and that second-life application of the Hymotion battery pack has the potential to deliver extended value in a stationary application.

OCC-PLR sizing (power & energy) and financial benefit can be estimated based on historical data from a given facility. A key finding that is relevant for the early-stage energy-storage market is to target customers that are on the verge of being forced into a GS2 rate schedule or are typically operating right on the boundary between GS1 and GS2 such that they are forced to stay on the GS2 rate schedule. Managing peak load to less than 20 kW can enable GS1 customers to stay on GS1 or can enable GS2 customers to transition to GS1 so that they can both avoid the peak charges.

At the beginning of the research study, the Hymotion battery was considered one with good second-life potential; however, at the time of writing this report, manufacturing of the Hymotion battery pack has been discontinued. Perhaps another vehicle battery could be targeted for integration into an OCC-PLR.

ROI for deployment of an OCC-PLR could be as short as 3.5 years in cases where the facility is able to either stay on GS1 or move from GS2 to GS1. This ROI is accelerated at the time of this writing due to the existence of the SGIP incentive program that delivers a substantial price reduction to the end customer. Increased production volume of batteries and power converters will continue to help reduce cost so that more competitive pricing can be offered to the customer; the SGIP incentive can help to increase market uptake of these new energy storage products to accelerate the growth of production volume and enable the desired cost reduction in the near future.

CHAPTER 6: Recommendations

Based on the demonstrated performance of the OCC-PLR, the following next steps are recommended:

(1) Develop a full-scale OCC-PLR that utilizes a larger battery pack and has scalable power rating by adding additional OCC-GTI modules in parallel.

(2) Increase the response speed of the OCC-PLR top-level control to enable closer to real-time peak management. Although speed is not critical for mitigating peak demand charges that are calculated on 15-minute intervals, it can mitigate peak dynamics imposed on the grid by intermittent loads and sources in real-time to enable the grid to support increased renewables penetration and to serve more load with the same infrastructure.

(3) Deploy a "constellation" of OCC-PLRs in a local geographic area, such as a commercial or industrial park to demonstrate: (a) improved local-grid stability through reduced load/DG-source dynamics so that penetration of renewables can be increased beyond the typical 15 percent to create a net-zero park, and (b) aggregated benefits of distributed energy storage in existing high-value markets such as capacity bidding, so that value can be delivered on both sides of the utility meter to accelerate the ROI and enable suitable return on investment without SGIP incentives.

(4) Market and sell OCC-GTI and engineering services to enable accelerated deployment of energy storage systems by multiple companies. The experience gained on this research program is already having a multiplicative effect to help enable other energy-storage system developers. There are many types of energy storage and each has applications that can deliver value to customers. OCC, Inc. is actively pursuing these opportunities and to date seven entities have adopted OCC-GTI as the preferred grid interconnection for their energy-storage system.

(5) Complete UL1741 testing on the OCC-GTI so that commercial deployment opportunities can be expanded to satisfy growing demand as OEM customers gain traction in the marketplace.

(6) Integrate a popular electric vehicle or hybrid electric vehicle battery into a stationary energy-storage application, e.g. from the Chevy Volt or Nissan Leaf. Since these vehicles are gaining market traction, it is likely that a second-life battery market will blossom in the near future.

CHAPTER 7:
Public Benefits to California

(1) What Benefits has California already received from this contract, if applicable

This project demonstrates the effectiveness of peak load regulation using an OCC-GTI combined with energy storage (Li-Ion transportation batteries). Considering the large market size, OCC has positioned itself as an enabler, delivering the critical power electronics (OCC-GTI) to other companies to amplify market growth. The OCC-PLR project has enabled the OCC team to demonstrate its integration capability and has attracted many entities in the energy storage business to adopt the OCC-GTI and OCC services. To date, five entities in California and two outside California have leveraged OCC technology and/or services to accelerate their energy storage product development. OCC is in active negotiations with several others. This product and market strategy has made and will continue to make lasting impact in California.

(2) If this project is successful and the results widely used, how will California Benefit.

