

Accelerating PV Cost Effectiveness Through Systems Design, Engineering, and Quality Assurance

**Final Subcontract Report
June 2007**

Jonathan Botkin
*PowerLight Corporation
Berkeley, California*

Subcontract Report
NREL/SR-520-42420
December 2007

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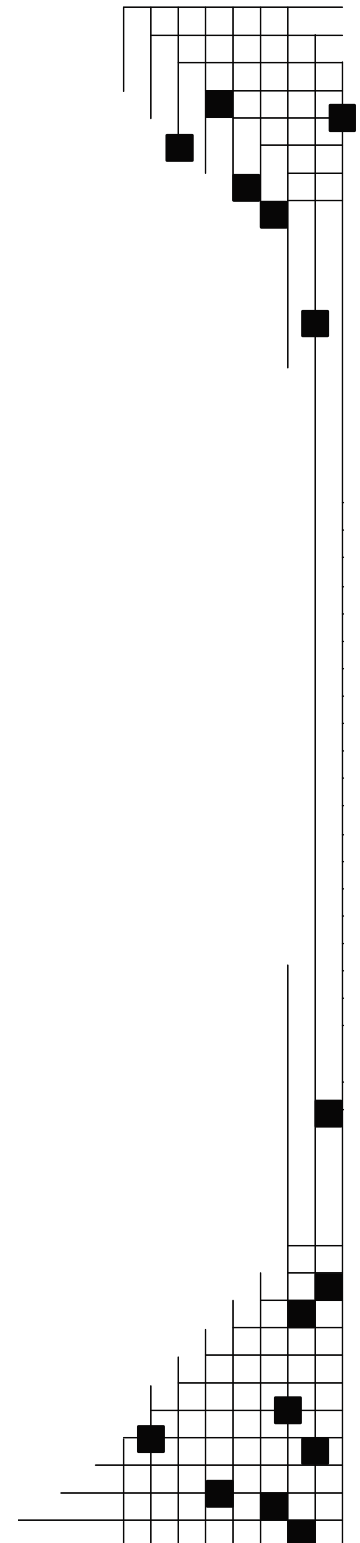
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Abstract

During this PV Manufacturing R&D subcontract, PowerLight® Corporation¹ has made significant progress toward the reduction of installed costs for commercial-scale, rooftop PV systems. PowerLight has worked to reduce operating costs by improving long-term reliability and performance through the development of more sophisticated tools used in system design and monitoring. Additionally, PowerLight has implemented design improvements with the goal of reducing cost, while maintaining and/or improving product quality. As part of this effort, PowerLight also modified manufacturing and shipping processes to accommodate these design changes, streamline material flow, reduce cost, and decrease waste streams.

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Executive Summary

PowerLight Corporation provides the products and services required to install large-scale solar electric generation at any suitable site. PowerLight designs and installs complete systems, ensuring reliability, efficiency, and cost-effectiveness.

In 2004, PowerLight initiated the PV Manufacturing R&D subcontract, “Accelerating PV Cost Effectiveness through Systems Design, Engineering, and Quality Assurance.” This work effort focuses on cost reductions for PowerLight’s commercial rooftop product offerings: PowerGuard Roof System; PowerLight Fixed Tilt Roof System (RFT10), and PowerLight Metal Roof System (RMR).

As part of this effort, PowerLight focused on developing improved tools for system design and monitoring in order to optimize system performance and minimize downtime under Task 1. PowerLight selected a GPS-based site audit tool to facilitate the design process. In addition, PowerLight tested alternative hardware for data acquisition and reference sensors. Coupled with the more sophisticated alert algorithms under development, these devices provide PowerLight with better monitoring and diagnostic tools that will improve system performance and availability. Overall, these improvements have led to better layout design, fewer design-related delays during installation, and improvements in system output. Performance indices for test sites with new monitoring algorithms were 11% higher than control sites. Availability was also higher, showing 0.7% improvement over the control sites.

Prior to the start of this subcontract, PowerLight had completed design work on the first version of a mounting system with sloped PV, RFT10. Like PowerGuard tiles, this system was designed for installation on flat roofs without penetrations, but it does not have the foam insulation of the PowerGuard tiles. PowerLight launched a full production version of the RFT10 product during Phase I of this project, and then launched a modified design in Phase II that incorporated many improvements based on lessons learned during this project, resulting in a more versatile product for a wider range of applications. PowerLight advanced this new design to full commercial deployment, realizing a 70% reduction in mounting hardware cost and a 10% reduction in overall system cost. Additionally, PowerLight developed design guidelines for installations on tall buildings and mechanically attached roof membranes. PowerLight also reduced raw material use in the production of PowerGuard tiles and increased shipping density, which combined for a 17.8% reduction in PowerGuard backerboard cost. Other work on the PowerGuard tile enabled PowerLight to adjust to changes in PV module backing materials.

PowerLight evaluated product improvements through comprehensive testing in order to verify that product quality is maintained throughout the design process. This reliability evaluation included wind studies; structural evaluation; seismic modeling; thermal monitoring; and electrical testing.

PowerLight worked with PV suppliers to establish quality and performance standards. By ensuring that suppliers have adequate quality systems in place, PowerLight avoids costly field repairs and delays. This also ensures that PowerLight’s systems perform at their maximum output, satisfying customers’ expectations.

By continuing to implement lean-manufacturing techniques and through the implementation of improved equipment, PowerLight achieved a 99.99% yield for PowerGuard tile production, outstripping the goal of 99.9%. This yield is the result of improvements in manufacturing equipment and inputs from factory workers.

To address ES&H concerns, PowerLight modified shipping practices and succeeded in increasing packing density, thereby reducing shipping costs by 20%.

The design improvements implemented during Phase I were evaluated through commercial demonstration projects. PowerLight monitored cost and performance of over 2.5 MWp in new installations to verify cost and performance predictions. The data collected during these installations provided the results listed above and discussed in this report.

PowerLight is proud of the progress that has been made in system performance and system cost through the funding provided by the National Renewable Energy Laboratory and the PV Manufacturing R&D program.

1 Introduction

1.1 Objective

The overall objective of this subcontract is the reduction of installed system costs for PV systems utilizing PowerLight(R) Corporation's rooftop products.

1.2 Background

PowerLight manufactures its flagship product, the PowerGuard(R) tile, in a facility in Berkeley, California. PowerGuard building-integrated photovoltaic roofing tiles generate electricity from solar energy. A PowerGuard tile consists of a flat plate photovoltaic (PV) laminate mounted onto a flat, rigid, extruded polystyrene (XPS) board. The XPS board is covered with a cementitious coating. Two edges of the XPS board are routed into a tongue profile, while the other two edges are given a groove profile. This design allows PowerGuard tiles to be assembled adjacent to each other in an interlocking fashion, as shown in Figure 1 below.



Figure 1: PowerGuard tiles showing interlocking tongue and groove profile.

PowerGuard tiles provide benefits in addition to the electricity produced in the form of added insulation and protection of the roof membrane from ultraviolet light. PowerGuard systems can reduce the heat transfer into a building and reduce operating costs.

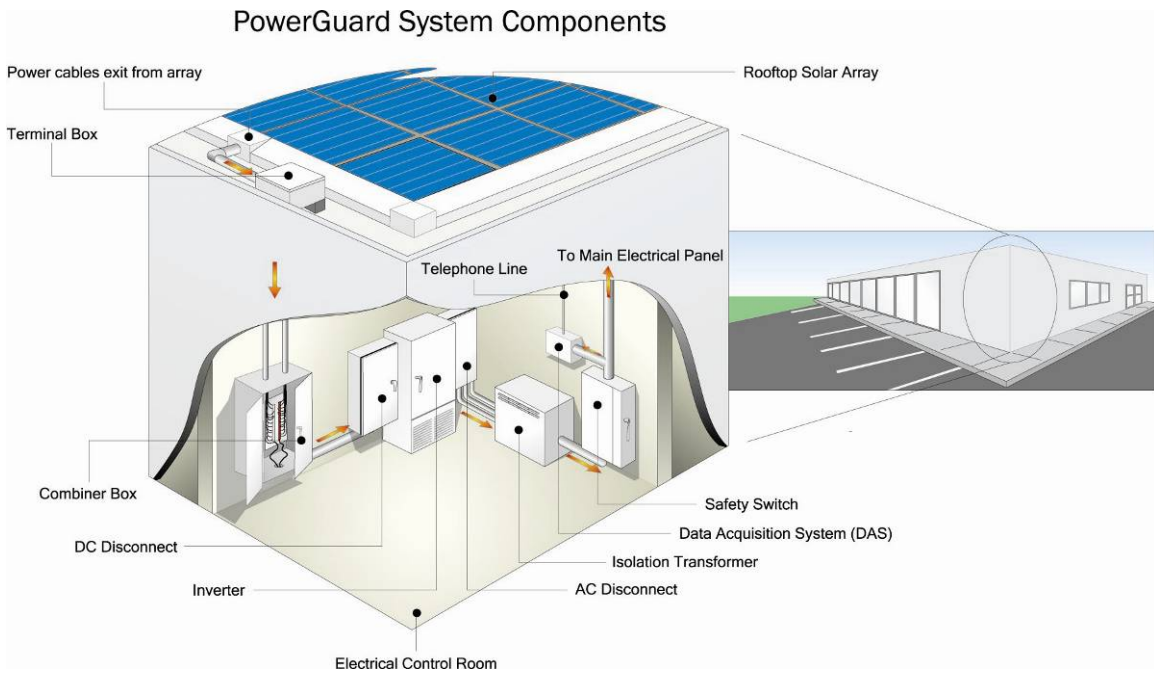


Figure 2: Building cross-section showing PowerGuard System Components.

Adjacent tiles are tied together electrically through connectors supplied on each PV module, thus creating an electrical string of PV modules. One or more strings are then electrically connected in parallel at a remote location creating a solar electric array. The resulting DC current from the array is passed through a DC/AC inverter and isolation transformer before being tied into the building's electric distribution panel. Figure 2 depicts the system components for a PowerGuard array.

PowerLight also manufactures a PV mounting system for metal roofs called PowerLight Metal Roof System (RMR), using custom clips, shown in Figure 3, and a 10-degree sloped PV mounting system for flat roofs, RFT10, shown in Figure 4.

PowerLight has implemented design improvements to all three products to expand market applications, reduce cost, and improve quality and reliability. This report outlines the activities completed under this subcontract.



Figure 3: RMR System.



Figure 4: RFT10 Array.

2 Results & Recommendations

2.1 Design & Performance Reliability Improvements: Tasks 1 & 8

The objective of this task is to improve the tools used to design and monitor PV arrays in order to optimize performance and minimize downtime. As part of this effort, PowerLight initiated development of an array-design tool with improved quality of data transfer from the roof to the system designer. In addition, PowerLight began development of an improved monitoring and diagnostic system to optimize system performance.

2.1.1 Site Audit Tool

Background

An accurate site audit is an important step in the design of a PV system. If the site audit does not capture all potential obstacles or shading issues, installation costs can increase, and system performance can suffer. At the start of this project, the methods used to measure rooftops involved the use of distance measuring wheels and tape measures, generally measuring from the closest edge of the roof to the point or object being measured. This method resulted in points being defined from numerous reference points, and, occasionally, resulting in disorganized information and missing critical dimensions.