Peak demand charges are typically 30 percent to 50 percent of the electricity bill for small to medium commercial/industrial facilities in California. Cost-effective peak load regulation can enable reduction of electricity bills to improve the bottom-line financial strength of these businesses while also having a stabilizing effect on the grid. A 15 kW demand reduction for each of the 77,000 industrial customers and 1,800,000 commercial customers (Table 3) in CA. Assuming all of these facilities converted, it could result in an annual financial benefit of $3,210 per facility, following completion of the ROI, for a total financial benefit of $6.0 billion per year. A US-wide deployment could translate to a $58.9 billion per year financial benefit (

Table 4),
Furthermore, the deployment of large numbers of distributed OCC-PLR systems can enable increased penetration of renewables to achieve the California goals of 33 percent renewables by 2020 within the built-up areas where the power is needed, so that transmission line upgrades can be postponed or eliminated. Increased renewables without transmission-line upgrades will deliver substantial health and monetary benefits to California ratepayers and society.

Table 3: Electricity Consumers and Consumptions in California and US

Sector	Census Division State	Number of Consumers	Average Consumption (kWh/Month)	Average Price (Cents/kWh)	Average Bill ($/Month)
Industrial	California	77,326	54,996	10.04	$5,523.65
	U.S. Total	774,713	108,567	6.83	$7,413.54
Commercial	California	1,807,261	5,765	12.54	$722.88
	U.S. Total	17,562,726	6,339	10.36	$657.02

Source: http://www.eia.gov/cneaf/electricity/esr/table5.html

Table 4: Estimated Financial Benefit and Market Size (Assume 1x OCC-PLR / Customer)

Sector	Census Division State	Number of Consumers	Annual Electricity Cost Saving ($)	Market size ($)
Industrial	California	77,326	$247M	$1,540M
	U.S. Total	774,713	$2,484M	$15,480M
Commercial	California	1,807,261	$6,047M	$36,140M
	U.S. Total	17,562,726	$56,374M	$351,240M

Potential industrial and commercial market size for the OCC-PLR in California is approximately 1,885,000 facilities; many of which could require multiple units. Assuming one unit per facility and a sales price of $20,000 each, that is a $37.8 billion market opportunity. When the whole United States is considered, the market size is estimated to be $366 billion.

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"Southern California Edison Rate Schedule GS-2, General Service Demand." Issued by A Jazaveri, Vice President. Effective: October 1, 2009.

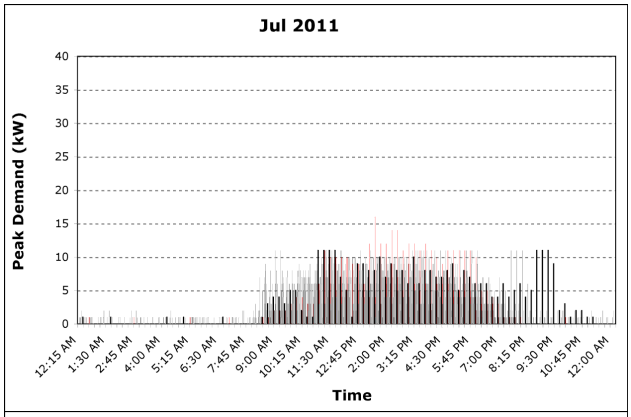
2013 Self-Generation Incentive Program (SGIP) Handbook, California Public Utility Commission, February 1, 2013.