PowerLight has developed improved procedures and implemented greatly improved tools for measuring the available space on flat rooftops for installation of solar arrays. These advances have improved the accuracy of site audits, which will help to minimize design and installation time and will also ensure that arrays are designed for maximum performance.

Approach

In Phase I, PowerLight reviewed available tools that could be used to improve the accuracy of site audits and would improve the transfer of information to the array designers. Several rounds of equipment trials were completed with tools based on laser measurement and global positioning satellite (GPS) systems. By the end of Phase I, a GPS-based tool was chosen and purchased. During Phase II, PowerLight focused on the implementation of the new tool through field training of audit crews as well as the development of a system to transfer the audit information efficiently to the array designer.

Once the audit tool had been chosen, the audit crews set about creating the system for information storage and transfer. This was tested through several trial runs. This system will continue to evolve as the range of site conditions expands.

Results

PowerLight originally decided to pursue the use of a laser-based tool. However, this system proved to be suboptimal during field trials due to its complexity and cost. PowerLight returned to a GPS approach, which had originally been rejected because GPS tools with a single receiver did not have sufficient accuracy for our needs. However, a new tool with two GPS receivers instead of one proved to be more accurate.

With this tool, one GPS unit is used as a stationary base station at some arbitrary point on the roof. The second GPS unit (the rover) is moved around the roof to various features. Though the absolute precision of either unit is not sufficient for an accurate site audit, the relative measurement of one unit to the other provides an extremely accurate measurement. The accuracy of the measurement is ± 1 cm horizontally and ± 2 cm vertically. This tool proved to be the most practical of all tools that were evaluated.

The tool selected uses two GPS receivers as discussed above. The audit team places the base station in one location on the site, and they then move the other unit around the site to each feature that must be included on the site map. For each feature, the operator is able to select what type of feature it is, such as an edge of the roof, a wall, a piece of equipment, or a skylight. The height of each feature is included, and the system will insert an appropriate sized shadow diagram.

When the audit is completed, the data is downloaded into a computer, which then interprets the information and produces a site layout. The layout includes all the various features and places them on predetermined layers within the layout drawing. This file is then opened in AutoCAD, where the array designer can then start to populate the site with PV modules. Figure 5 shows the raw data as downloaded from the GPS unit. The automatic translation into a site layout is shown in Figure 6. These images are from actual site audits performed recently by the PowerLight audit team with the new tools.

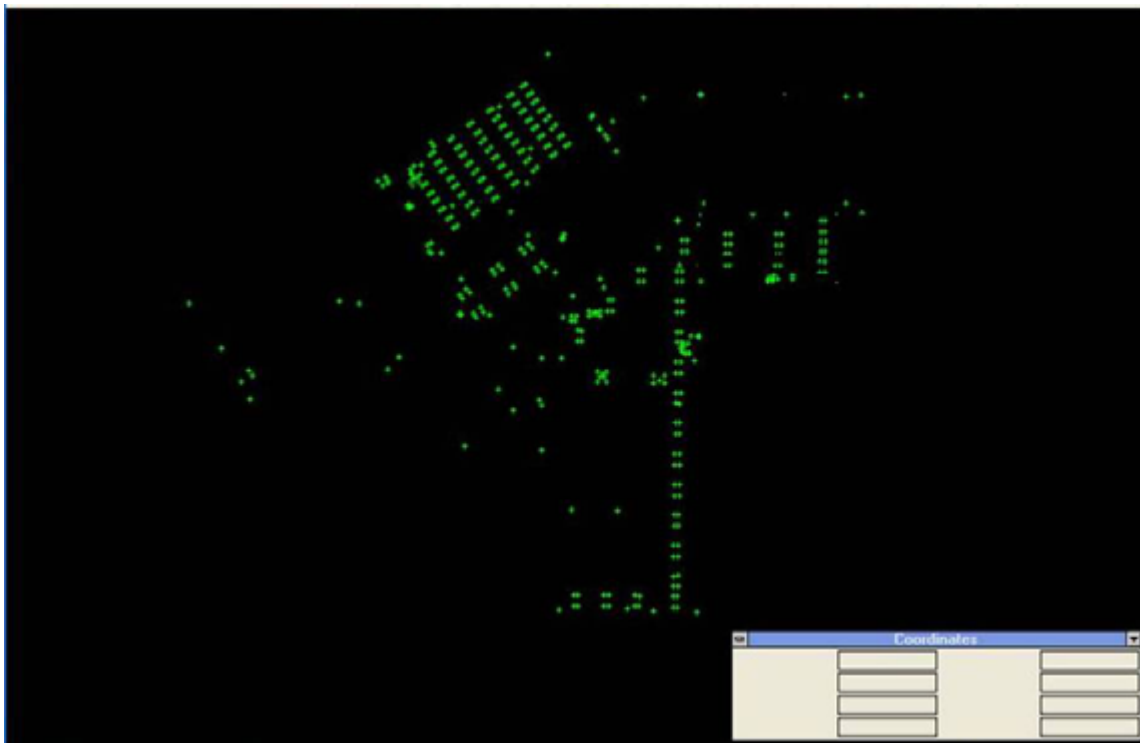


Figure 5: Raw data points downloaded from GPS unit.

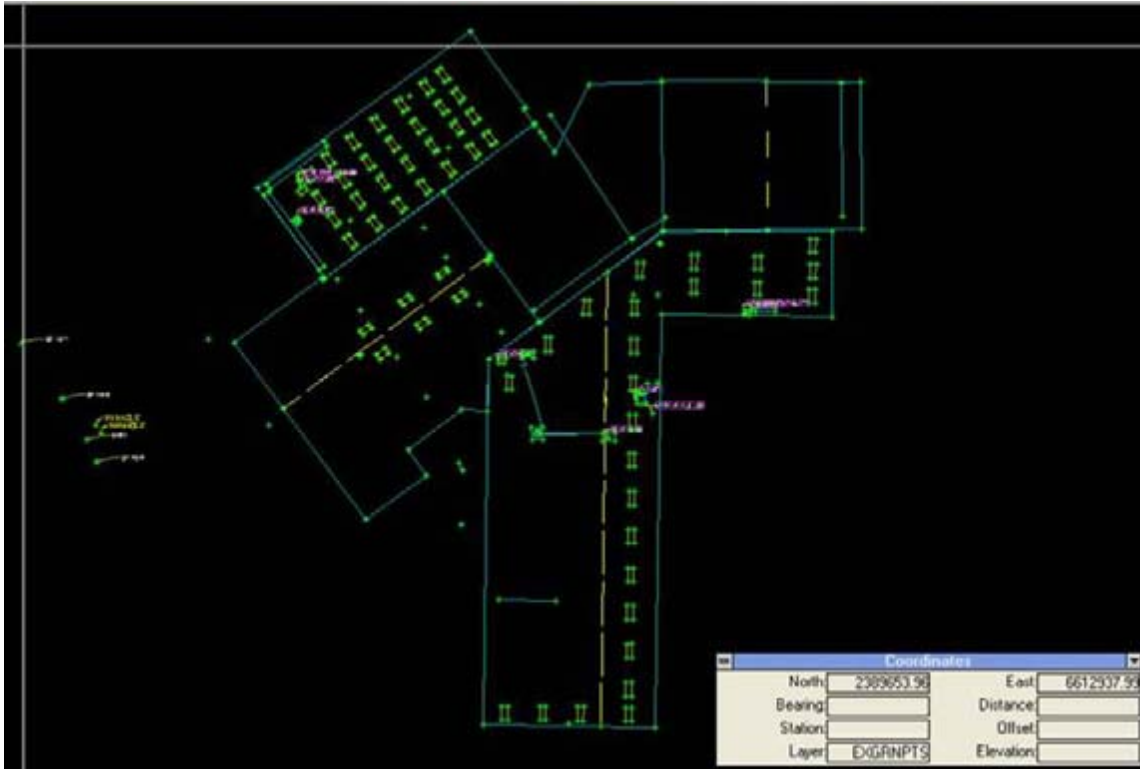


Figure 6: Automatic drafting output showing building outline and roof features.

Figure6 shows how the points that define the roof edges and the other features are connected automatically by the system. Other points that appear on the layout that are not connected are survey points that provide reference points to determine roof height and roof slope.

Figure 7 below shows the addition of a shadow pattern that is done automatically by the audit system based on the height of an obstacle on the roof.

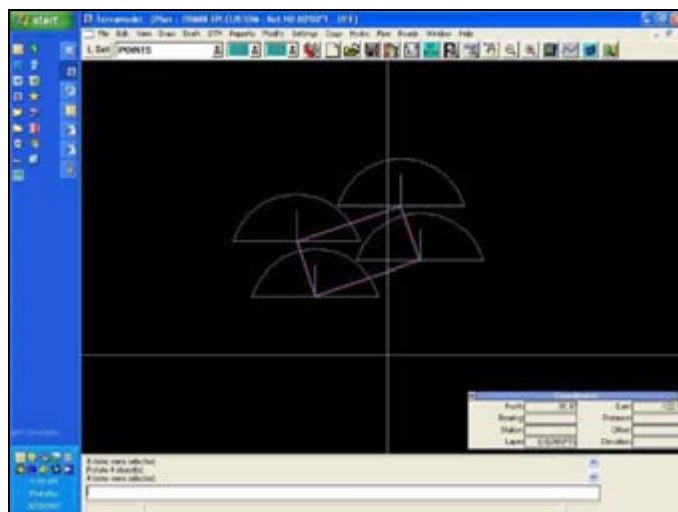


Figure 7: Shadow pattern added automatically to layout.

Conclusion

The implementation of the new site audit tool and procedures will dramatically improve the accuracy and completeness of site audit data. It will also significantly reduce the cost of audits. The improved accuracy will reduce the cost of designing and installing systems by streamlining the process and reducing rework due to unexpected obstacles encountered during installation.

At this point, the audit crews are still developing audit procedures for the equipment and system. Time spent on the roof doing an audit is somewhat longer than it was with the old system. However, the time spent transferring the information to a site layout has gone from several hours to the push of a button, so the total time is reduced by several hours for each audit. The auditors are confident that once they have more experience with the system the time on the roof will be reduced to something less than that required for the old system.

All of this will contribute to reduced system cost as well as improved system performance. An accurate site audit allows for optimization of system layout for maximum performance without increased design cost.

2.1.2 Monitoring & Diagnostics

Background

Currently, PowerLight actively monitors over 40 MW of installed PV systems. Monitoring includes daily alerts on system availability and performance, as well as weekly trend analyses. With such a large number of systems, implementing a sophisticated diagnostic system results in streamlined customer support and optimized system performance.

Approach

PowerLight has pursued a two-pronged approach to meet the objective of improved system availability and performance through more sophisticated diagnostic capabilities. As part of this effort, we procured, tested, and fielded advanced monitoring system hardware with the goal of improving access to system performance information – both in terms of the level of information available and the timeliness of its reporting to customer service staff. Concurrently, we worked to improve the analytical system used to evaluate system performance data and send alerts and alarms to customer service staff. This analytical approach will result in faster recognition of more subtle performance problems and reduce instances of nuisance alerts and alarms. The combination of advanced hardware and improved analytical tools will lead to an improvement in overall system reliability and performance.

Hardware Approach

Advanced hardware monitoring systems reviewed for this project include stand-alone data acquisition systems (DAS) and data collection modules embedded in system inverter (power conditioning) units. PowerLight tested two types of hardware monitoring systems, which were installed in five test systems. The performance of these test systems was compared to that of a group of control systems. The various test and control sites are identified in Table 4 in Section 2.7.1.