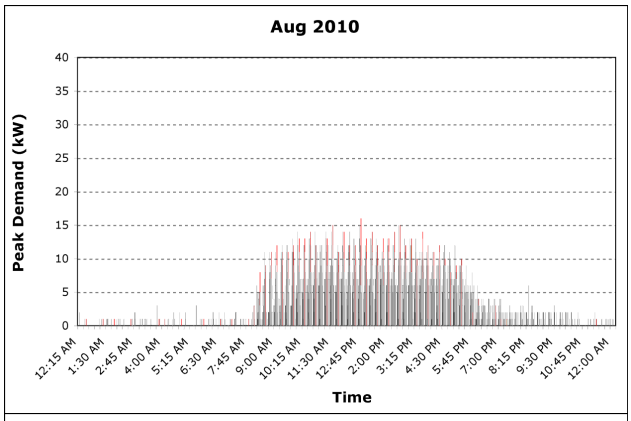
GLOSSARY

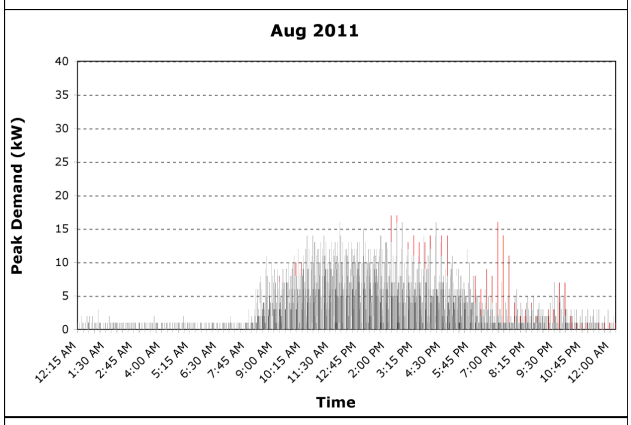
Term	Definition
BOM	Bill of Materials
CA	California
CAD	Computer Aided Design
CEC	California Energy Commission
CSULB	Cal State University, Long Beach
DOC	Department of Commerce
HMI	Human Machine Interface
kW	kilowatt
kWh	kilowatt hour
M&V	Metering and Verification
OCC-BDC	One-Cycle Control BiDirectional Converter
OCC-GTI	One-Cycle Control Grid-Tied Inverter
OCC-PLR	One-Cycle Control Peak Load Regulator
OEM	Original Equipment Manufacturer
PLC	Programmable Logic Controller
SCE	Southern California Edison
SDGE	San Diego Gas and Electric
SGIP	Self-Generation Incentive Program
TLC	Top Level Control
UCI	University of California, Irvine
UCLA	University of California, Los Angeles
UI	User Interface
USC	University of Southern California

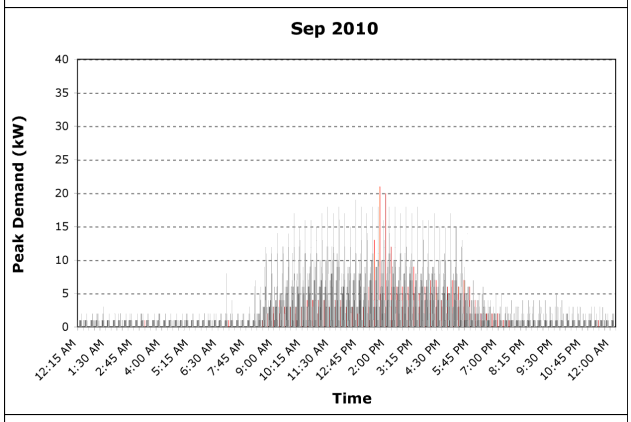
APPENDIX A:
Peak Demand at the Demonstration Site

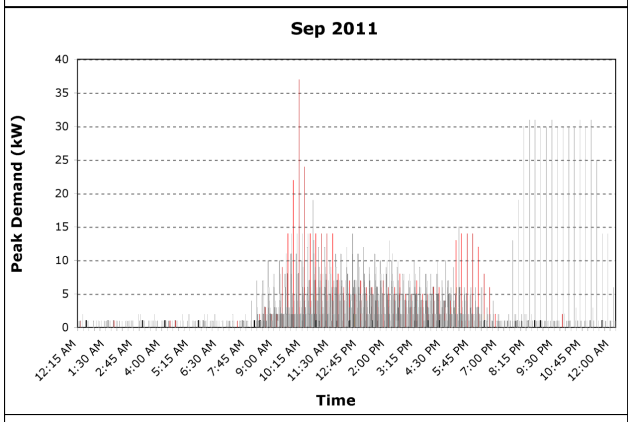
No Data

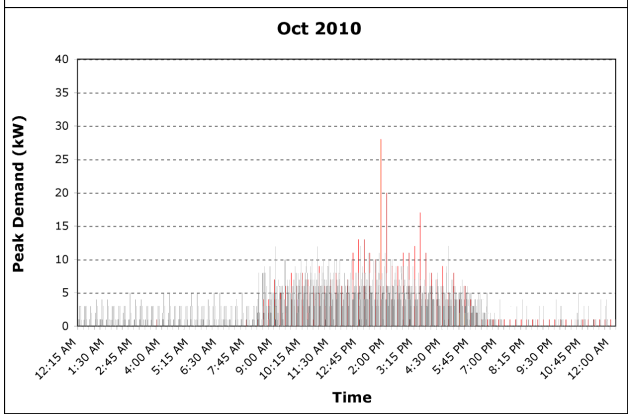












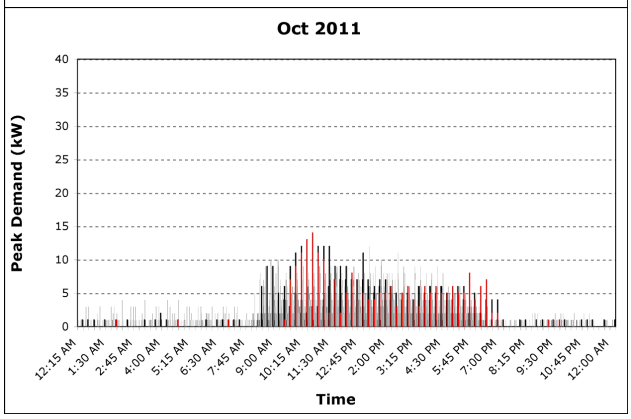
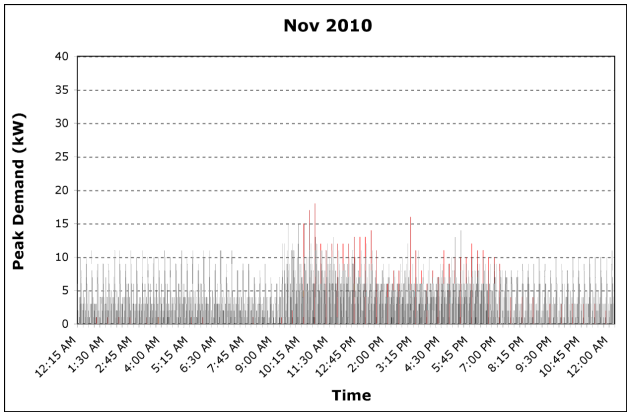
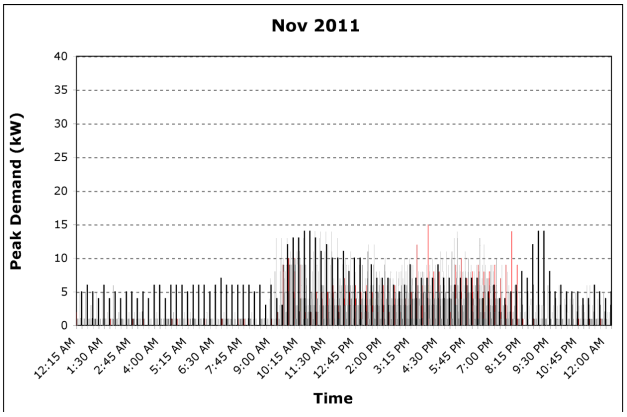
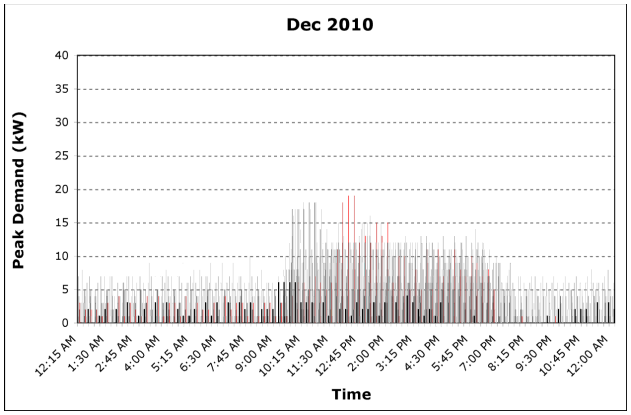


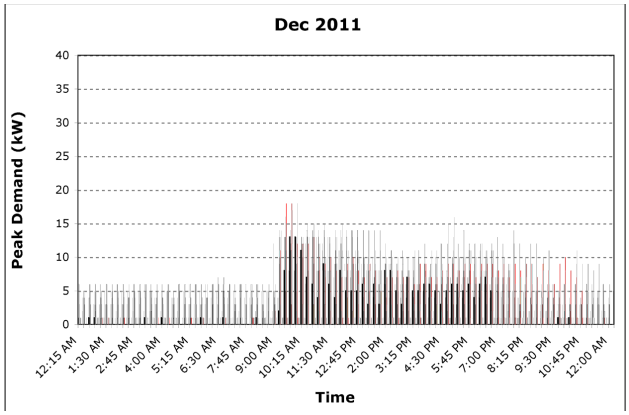
Figure 15: Demand Comparison: Aug-Oct 2010 (no PLR); Jul-Oct 2011 (PLR)