As a first step toward improved monitoring capabilities, PowerLight looked for alternative data loggers with better real-time data and alarm functionality than those used currently.

PowerLight focused on data loggers that have embedded web servers and firewalls and that can post data to the web in XML format. These features are desirable for many corporate clients concerned with network security issues.

At the end of Phase I of this project, we reported the results of our testing on several stand-alone data acquisition system (DAS) systems and one embedded inverter monitoring device. Based on our research in Phase I, PowerLight chose to install the Campbell CR1000 stand-alone DAS and the Xantrex Graphical User Interface (GUI) embedded monitoring system.

By December 2005, the Xantrex GUI had been installed and was fully functional at Test Site 10241. However, we found that the Xantrex GUI had significant limitations, causing PowerLight O&M staff to use the GUI as a control tool only and not a monitoring tool. In particular, the Xantrex GUI lacked the ability to send proactive alerts from the inverter to field service personnel. Although the GUI could give detailed and specific diagnostic information about the inverter, it could not transmit this information to the customer support staff (for example, via an e-mail, fax, or pager alert). As a result, PowerLight O&M staff continued to use PowerLight's standard DAS as their primary monitoring device and use the Xantrex GUI only to accelerate troubleshooting and repair of the inverter once the PowerLight DAS identified a problem. Because of this limitation, PowerLight decided to pursue alternate means of remote inverter monitoring and control.

In December 2006, PowerLight and its subcontractor completed the installation of the CR1000 direct inverter monitoring at an additional test site; this test site was not part of the original 28 monitored systems listed in Table 1. The program is now fully functional, and PowerLight is collecting twenty-eight key inverter parameters, including inverter fault status. In addition, the program has successfully dialed out to PowerLight's DAS servers under faulted conditions, as desired. Finally, the integrated CR1000 program allows remote dial-in to the Xantrex inverter via the CR1000 logger for remote reset of the inverter. The final step in full implementation of this solution is currently underway. This final step involves working with PowerLight's internal IT department to automate an e-mail alert from the DAS servers to field service personnel. This solution is so promising that three additional test sites have already been identified, and PowerLight plans to roll out the solution as a standard with all Xantrex systems when the test phase is complete.

Because this approach is not tied to a particular brand of inverter, the same solution can be easily adapted to work with other inverter products. A key benefit of this approach is that it allows our field service team to use just one interface to interact with and control all types of equipment. This will reduce the amount of training required and will make monitoring more efficient.

PowerLight has begun to implement this solution with SMA inverters, so that we can take advantage of the same desired benefits: detailed diagnostic information; proactive, real-time alerts on system status; and remote inverter diagnostics and control capabilities. In February 2007, PowerLight obtained the protocol used to communicate with all SMA inverters and submitted this to our CR1000 programming contractors. In March 2007, we agreed to a scope of work to create a standard data logger program to implement the same monitoring and control capabilities that were implemented for the Xantrex inverters. In the second quarter of 2007, we plan to modify the data logger program and test it at a site with SMA inverters.

Analytical Approach

The second approach to improving system performance and reliability is through improved analysis of the performance data collected from each system. At the start of this project, PowerLight received performance index alerts for systems when the performance index (PI) dropped below a user-defined threshold for the site. Performance index is determined by dividing the actual energy produced by a site during the day by the amount of expected energy for the day. Expected energy for the day is calculated using basic system parameters and meteorological data recorded at the site, including irradiance from a LICOR pyranometer, ambient temperature, and wind speed. PowerLight worked to improve the following aspects of this monitoring approach:

- 1) Current performance index alert thresholds are set to ensure that we are aware of performance problems while minimizing the number of nuisance alarms from expected influences like soiling. With a more sophisticated alert algorithm, PowerLight could be more sensitive to performance problems that occur between the threshold and the 100% performance index level. Currently, we do not receive alerts for potential performance problems that do not cause the PI to dip below the user-defined threshold.
- 2) Calculating expected energy for the day using pyranometer data sometimes results in inaccurate PI values because the spectral response of the pyranometer is different from that of the PV array. This effect is particularly pronounced on cloudy days and in winter.

To address these limitations, PowerLight conducted two studies. In the first study, PowerLight devised and tested several sophisticated alert algorithms for performance index. We have developed and tested six different algorithms, using between five and seven months of recorded data for nine different systems. To date, PowerLight has developed algorithms to compare sites in similar regions and to evaluate trends in long-term system performance. These algorithms provide better reference points for expected system performance, resulting in fewer nuisance alarms and more alarms for non-outage-related problems. Overall, these algorithms are expected to yield improved performance alerting following implementation.

The second study involved the difference between PIs as calculated using different irradiance sensors, namely pyranometers and reference cells. As mentioned above, the spectral response of the pyranometers is different from that of a reference cell, with the response of the reference cell being closer to that of the array. Because of this, PIs calculated with reference cell data should be steadier and produce fewer nuisance alarms and inaccurate PI values than PIs calculated using pyranometers.

Based on the Phase I analysis of various potential alerting algorithms, PowerLight chose to implement an alert called the "pair-wise alert". This algorithm compares the relationship (or ratio) of the metric "kWh/kWac" (where kWh is the actual energy generated and kWac is the AC system rating) of two systems on a running three-day basis. The alert algorithm is calculated daily and sends an alarm when the most recent 3-day metric is more than 5% different from the previous calculation. Figure 8 illustrates the ratio of kWh/kWac for a pair of systems located on the same corporate campus (yellow line) and shows how steady this ratio is. Tracking this ratio allows the DAS to alert operations personnel when there is a deviation in performance from one day to the next without relying on DAS sensor data or calculated performance indices.

The algorithm was tested for six weeks to ensure minimization of nuisance alerts, and then was automated and rolled out to the field service team in the form of a daily e-mail alert. This alert is now one of the two primary alerts used by the field service team to determine whether field service is required at a site.

kWh/kWac Relationship April 2004 - April 2006

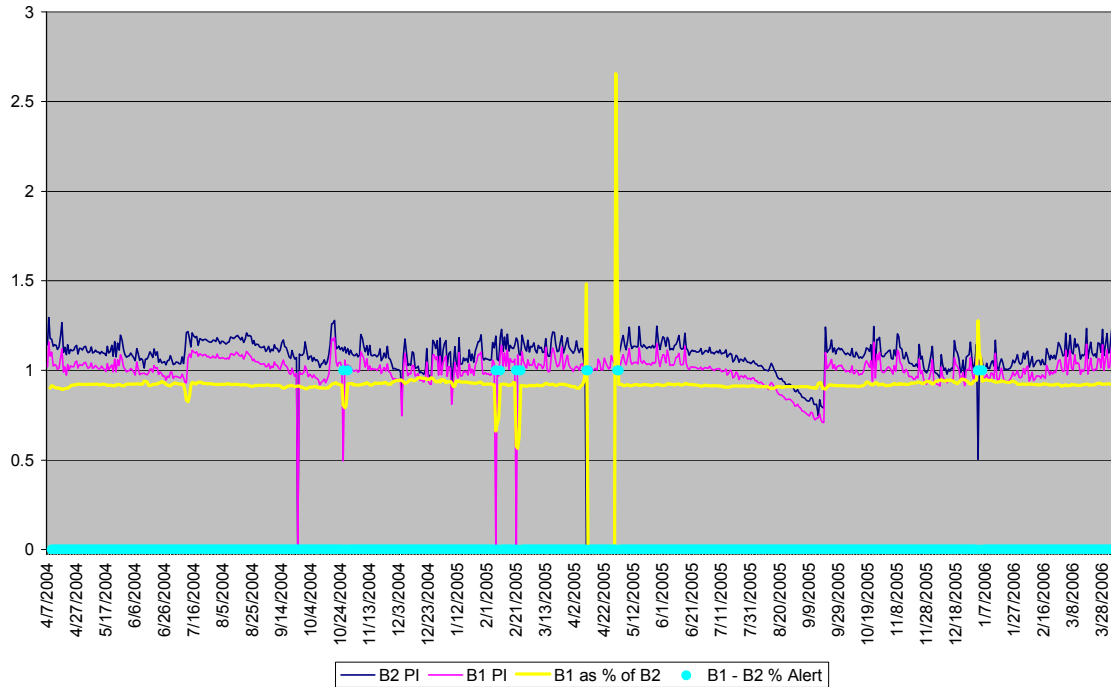


Figure 8: Comparison of kWh/kWac ratio for two sites in close proximity to each other.

In January 2006, PowerLight identified two manufacturers of silicon reference cells and began evaluating their products. In late January, we purchased two EETS reference cells for evaluation and concluded that they were compatible with the Campbell Scientific CR100 and CR10X data loggers that we use in our standard DAS. We sent them to the Sandia National Laboratories (SNL) for calibration. SNL calibration showed the manufacturer’s calibration to be accurate, however, the Sandia calibration gave more detailed factors for calculating reference cell temperature.

In mid-February, we received a sample IMT Si-01 reference cell and found that it is also compatible with the Campbell Scientific CR100 and CR10X data loggers that we use in our standard DAS. We also compared readings from this reference cell to readings from a cell calibrated at the Sandia National Laboratories and found the readings from this less expensive cell to be within 3% of the readings from the Sandia-calibrated EETS reference cells.

Based on relative price and accuracy, in March 2006, PowerLight decided to go forward with the IMT reference cell and began the process of designing a mounting system for the cell.

In April 2006, PowerLight completed engineering design of a mounting system for the IMT reference cell. However, engineering of a standard method for cable installation for rooftop and ground-mounted systems proved more complicated than initially anticipated, and this work was completed in January 2007. The reference cells are now a standard

part of PowerLight's meteorological station, and we have released a full complement of design drawings and installation manuals for this product. The first commercial applications were installed in early 2007.

Results

PowerLight has begun installing Campbell CR1000 loggers, shown in Figure 9, at customers' sites as part of the hardware improvements to the monitoring systems.



Figure 9: Campbell CR1000 Data Logger.

To determine whether replacing pyranometers with reference cells will improve PI evaluation, we monitored five sites with both types of sensors at each location. The data from the reference cell produced a steadier calculation of PI for all sites. Figure 10 shows the comparison between PI as calculated using pyranometer data and PI as calculated using reference cell data for a sample site. The circled regions highlight the steadier nature of the PI calculated with reference cell irradiance data.