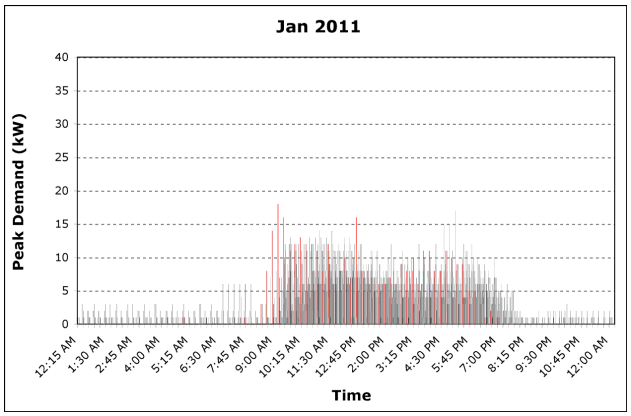
Figure Credits: OCC, Inc. *(day with max peak demand is highlighted in red)*

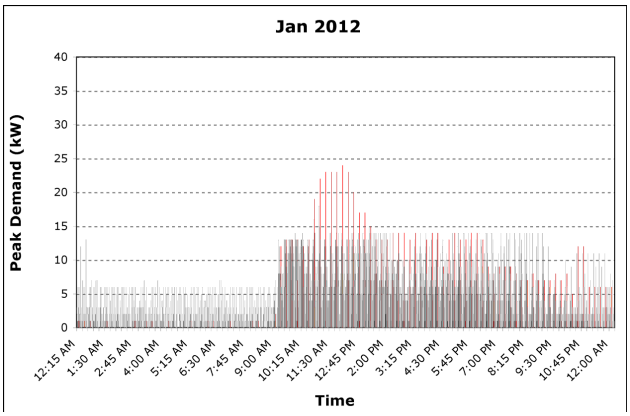

Nov 2010
Peak Demand (kW)
Time

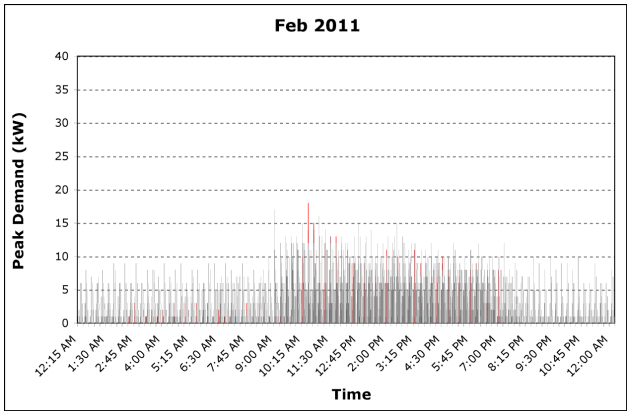

Nov 2011
Peak Demand (kW)
Time


Dec 2010