Sample System PI as Calculated from Reference Cell and Pyranometer Data Charted Against Energy Produced and Insolation Measured by these Instruments

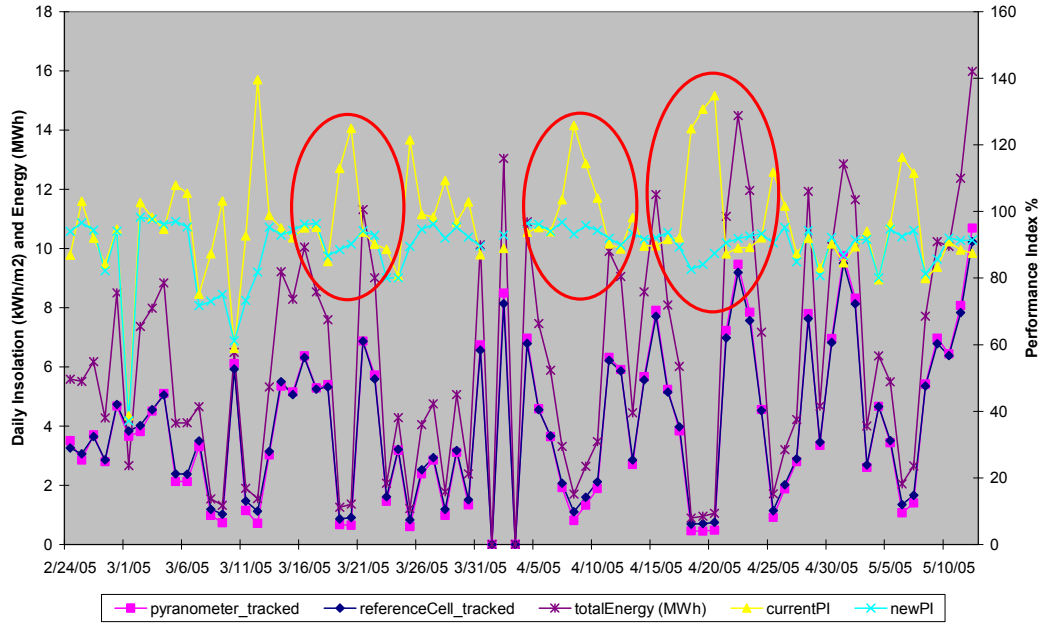


Figure 10: Comparison of site performance index using a reference cell and pyranometer.

In addition, PowerLight tested the six performance alert algorithms from the first study on the two sets of performance indices (pyranometer-based and reference cell-based) and concluded that PIs calculated with reference cells result in 37% fewer nuisance alarms. Further work on this study will include the investigation of PIs for a larger pool of systems.

Results

The effectiveness of the improvements made during this project were gauged through monitoring a range of sites during the period of the project. A group of sites were chosen as control sites, and a small number of sites were chosen as test sites. The improvements were made to the test sites. The performance of all sites was monitored. Because the conditions at different sites vary, it is difficult in a short period to accurately gauge the effect of improvements on system performance. However, there is solid evidence in these results of a positive trend in the data for the test sites.

Table 1: Summary of Performance Index and Availability metrics for study sites

PVMR&D Data Table					Performance Metrics for September 1, 2004 - August 31, 2005		Performance Metrics for October 1, 2005 - March 29, 2007	
System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability	Performance Index	System Availability
System 1	Control	Los Angeles, CA	4/30/2003	115.1	98%	100%	98%	100.0%
System 2	Control	Hayward, CA	1/8/2004	261	95%	100%	95%	99.9%
System 3	Control	Hayward, CA	2/14/2004	101.8	95%	100%	95%	99.9%
System 4	Control	Hayward, CA	3/24/2004	114	101%	98%	95%	98.9%
System 5	Control	Hayward, CA	1/5/2004	243.3	106%	100%	95%	97.8%
System 6	Control	Hayward, CA	1/5/2004	279.7	105%	95%	110%	99.6%
System 7	Control	San Francisco, CA	10/18/2003	234.5	97%	99%	94%	98.7%
System 8	Control	San Francisco, CA	10/18/2003	234.5	99%	100%	92%	99.0%
System 9	Control	San Francisco, CA	2/27/2004	207	102%	99%	96%	97.0%
System 10	Control	Walnut Creek, CA	1/30/2003	93.6	108%	100%	104%	99.9%
System 11	Control	Healdsburg, CA	6/18/2004	258.3	96%	99%	99%	95.7%
System 12	Control	Healdsburg, CA	6/18/2004	199.1	106%	100%	104%	99.6%
System 13	Control	San Mateo, CA	1/27/2003	233.7	94%	96%	99%	99.8%
System 14	Control	Sacramento, CA	2/3/2004	201.4	96%	94%	84%	93.6%
System 15	Control	Sacramento, CA	2/3/2004	201.4	95%	93%	88%	99.7%
System 16	Control	Rohnert Park, CA	1/29/2003	96	95%	100%	88%	100.0%
System 17	Control	Torrance, CA	2/6/2003	37.1	98%	96%	103%	100.0%
System 18	Control	Torrance, CA	2/5/2003	124.7	105%	100%	109%	99.7%
System 19	Control	Torrance, CA	2/5/2003	124.7	100%	100%	105%	99.7%
System 20	Control	Torrance, CA	2/5/2003	124.7	101%	100%	108%	100.0%
System 21	Control	Torrance, CA	2/5/2003	124.7	97%	100%	103%	99.6%
System 22	Control	Vallejo, CA	3/14/2003	107.8	89%	100%	80%	99.5%
System 23	Control	Vallejo, CA	3/14/2003	224	95%	98%	84%	99.2%
Averages, Control Systems					98.8%	98.6%	96.9%	99.0%
System 24	Test	Oakland, CA	6/9/2005	100	N/A	N/A	107%	99.9%
System 25	Test	Oakland, CA	7/28/2005	265	N/A	N/A	107%	99.0%
System 26	Test	Oakland, CA	7/28/2005	265	N/A	N/A	112%	99.9%
System 27	Test	Oakland, CA	7/28/2005	252	N/A	N/A	105%	100.0%
System 28	Test	Oakland, CA	7/28/2005	121.8	N/A	N/A	108%	99.4%
Averages, Test Systems							108.0%	99.6%

Table 1 above summarizes the Performance Index and Availability metrics for each of the systems in the study. Data for the 18 months beginning in October 2005 and ending on March 29, 2007 is shown for each system and is compared to data for the 12-month baseline period from September 2004 – August 2005. The table shows that the average availability of control group sites increased slightly from the baseline period to the 18-month test period, while average performance index fell slightly. Both the availability and performance index of the test sites was better than that of the control sites during the test period. The average Performance Index of the test sites was 11% better than the control sites and the availability was 0.7% better than the control sites. The improvement in Performance Index is considerably higher than the goal of 3%. The improvement in availability is close to the goal of 1%. Also, the use of a reference cell, in place of a pyranometer, provides in more consistent performance tracking and is estimated to result in 37% fewer nuisance alarms.

2.2 High Reliability Cost Reductions: Tasks 2 & 9

The objective of this task is to lower balance-of-system costs by making improvements to the design of PowerLight systems in an effort to broaden the market for its rooftop products.

2.2.1 PowerLight Fixed Tilt Roof System – RFT10

As part of this effort, PowerLight has developed a PV mounting system design targeted for customers with flat roof buildings, but without a need for the added-insulation value of PowerGuard. The new product is called RFT10. It features a 10° sloped PV module and an aluminum and stainless steel support structure.

Prototype Design

Background

The thermal insulation benefit of PowerGuard tiles is valued by many customers, but not by all. Customers who want to install a PV system on the roof of a building in which temperature is not controlled may not place a high value on increasing the insulation value of the roof. For those customers, a lower cost option that does not include thermal insulation is more attractive. For this reason, PowerLight has developed an alternate tile design without the XPS insulation.

Approach

At the start of this subcontract, PowerLight had completed design work on the first version of RFT10. A small system was installed in December 2004 based on this initial design. Since the start of this subcontract, the RFT10 design has been modified to accommodate a larger PV module with higher output. Several features were redesigned based on lessons learned during this installation and also to improve function or reduce cost of the parts.

Like the PowerGuard tile, the new RFT10 product is designed to install on a flat roof without penetrating the roof membrane. In order to ensure the safety of this design, it was necessary to understand the behavior of the tiles in the range of wind conditions to which installed arrays would be subjected. An extensive series of wind tests were initiated to quantify the wind performance of the product. These tests were a combination of computational fluid dynamics (CFD) modeling and wind tunnel testing. CFD modeling is a useful tool for comparing the performance of various designs without the cost of testing in a wind tunnel. Once a design has been optimized using CFD, it can be tested in the wind tunnel to verify the model predictions.

The wind performance of the RFT10 product is related to the specific weight of the array (the weight per unit area). One of the results of the wind testing was the calculation of the specific weight required to withstand various wind conditions. For areas that do not experience high velocity winds, a low array weight can be used. In higher wind zones, the array weight must be increased to ensure that the array stays in place. Each module has a wind deflector on the north side. As part of this effort, the design of the wind deflector was modified to hold concrete pavers. The number of pavers inserted into each deflector is determined by the specific weight required.

At the end of Phase I, the RFT10 design had been launched commercially. Two large commercial arrays were installed the following summer in California. Many lessons were learned during these installations, and a range of improvements were implemented in Phase II based on this experience.

The original design of RFT10 was specific to the PV module that was to be installed. Expanding the range of modules to be used with the RFT10 system resulted in a large number of parts that would have to be inventoried and tracked. The primary improvement implemented during Phase II was the creation of a universal RFT10 design

that would accommodate any PV module with a set of common parts. This required a general redesign of the support structures and PV retaining clips. During this process, many other improvements were implemented. These included the redesign of wind deflectors to reduce the number of fasteners and to allow for easier accommodation of roof contours and modifications to the support structure for north deflectors to decrease the number of different parts and to reduce cost.

Near the end of Phase II, a 1-MW system was installed using the new universal RFT10 design. This installation proved the efficacy of the many improvements that were made, leading to significant reductions in installed cost. The results of this are discussed below in Section 2.7 Commercial Demonstrations: Tasks 7 & 14.

Results

Figure 11 and Figure 12 show photos of RFT10 systems during installation and after completion.



Figure 11: Completed Phase I RFT10 installation – 654 kWp system.



Figure 12: Installed Phase II universal RFT10 system – 1MWp system.

As of the end of Phase II, PowerLight has installed over 3 MW of RFT10. The product has also been introduced to PowerLight’s network of resellers where it has been well received.

Array Securement Design

Background

For most applications, RFT10 can be installed without being fastened to the building roof. In sites that have severe wind loads, however, positive securement of the array may be required. In most cases, the weight of the system is adjusted with concrete pavers to meet the wind loads of each building site. If the wind loads are high enough that the minimum array weight required by the wind loads exceeds the number of pavers that can be accommodated, then the array requires positive securement to the roof.

When positive securement is required, the array must be able to transmit lateral load across the array to the anchor points. Additionally, some method of attaching the array to the anchor points must be provided. In order to incorporate these features into the design of the RFT10 product, PowerLight calculated the magnitude of the lateral loads under varying wind conditions. Using the results of wind tunnel tests and computational fluid dynamic modeling carried out under this project, PowerLight analyzed the loads to which the array is subjected and created a design for the securement.

Approach

Once the basic design was completed, as discussed in the previous section, PowerLight began working on additional features that would allow the system to be installed in sites at which the array needed to be positively secured.

Once the loads were understood, the first step was to create a design that allowed lateral transfer of loads from one module to another. The basic design consists of a PV module, supports, and a wind deflector, as shown in Figure 13. These components form the top two legs of a triangle. The roof forms the bottom leg of the triangle. However, when a large load is applied laterally, the supports slide on the roof, as the triangle becomes stretched across the roof. To prevent this, PowerLight added a wire rope that connects each support to the next one, preventing them from sliding apart and creating a strong triangular structure.

Once the array was capable of transferring lateral loads, PowerLight developed a design for attachment points to connect the array to an anchor on the roof. The loads on this anchor depend on the number of rows within the array. PowerLight created design guidelines to calculate the load that must be supported by the anchors.

Results

The changes to the RFT10 design are shown below. A wire rope was incorporated into the design to allow the array to transfer lateral loads, as discussed above. The wire rope and connection are shown in Figure 13 and Figure 14. At each end of the wire rope, a swaged-on ball engages a keyhole slot that is stamped into each end of each support piece.



Figure 13: Prototype parts with securement features.



Figure 14: Southern support with keyhole slot and spreader bar attachment points.

2.2.2 Tall Buildings and Mechanically Attached Roof Membranes

Objective

The objective of this subtask was to develop design guidelines for PowerGuard systems installed on tall buildings and buildings with mechanically attached roof membranes.

Background

PowerGuard is a ballasted, lightweight PV roofing system. Depending on the array geometry, a PowerGuard system may weigh 4-9 lb/ft². The array weight is far less than typical wind uplift pressures on most buildings, which can range from 20 lb/ft² to over 100 lb/ft². PowerGuard remains stable when subjected to high wind uplift pressures due to the permeability of the system, which equalizes pressures on the top and bottom surface of the tiles. While this phenomenon is well documented in the wind and roofing industries, wind tunnel testing in accordance with the American Society of Civil Engineers (ASCE) Practice No. 67 is the only recommended approach for quantifying the wind performance of a permeable roofing system.

PowerLight has conducted extensive wind tunnel testing in compliance with the ASCE standard. Prior testing was conducted on buildings with heights up to 50 ft. Due to limitations on the size of the wind tunnel selected and the ability to fabricate accurate scale models of PowerGuard systems, it is not possible to model wind loads on a PowerGuard system installed on a building taller than 55 ft. When PowerGuard systems were installed on buildings taller than 50 ft, wind tunnel data had to be extrapolated to the taller building heights. While preferable to interpolate between test data points, this method was considered acceptable for buildings up to 80 ft in height, but undesirable when extrapolating to buildings that were several hundred feet in height.

PowerGuard can be accurately modeled at a scale as low as 1:32. At this scale, a 55' tall building creates the maximum allowable blockage in the wind tunnel. When the maximum allowable blockage is exceeded, the atmospheric boundary layer will not be simulated properly, which would result in an inaccurate modeling of the flow over the wind tunnel models. Wind tunnel experts suggested that pressure measurements be taken for a model of a tall building at a smaller scale. The results could then be compared to those for low-rise buildings for which PowerGuard failure data had been collected during prior tests. One could then identify the pressure conditions on rooftops that are likely to induce a failure in PowerGuard systems on a building of any height. This approach eliminated the need to include a model of a PowerGuard system on top of a tall building.

Mechanically attached roof membranes also present a design challenge for ballasted PV roofing systems. In certain wind conditions, these membranes may billow because the membranes are secured only along the edges. Prior testing showed that if billowing occurs, the membrane may lift over 12" in height, which is substantial enough to dislodge a lightweight, ballasted roofing system. However, there is disagreement among industry experts regarding the conditions that would cause membrane billowing and the appropriate method for assessing the billowing potential of a given site. There is clear agreement that billowing potential is dependent on the following parameters: wind speed; wind gust duration; width of the membrane between fasteners; quality of the roof seal around the perimeter of the building; permeability of the building walls; geometry of openings in the building walls, such as windows and doors; permeability and geometry of the building's HVAC system; geometry of partitions within the building; and permeability of the roof deck.

If all of the above parameters could be easily quantified, a test program could be carried out over a range of parameters and applied to specific buildings. At the beginning of this project, PowerLight expected to define a test program with a consultant and launch into the testing of the various parameters, leading to the development of design guidelines for PV systems on mechanically attached membranes. The creation of the test program has been a much greater challenge than anticipated. Many of the parameters are impractical, if not impossible, to quantify on specific buildings. It is especially challenging to determine the permeability of the HVAC system, building walls and roof decks without incurring a significant expense, as well as inconveniencing the building occupants. It is possible that these parameters could be studied for a broad range of building types and then applied to specific buildings.

Despite the above challenges, PowerLight has made some important progress on this task as discussed in the sections that follow.

Wind Tunnel Pressure Measurements on Tall Buildings

Pressure measurements were measured on buildings with heights of 30', 60', 120', and 240'. Parapet heights varied from 0' to 4'.

Mean uplift pressures on the rooftop were calculated and compared to code predictions. We found that the code under-predicts uplift pressures on the rooftops of buildings over 60'. It is believed that the test results are accurate and that the code is in error. The testing used in the code data was done with older technology and was extrapolated from data measured on shorter buildings. The error in the code has apparently not resulted in failures in the field. Roof deck failures may have not occurred because the roof decks of tall buildings are designed to not only withstand wind uplift but also provide reinforcement to the building against wind drag and wind-induced oscillation. However,

the error in the code could have negative consequences for roof cladding systems, such as PowerGuard.

The data collected in this study was used to calculate a correction factor so that PowerGuard failure data collected on low-rise buildings could be extrapolated to taller buildings and account for the high uplift pressures on tall buildings. This correction factor was then used to finalize wind design guidelines for PowerGuard systems on buildings up to 240' in height.

Mechanically Attached Roof Membrane Wind Securement

At the beginning of this task, PowerLight reviewed the possible ways to assess the risks associated with installing PowerGuard and RFT10 on mechanically attached roof membranes. The choices were to either:

1. Define a method to determine the likelihood of billowing on any particular roof based on the building characteristics; or
2. Create guidelines and mitigation techniques that would provide methods for designers and installers to minimize risk without requiring extensive site investigation.

PowerLight discussed methods of accomplishing the first option with several wind testing consultants. It was clear from these discussions that a study to create a predictive model would be an inordinately expensive and time-consuming task. It was also unclear whether the outcome of the study would yield a useful solution, so this option was abandoned. PowerLight then studied the problem with roofing consultants and came up with a set of installation criteria that can be used for mechanically attached roof membranes. In some areas, such as hurricane zones, installation is not allowed, given the limitations of current technologies. In other areas, installation is allowed, but mitigation steps must be taken if no reliable air barrier has been installed below the membrane.

Results

Wind tunnel testing on tall buildings has been completed and results have been incorporated into PowerGuard design guidelines.

A set of guidelines has been created for installation of PowerGuard and RFT10 on mechanically attached membranes. They are summarized below:

PowerGuard and RFT10 arrays may be installed on a mechanically attached membrane roof, provided that the following conditions are met:

Confirmed air barrier and proper edge termination of membrane:

There are no restrictions on the installation of PowerGuard or RFT10 arrays on a mechanically attached membrane roof that has a confirmed air barrier and proper membrane edge terminations.

Lacking an air barrier, the site must not be in a hurricane-prone region

PowerGuard and RFT10 systems may not be installed on a mechanically attached roof membrane without a confirmed air barrier and proper membrane edge terminations in any location that is in a hurricane zone.

Lacking an air barrier, termination bars must be installed

In areas that are not hurricane-prone, a PowerGuard or RFT10 system can be installed on a mechanically attached roof membrane that does not have an air barrier, provided that termination bars are installed in a continuous strip around the perimeter of the array. In the case where there are separate sub-arrays, each sub-array must be surrounded by termination bars in a continuous strip.

If a site does not meet the above acceptance criteria, a PowerGuard or RFT10 array can be installed still be installed if the membrane in the area of the array is fully secured and then covered with a fully adhered membrane.

2.2.3 Alternative PV Backing Material

Background

Historically, PV vendors have used Tedlar®, a fluoropolymer manufactured by Dupont, as a backing material. Recently, some vendors have been switching their backing material from Tedlar to PET (polyethylene terephthalate, a plastic resin and form of polyester). The structural integrity of the PowerGuard tile depends in part on the adhesive bond between the XPS standoffs and the PV backing material. Extensive testing was conducted on the bond between XPS and Tedlar to ensure that a reliable bond would be maintained over the design life of the product. This testing had to be repeated in order to ensure an adequate bond to the PET backing material.

Approach

In order to accommodate this change, PowerLight evaluated different adhesives to use in the assembly process of PowerGuard tiles. An adhesive had been identified, and in November 2005, the first full scale production occurred using this new adhesive. Despite good results in test conditions, initial results in the factory did not yield the required bond strength. A variety of tests showed that the surface energy of the PET needed to be increased through the application of a corona discharge treatment. Once a procedure was implemented to apply this treatment, the bond reached the required strength and production resumed.

Results

The initial approach to find a new adhesive did not yield acceptable results. The second approach, using a modified process, yielded excellent results and also provided a lower-cost solution than the first approach would have. Once the details were worked out, a new PV preparation line was designed and implemented as part of Task 5.

2.2.4 PowerGuard Cost Reduction

Background

Excluding the PV module, the mortar coating is the most expensive component of the PowerGuard tile. In an effort to reduce product cost, PowerLight focused on reducing direct material cost for the backerboard.

Approach

PowerLight identified the following three options to reduce the cost of the mortar coating:

1. Reduce the amount of latex in the mortar - The latex in the PowerGuard coating increases flexibility, compressive strength, freeze-thaw resistance, workability of the wet mix in the production line, and the bond strength of the mortar to the extruded polystyrene (XPS) foam. PowerLight's initial estimate was that a reduction in the latex content of the mortar could result in significant annual savings at current production levels.
2. Reduce the thickness of the mortar - The standard thickness of the PowerGuard mortar is 0.24". However, the UL listing and fire rating for PowerGuard is applicable to a mortar thickness as low as 0.125". A reduction in the thickness of the mortar would also result in a substantial savings, as stated above. Possible negative affects of a reduction in thickness include reduced resistance to impact; difficulties in maintaining a thinner coating in the production line; and reduced bond strength to the XPS spacers if insufficient mortar is between the spacer and XPS backer board.
3. Evaluate alternate latex and potential latex suppliers - At the beginning of this project, PowerLight had received quotes from a latex supplier that could replace the current supplier at significant cost savings.

In order to evaluate the feasibility of these approaches, PowerLight carried out a comprehensive testing program during Phase I, which are discussed in Section 2.3.1. In Phase II, the changes were put into production. The modifications required to put the new tile design into production were primarily adjustments to the existing equipment. As part of this process, we replaced a portion of the router tools that made the cut around the perimeter for the increased coating thickness in that area. Existing tools were used to make the prototypes, but this slowed production, so new tools were ordered once the dimensions were finalized.

Extra quality checks were performed during the first production runs to ensure that the thinner coating did not affect adhesion of the spacers or finish of the completed tiles. PowerLight also implemented extra checks during shipments to confirm that the new tiles were not prone to increased damage during shipment or installation. Once these checks were completed, the tiles were put into full production.

Results

Based on the results of the reliability evaluation, PowerLight implemented process changes to adopt the reduced mortar thickness. Efforts to change the mortar composition did not yield satisfactory results. However, PowerLight was able to negotiate a lower price on the latex with the current supplier. These changes have resulted in significant cost savings.

Production of the new tile design was implemented during Phase II with very few problems. Photographs of the new tiles during production are in Figure 15 through Figure 18.



Figure15: New tile on production line.



Figure 16: Measuring coating thickness during pilot production.



Figure 17: New tiles being installed.



Figure18: New tiles installed prior to wiring.

2.3 Reliability Evaluation: Tasks 3 & 10

2.3.1 PowerGuard System Testing

Objective

PowerLight identified ten possible product improvements that would result in increased markets for PowerGuard, reduced cost, and/or improved reliability and quality. To take advantage of these benefits, the proposed product improvements needed to be researched, validated, and implemented when results are favorable.