Peak Demand (kW)
Time


Dec 2011
Peak Demand (kW)
Time


Jan 2011
Peak Demand (kW)
Time


Jan 2012
Peak Demand (kW)
Time


Feb 2011
Peak Demand (kW)
Time

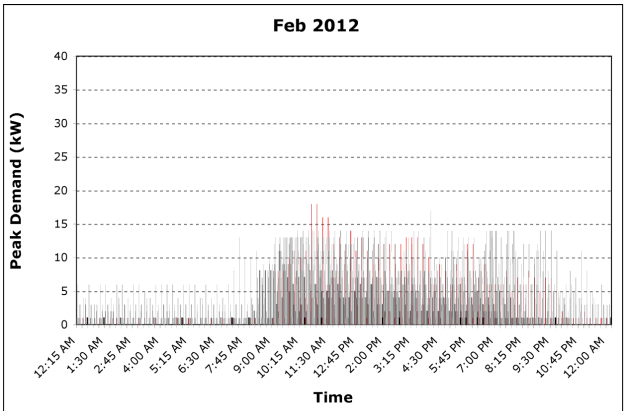
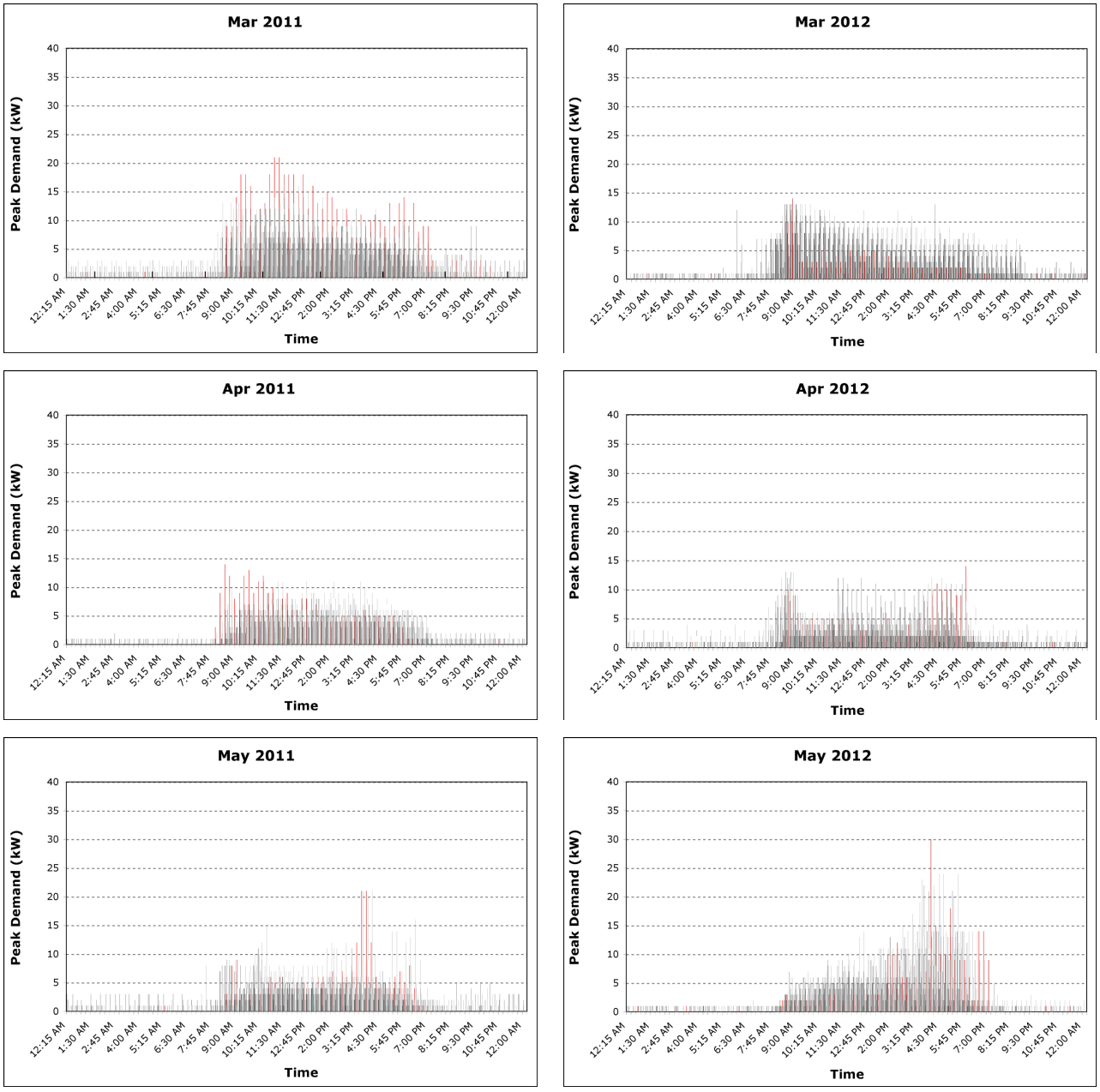
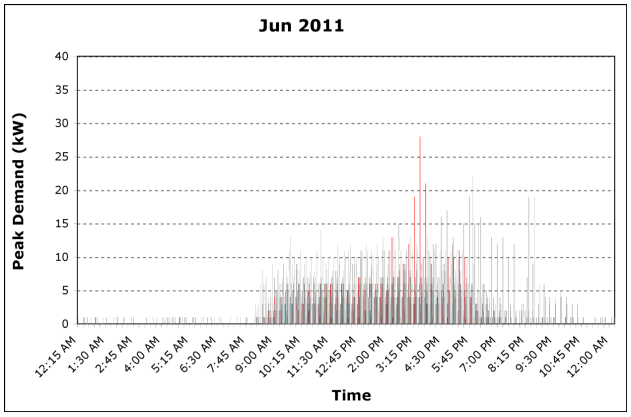

Feb 2012
Peak Demand (kW)
Time

Figure 16: Demand Comparison Nov 2010 – Feb 2011 (no PLR); Nov 2011 – Feb 2012 (PLR)

Figure Credits: OCC, Inc. *(day with max peak demand is highlighted in red)*





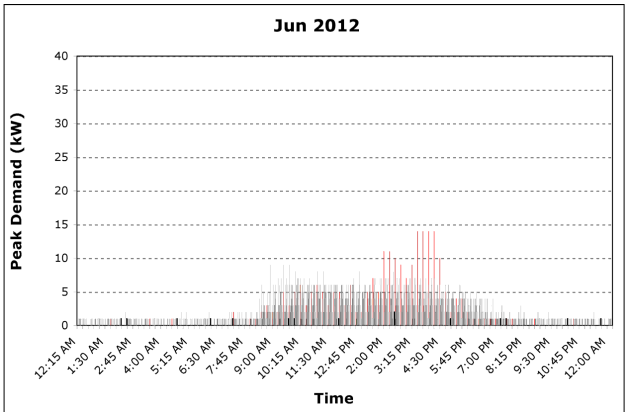
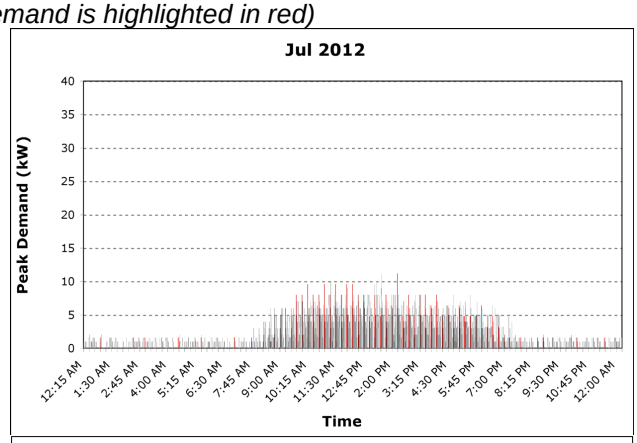


Figure 17: Demand Comparison: Mar – Jun 2011 (no PLR); Mar – Jun 2012 (PLR)

Figure Credits: OCC, Inc. *(day with max peak demand is highlighted in red)*

N/A



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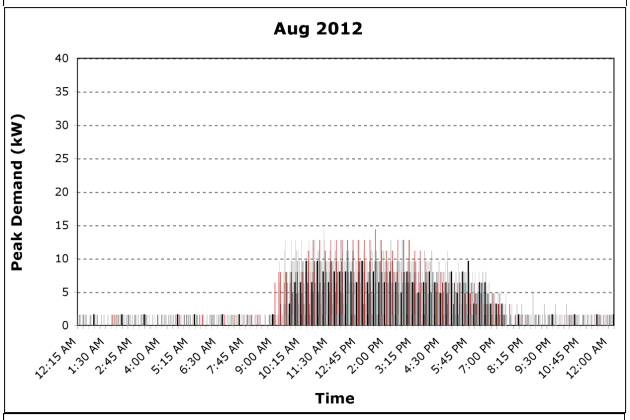
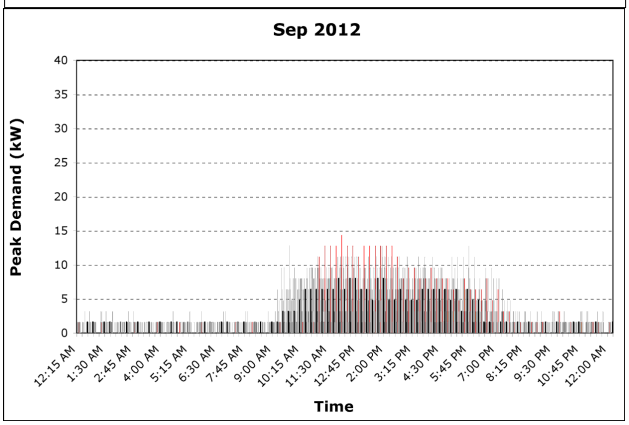