The product improvements are summarized in Table 2. The product improvements and thermal monitoring project are then described in more detail in the following sections.

Table 2. PowerGuard Product Improvements

Item	Product Improvement	Benefit
1	Create design guidelines for mechanically attached, single-ply membrane roofs	Increase the range of approved roofing types for PowerGuard systems.
2	Update product design guidelines to address wind performance of PowerGuard when air gaps are present under the perimeter curb.	Large air gaps under the PowerGuard perimeter curb may affect wind performance. The result of this research will improve the reliability of PowerGuard systems while also ensuring that the systems are not over-designed.
3	Update product design guidelines to address wind performance of PowerGuard when installed on top of gravel-ballasted roofs.	Significant cost savings could be achieved if gravel can be left in place underneath PowerGuard systems.
4	Finalize design guidelines for a light-weight curb.	A lighter-weight curb would expand the market for PowerGuard to include roofs with a low dead-loading capacity. In addition, a lighter weight curb would save money by reducing the amount of roofing pavers used to ballast the system.
5	Reduce latex-content of the PowerGuard mortar coating	The latex is the most expensive component in the PowerGuard mortar coating. Reducing the amount of latex in the mortar would result in a significant savings.
6	Reduce mortar thickness	Reducing direct material consumption results in reduced cost of for the PowerGuard tile assembly.
7	Alternative latex	Identifying alternative latex would allow PowerLight to negotiate lower pricing with vendors.
8	Shipping Cost Reduction	Reducing system cost and site waste

Item	Product Improvement	Benefit
9	Alternative PV Backing Material Validation	Allowing the use of PET-backed modules reduces the environmental impact of producing PowerGuard tiles.
10	Validation of in-line PV attachment manufacturing process	Converting the production of PowerGuard tiles into a single continuous process will reduce cost by eliminating labor between steps.

Wind Research on Mechanically Attached Membrane Roofs

Background

Mechanically attached membrane roofs are a common roofing system on flat, commercial buildings. Because these systems offer an inexpensive way of installing white, reflective roofs without the use of adhesives that contain volatile organic compounds, mechanically attached membrane roofs are becoming increasingly more common.

Under some wind conditions and on certain types of buildings, the mechanically attached roof membrane can billow, which could compromise the structural integrity of a ballasted PV system. Past research resulted in the following conclusions:

1. Roof membrane billowing can occur on these types of roofs to the extent that light-weight ballasted PV systems could dislodge. However, it is also believed that some buildings, especially those in low wind zones and with small wall openings, never have a billowing problem.
2. In most cases, billowing occurs along the outer edges of the roof (with 25' of the edge on most buildings); however, in some cases, it could also occur in the middle of the roof.
3. Within some limits, roof membrane manufacturers, roofing consultants, and building owners are not concerned if the roof membrane billows. If the membrane is not structurally damaged, remains water tight, and does not make noise within the building, the roofing industry accepts that light to moderate billowing may occur, and the mechanical fastening of the roofing system is designed accordingly.
4. A simple and inexpensive way of quantifying building-wall and roof deck permeabilities has not been identified. Further, although abundant data for these parameters is available for residential buildings, very little published data beyond expected ranges of permeabilities is available for commercial buildings.
5. A method for determining the likelihood that membrane billowing could occur beyond "engineering estimates" has not been developed.
6. Buildings with large openings, such as roll-up doors, or buildings that could develop large openings during a wind storm, such as broken windows during a hurricane, are highly susceptible to membrane billowing. In some cases, membranes can be completely torn off the roof.
7. Wind tunnel experts did not believe that this problem could be simulated in a wind tunnel in a way that would yield useful data.

Approach

PowerLight worked on several different test plans to identify the wind conditions and building types that could cause a membrane to billow. Eventually, this proved to be unlikely to provide meaningful results. The focus was switched to looking for mitigation efforts that would not be prohibitively expensive.

Results

PowerLight constructed a roof section and installed a small section of mechanically attached roofing membrane to it. The membrane was then pressurized, and deflections were measured. An array of RFT10 modules was installed on the membrane, and the membrane was inflated repeatedly to determine the point of failure. The array proved to be much more robust than expected. However, eventually there was some yielding of the sheet metal parts.

After the first series of tests, batten bars were added across the seams of the membrane. This drastically reduced the deflection of the membrane when it was pressurized and made the deflection much more uniform. The array was not stressed in any particular location under these conditions, but it did get lifted up uniformly by the membrane.

The conclusion of the PowerLight's in-house roofing expert is that if the array has a perimeter of termination bars that prevent pressure from infiltrating the area under the array from the edges, then the array will be stable on the roof. If there are no signs of previous billowing of the roof in the area where the array is going to be installed, then the array will not experience any problems. A set of guidelines has been created and is discussed in Section 2.2.2.

Wind Research – Gaps Under the PowerGuard Perimeter Curb, Gravel Under PowerGuard Systems, and Light-weight Perimeter Curb

Background

Several questions have arisen regarding the wind performance of PowerGuard:

1. Current wind design guidelines are based on wind tunnel testing where the scale-model perimeter curb was placed on a model roof with a very flat surface so that little to no air could penetrate beneath the curb. On some buildings, the roof is not perfectly flat due to the presence of overlapping roof seams and the normal development of low and high areas on the roof surface over time. *When the curb is placed on a non-flat surface, allowing air to penetrate beneath the curb, is wind performance affected?*
2. Prior research in the wind testing industry has shown that air gaps under an array of roofing pavers reduce wind performance. On gravel-ballasted membrane roofs, a significant amount of air is trapped within the voids in the gravel. Although the effect of trapped air under the system has not been quantified for PowerGuard, gravel is typically removed from gravel-ballasted roofing systems before installing PowerGuard to ensure structural integrity in high winds. *Despite a possible reduction in wind performance, can gravel be left in place on some buildings in low wind zones and still exceed design wind conditions?*

3. The weighted PowerGuard curb sometimes exceeds the roof loading capacity of some buildings, while also necessitating the shipping and handling of large quantities of heavy roofing pavers on each project. *Is it possible to reduce the weight of the curb for some projects?*

PowerLight developed one test program to address these questions, as described below.

Approach

Wind tunnel testing was conducted on scale models of PowerGuard arrays in various configurations. First, tests were conducted on some control configurations to compare to prior results. A good match was obtained, and new configurations were tested. These configurations included: (i) the presence of gaps underneath the curb to simulate a non-flat roofing surface; (ii) the introduction of gaps underneath the entire array to simulate the presence of gravel; and (iii) a lightweight curb.

PowerGuard Wind Performance

Wind tunnel testing in Phase I showed that the wind performance of the curb could be significantly improved with a detailed treatment around the perimeter curb. Several curb design concepts yielded promising results in the wind tunnel. In Phase II, a series of prototypes were tested in the wind tunnel. Pressures were measured above and below the PowerGuard tiles to provide a relative measurement of uplift. The results of the tests were compared with the relative cost of the different designs, and the most promising design was chosen for further development. Once the design was completed, prototypes were made, and tests were conducted on water drainage to ensure that the new design did not affect the flow of rain water through the array.

Results

Results for the curb with gaps, simulating a non-flat roofing surface, showed that the wind performance is highly sensitive to the presence of gaps. Test results showed that when gaps are present under the curb, performance may be reduced or increased depending on whether a proprietary edge treatment is installed around the curb. This edge treatment was developed during these tests and increased the performance of the array beyond that of a PowerGuard system installed on a perfectly flat roof. These results show that gaps under the curb can help or hinder wind performance depending on the curb design.

A wide range of curb designs was tested in the wind tunnel. Pressure measurements were made above and below the tile in various locations to determine the total uplift force. It was quickly determined that some form of seal would improve the wind performance, but it was a challenge to find a seal that performed well in the wind tunnel and would not interfere with roof drainage.

An example test results are shown in Figure 19. The data shows pressure measurements above and below the tile. The desired result is one in which the pressures below the tile are less than the pressures above, creating a downward force. If that cannot be achieved, the goal is to minimize the magnitude of the upward force.

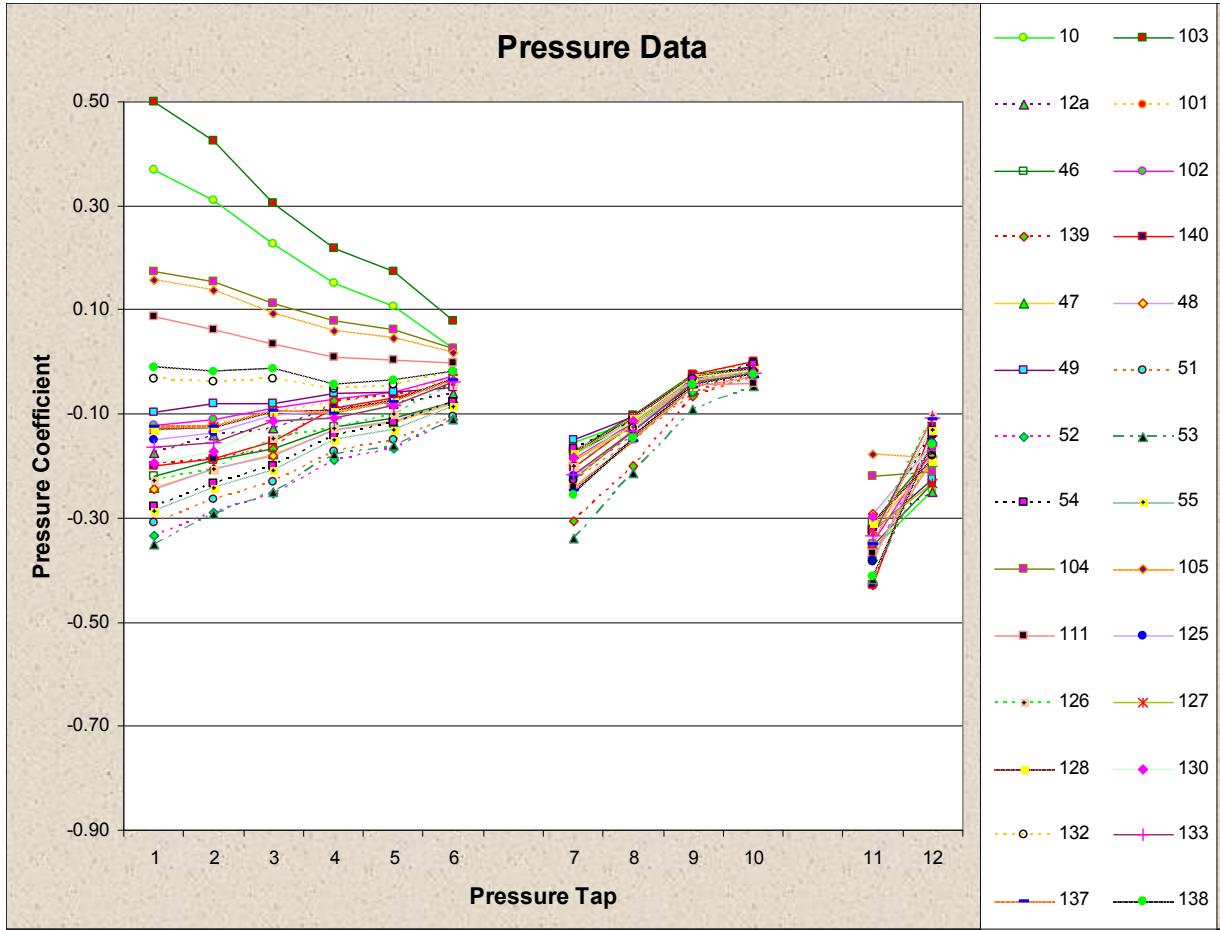


Figure 19: Example of pressure measurements from the wind tunnel.

Two rounds of wind tunnel testing were performed. Once the results were studied and compared, a seal design was chosen that held the most promise. Prototypes were assembled on the roof of PowerLight's office for drainage testing. The new curb design drained at least as well as the current design, if not slightly better. The presence of ballast pavers did not interfere with the passage of water through the drainage holes.

Results of the testing on an array installed over gravel showed that in many cases, gravel will need to be removed from underneath the array, but on buildings under 30' in a wind zone of 85 mph, gravel may be left in place.

The lightweight curb results showed that a reduced-weight curb can be used on many projects in low wind zones, provided that a perimeter treatment is used when curb gaps are present.

Mortar Research – Reduced Latex Content, Reduced Mortar Thickness, and Alternative Latex

Background

As part of the cost reduction effort in Phase I, PowerLight produced prototype backerboards with reduced latex in the mortar and reduced mortar thickness. In addition, efforts were underway to evaluate the possibility of using an alternate latex to reduce cost. PowerLight implemented a research and testing program to evaluate the feasibility of these potential changes to the PowerGuard production process.

Approach

To evaluate the reduction in latex content and the reduction in coating thickness, PowerLight performed the tests listed below on three types of samples: control samples with a standard thickness and latex content; samples with reduced latex; and samples with reduced mortar thickness.

1. Resistance to freeze-thaw cycling (based on ASTM C666)
2. Tensile bond strength of mortar to foam before and after freeze-thaw cycling
3. Shear bond strength before and after freeze-thaw cycling
4. Resistance to impact
5. Reinforcement strength of groove (control and reduced thickness only)
6. Compressive strength before and after freeze-thaw cycling (control and reduced latex only)
7. Full-scale uplift test (reduced thickness only)

Results

Table 3 shows the pass/fail results of the mortar testing. The impact and compressive strength of the samples with reduced latex content were determined to be unsatisfactory. However, the performance of the reduced mortar thickness samples in all tests was found to be adequate. The cost savings afforded by this design change are substantial, so this improvement was immediately incorporated into the production line.

Table 3: Mortar testing results

Item	Test	Reduced Latex	Reduced Mortar Thickness
1	Freeze-thaw resistance	N/A*	Pass
2	Tensile strength	Pass	Pass
3	Shear strength	Pass	Pass
4	Impact resistance	Fail	Pass
5	Reinforcement strength of XPS groove	Pass	Pass
6	Compressive strength	Fail	N/A
7	Full scale tile uplift	N/A*	Pass

*Tests were not completed due to failure of impact resistance and tile uplift tests.

Shipping Cost Reduction

Background

As part of Task 6 of this subcontract, PowerLight had the goal of reducing shipping costs and site waste by at least 20%. In order to accomplish this, PowerLight changed the height of the stacks of PowerGuard tiles from 12 tiles to 15. The details of this effort are discussed under Section 2.6.2 Waste Stream Reduction.

This change in stack height increases the loads applied to the tiles at the bottom of the stack during shipping. Prior to implementing this change in production, we implemented a shipping test with the increased stack height to determine impact on product reliability due to shipping damage.

Approach

In the shipping tests, control pallets with a standard number of tiles were shipped alongside pallets with an increased number of tiles. Standard shipping practices were followed. A datalogger capable of measuring shock was placed in a pallet to record accelerations in three directions. Tiles were inspected before and after shipping. The acceleration data was analyzed to determine the loads to which the tiles were subjected.

Once the change was implemented in production, PowerLight planned to inspect the pallets of tiles as they were unloaded at job sites during the first months after the process change. This approach would provide feedback from a much larger sample size.

Results

No damage was found during the first round of shipping tests, so the change was put into production. There were six reported instances of damage reported during the first few shipments. PowerLight engineers conducted a second round of testing with accelerometers and found that the loads applied to the tile could be greater during handling with a forklift than those measured during shipment by truck. Field crews were instructed to avoid sudden bumps with the taller stacks. At the same time, PowerLight had been working on reducing the thickness of the mortar coating on the PowerGuard backerboards. This change was implemented while these initial shipments were taking place. The change in mortar thickness results in a lighter tile. When the lighter weight tiles were put into production, no more shipping damage was observed. PowerLight continues to inspect shipments periodically to ensure that no damage is occurring; many thousands of tiles have been shipped with the increased stack height without any problems.

Alternative PV Backing Material Validation

Background

As discussed in Section 2.2.3, PowerLight modified the manufacturing process for PowerGuard tiles to accommodate new backing material being used on PV modules by some suppliers. An extensive validation program was implemented to verify structural integrity of the PowerGuard tiles made with this new process.

Approach

Much of this testing was done in conjunction with a search for new adhesives and process changes that would provide an adequate bond to the PET. Initial tests were

carried out on a variety of samples, and when a promising material was found, it was subjected to a full range of tests.

In this test, samples consisting of PET-backed modules adhered to XPS standoffs were fabricated. Unconditioned samples were used as controls, and some samples were conditioned in a temperature cycling test, humidity-freeze test, and water-immersion test. All conditioning tests are based on UL 1703 and IEC 61215 tests.

Alternative PV Backing Material Validation

During Phase I of this project, testing was conducted on the bond between XPS and PET. The results of testing in Phase I showed that a highly reliable adhesive bond can be achieved when using a corona-discharge treatment on the backskin before applying the adhesive. Initial testing has shown that the surface preparation does not do any damage to the backing material. However, PowerLight determined that a more rigorous testing program would be beneficial. Testing was to involve wet high-potential testing and I/V curve measurements of modules before and after the surface preparation process. The testing would be performed on a set of modules before and after the surface treatment was done to the backskin.

Results

PowerLight completed testing on small-scale samples with the chosen adhesives. Once the testing was completed on small-scale samples, full-scale tiles were made with the new adhesive. Initial tests showed good results using a reactive hot-melt adhesive, but when it was implemented on full-scale tiles, the results were not acceptable. Modifications were then made to the adhesive process wherein the PET material was treated with a corona-discharge probe prior to being adhered to the spacers of the PowerGuard backerboard. The addition of this process allowed the use of a lower-cost adhesive. Once this change was made, we had good results both in the lab and in the factory.

Because of this change to the adhesion process, we expanded the testing plan to include some testing of the PV modules to ensure that the corona-treatment process did not damage the backskin. PowerLight conducted testing of the electrical resistance of the backskin of several modules before and after corona treatment. The resistance was within specifications before and after treatment.

After subjecting modules to the surface treatment process required for PET-backed modules, the electrical resistance of the backskin material was tested while immersing PV modules in water. The results showed that the insulating properties were within specification both before and after the treatment. This was sufficient to determine that the surface treatment did not pose any reliability risk.

Validation of In-Line PV Attachment Manufacturing Process

Background

As part of the ongoing effort to remove any non-value added activity from the manufacturing process for PowerGuard, PowerLight investigated combining the two parts of PowerGuard production into one continuous operation. Currently, the backerboards are made and then stacked for curing of the cementitious coating. Once the coating is cured, the PowerGuard tiles are assembled with the PV laminates and

packaged for shipment. The next goal in improving the manufacturing process is to add the PV laminates during the coating process so that once the coating is cured; the tiles are ready to be packaged for shipment. This approach eliminates the labor involved with stacking and unstacking the tiles between operations. It also reduces the floor space required for the manufacturing process and reduce opportunities for damaging work-in-process.

To ensure that this change does not negatively affect the bond between the XPS spacer and mortar, testing was conducted on tiles made in a batch process and compared to tiles made during pilot runs of the inline PV attachment process.

Approach

Testing consisted of a destructive tensile test on the tiles to ensure the tiles can meet an uplift requirement of 50 lbs per square foot (psf). The test setup is shown in Figure 20.



Figure 20: Tensile test of PowerGuard tile made with continuous process.

Results

PowerLight conducted a series of pilot runs to determine the feasibility of the continuous manufacturing process. Samples were taken from these pilot runs and tested in PowerLight's testing facility. The initial results showed a slight decrease in bond strength. However, the results also indicated that the load may have been applied unevenly during the testing. The test apparatus will be improved for the next round of developmental tests. Based on the results, the manufacturing engineers began looking into alternate methods of handling the tiles during the continuous process so that there would be no disturbance of the bond.

2.3.2 PowerLight Metal Roof System

Objective

The PowerLight Metal Roof System (RMR) is a PV mounting system for metal roofs that does not require penetrations through the roofing. Two engineering requirements must be met with this design: (1) the structural components must withstand all environmental forces such as wind, seismic, and gravity; and (2) all accessible conductive parts of the array must be grounded according to the National Electric Code (NEC) requirements.

The objective of this task was to ensure that RMR designs, which vary to accommodate different PV frames, meet these engineering requirements. The approach used to investigate these issues and the results of work performed are summarized below.

Approach

Grounding Tests

UL 1703 specifies that the resistance between accessible conductive components in a PV system cannot exceed 0.1 Ohms. PowerLight evaluated the clip assemblies to ensure that the resistance was below this value. In this test, leads of a highly sensitive milli-ohmmeter are connected to two adjacent PV frames to measure the resistance across the clip assembly, as shown in Figure 21

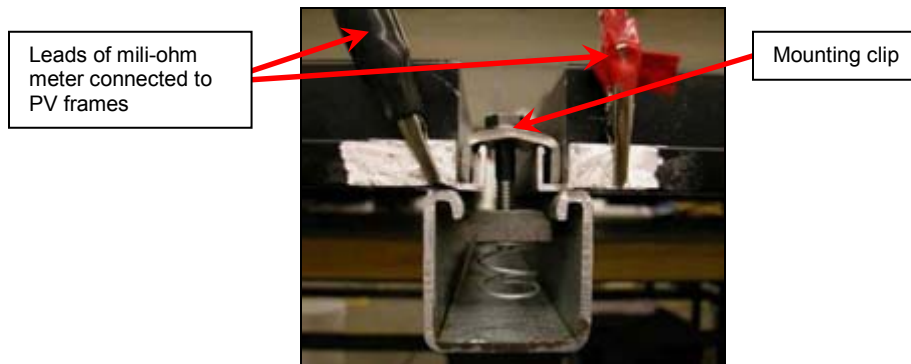


Figure 21: Ground testing of mounting clip and frames.

Uplift Resistance Tests

UL requires that PV modules pass a loading test where 45 psf is applied to the module surface. Permeable PV roofing systems typically have excellent pressure equalization, resulting in lower wind loads on the module. PowerLight tested the IFF and EFF clips in a tensile test, as shown in Figure 22. A vertical load was slowly applied until failure occurred, and the load causing failure was recorded and compared to the UL requirement.