N/A



N/A

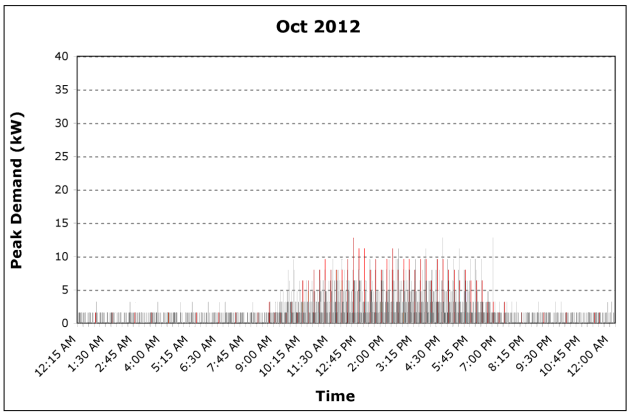


Figure 18: Demand Jul – Oct 2012 (with PLR)

Figure Credits: OCC, Inc. *(day with max peak demand is highlighted in red)*

APPENDIX B:
OCC-PLR & OCC-GTI Brochures

One-Cycle Control, Inc.
The Art of Power Processing

OCC-Peak Load Regulator

Enabling Advanced Power Conversion

Invented at Caltech and UC Irvine, developed under DOE, DOD, CEC, and CIEE support, One-Cycle Control products deliver a new paradigm: active conversion of 3-phase power with hardware-based fast, precise, and robust universal control.

onecyclecontrol.com

Breakthrough Technology:
OCC-PLR leverages unique patented technology invented at Caltech & University of California and developed by the world leading power electronic experts under partial sponsorship of California Energy Commission. It features the first hardware-enabled 3-phase 4-quadrant OCC-GTI and OCC-TLC technology for battery charging and discharging with high reliability, ultrafast dynamic response, and simple user interface, enabling peak load reduction, demand response, voltage support, frequency regulation, PV firming, and /or wind power firming in real-time.

Problems:
- Facility owners face utility penalties for high peak load
- Power demand exceeds the transformer capacity
- Fast load transient causes voltage flicker and sag
- Intermittency of renewables causes grid voltage transient and must be curtailed
- High demand causes voltage collapse and large area blackout

OCC Solution:
- Shave peak load to avoid high peak penalties
- Reduce peak demand to free up transformer capacity
- Regulate load transients to maintain high power quality
- Stabilize the grid against intermittency to increase renewable penetration
- Support voltage, regulate frequency, prevent blackout, and protect the power grid and customers

OCC Benefits:
- Hardware enabled control — ultrafast and precise real & reactive power on demand
- Simple user interface — low maintenance & low service
- Modular plug & play architecture — scalable
- Long life design — low logistics & installation cost
- Power converter light weight — minimum raw material usage, environmentally friendly
- Power converter small size — space saving
- ETL listed — safe and high quality
- California Energy Commission sponsored and award winning technology — highly competitive

OCC-PLR

– Regulate power demand using energy storage

OCC Features:
- One-Cycle Control technology
- Power factor >0.99
- Current harmonics <3%
- Converter efficiency >97%
- Stable zero load operation
- Leading response speed (100s of microsec)
- 400Hz or variable frequency by custom order
- Single unit 35kVAR scalable to MVAR

ETL LISTED

MADE IN CA

One-Cycle Control, Inc. 12 Mauchly Building P, Irvine CA 92618
www.onecyclecontrol.com

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Figure 19: OCC-PLR Brochure
Brochure Credit: OCC, Inc.

Figure 20: OCC-GTI Brochure
Brochure Credit: OCC, Inc.