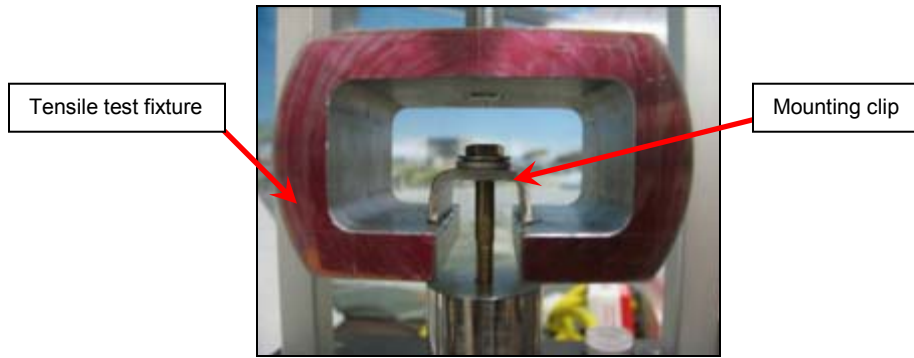


Figure 22: Mounting clip uplift test.

Lateral Load Testing

For most PV systems on a metal roof, wind and gravity loads create a negligible lateral load on the mounting system. However, the design must be able to withstand seismic loads.

PowerLight used International Building Code (IBC) guidelines to calculate expected lateral loads on the PV array in a severe seismic event. Then a lateral loading test was conducted to determine if the assembly could withstand the predicted load. A photo of the test setup is shown in Figure 23.

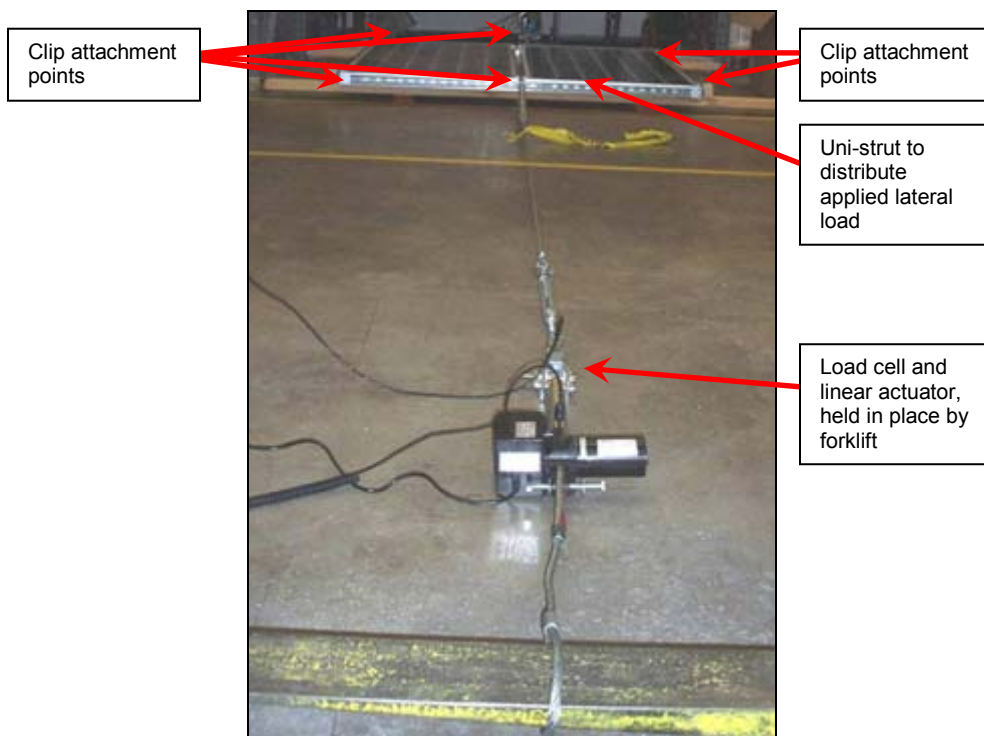


Figure 23: Lateral load test on RMR mounting clip.

Results

The clip assemblies passed the grounding, uplift, and lateral load tests. PowerLight obtained UL listing for these assemblies following evaluation.

2.3.3 PowerLight RFT10 System

Objective

The purpose of this task was to:

- Conduct wind tunnel testing to evaluate the sensitivity of the RFT10 product to building height, parapet height, and array orientation;
- Create wind design tools to be used to determine the securement requirements for various wind conditions;
- Conduct full-scale load testing on the RFT10 product to ensure that expected wind loads will not cause structural damage to components;
- Conduct ground testing to ensure that all accessible conductive parts are adequately bonded to a common earth ground;
- Conduct seismic testing and analyses to verify that the RFT10 assembly can withstand typical seismic events; and
- Test product changes

Background

Prior to the start of this subcontract, preliminary wind tunnel testing on RFT10 had been completed for a limited set of conditions. The test results showed the behavior of RFT10 in these conditions, but further testing was required to quantify the wind performance in a range of site conditions in which RFT10 is likely to be installed. In particular, the effect of tall buildings, varying parapet height, and high wind zones needed to be determined.

Wind tunnel testing was conducted on 1:32 scale models of RFT10 tiles. At this scale, the rigidity of the interconnect joints may deviate from the full-scale product. The RFT10 interconnects have some flexibility in the vertical and horizontal directions. Preliminary wind testing showed that the mode of failure for RFT10 arrays is usually by array sliding and, in some cases, by lifting in the edge and corner regions of the roof. To address these issues, testing on full-scale tiles in the laboratory was conducted to evaluate the structural integrity of the array during simulated sliding and uplift wind failure conditions.

RFT10 systems have accessible conductive components throughout the field of the array. Each conductive component must be bonded to a common earth ground according to NEC. Grounding tests were conducted internally to ensure an adequate ground was achieved. Additionally, PowerLight obtained UL listing for the grounding clips for two types of PV modules (EFF and IFF), following evaluation.

Experience with PowerGuard projects has shown that for sites in moderate to severe seismic zones, comprehensive documentation demonstrates to building officials that ballasted PV roofing systems with no mechanical fastening to the building structure will remain safe during and after a seismic event. PowerLight hired a seismic modeling consultant to predict the behavior of an array of RFT10 during a severe seismic event. The goal of the testing and analysis was first to document the ability for the RFT10 interconnects to withstand seismic forces, and second to analytically study the array's response to various seismic events and building types.

Approach

Wind Testing and Wind Design Tools

A scale model of the RFT10 array was fabricated. For these tests, the following parameters were varied: building height, parapet heights, array position, and array weight. The friction coefficient between the model array and model building was adjusted to represent worst-case field conditions such as a slippery single-ply roof membrane.

For each test configuration, the array was set up on the model building, and the wind speed in the tunnel was slowly increased until failure occurred. In some cases, failure occurred due to tile lifting around the edges of the array, and, in others, the entire model array slid on the roof surface. Figure 24 shows a typical test configuration.



Figure 24: Wind tunnel model for an RFT10 array installed on the edge of a building.

Wind tunnel data was used to create design charts for RFT10 systems. The charts show the type of securement needed for various building heights, local design wind speeds, and type of surrounding terrain.

Structural Testing

Four types of structural loading tests were performed on RFT10 assemblies. First, a lateral compressive load in the north-south direction was applied to a RFT10, as shown in Figure 25. The force was applied at the north end of the tile, while the south end was restrained. The purpose of the test was to simulate a strong wind hitting the north end of the array, causing the first row of tiles to be pushed into the interior sections of array. The force was increased until some part of the structure yielded. The force and displacement were then measured.



Figure 25: Lateral load test on RFT10 assembly. A compressive load is applied to the north side of the tile.

In a second test, a lateral compressive load was applied to the east side of a tile with the west side restrained. This configuration simulated a wind load hitting the outer eastern edge of the array. As before, the force was increased until some part of the structure yielded. The force and displacement were measured. A photo of the test set up is shown in Figure 26.



Figure 26: Lateral load test on an RFT10 assembly. A tensile load is applied to the east side of the assembly.

The third test simulated wind uplift failure. The purpose of this test was to ensure that the retaining clips were sufficiently strong to keep the PV module from being pulled loose under the most severe uplift loads that might be encountered. A photo of the test set up is shown in Figure 27.



Figure 27: Uplift test on RFT10 tiles with vertical force is applied to the center tile.

The strength of the PV mounting clips in the RFT10 assembly was evaluated in a loading test based on UL1703 and IEC 61215. In this test, 50 psf was applied to the module and clips.

Grounding Test

The RFT10 assembly has many accessible conductive components that must maintain a reliable bond to earth ground. A test was conducted to verify that the resistance across the assembly was below an industry-established maximum of 0.1 Ohms. A photo of the test set up is shown in Figure 28.



Figure 28: Grounding test on an RFT10 assembly.

Seismic Testing

The goal of the testing and analysis was first to document the ability for the RFT10 interconnects to withstand seismic forces, and second to analytically study the array's response to various seismic events and building types.

First, friction coefficients between the assembly and various roofing surfaces were measured. A horizontal load was applied evenly to the sides of three tiles until motion occurred. The load causing motion was automatically captured by the data collection system and used to calculate the friction coefficient on a membrane roof. A photo of the test set up is shown in Figure 29. A typical low value was chosen for further evaluation of system performance in a seismic event.

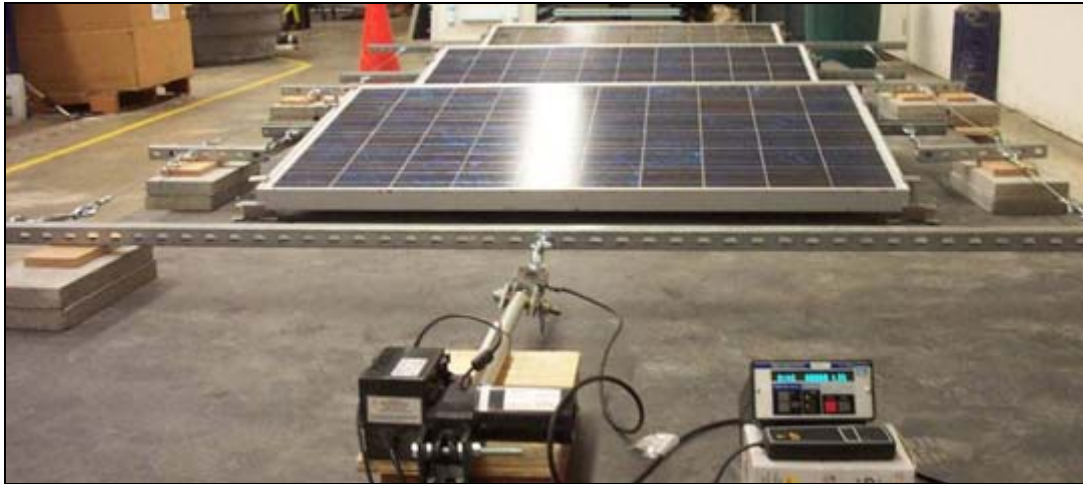


Figure 29: Friction test on an RFT10 assembly.

Once the friction coefficient had been measured, the seismic modeling consultant began the analysis to determine the loads that would be applied to the RFT10 product during a seismic event. This analysis takes into account: (i) the friction coefficient between the PV system and the roof; (ii) variations in building flexibility and local soil conditions; and (iii) several types of earthquakes.

Product Changes

During Phase II, several changes were made to the design of the RFT-10 product in order to accommodate a wide range of PV modules. Testing was done on the design of the retaining clips and the locating features for the PV modules. In the previous design, the locating features contacted the interior edges of the module frames, but on the new design, the locating features contact the outside edges. A test was conducted to ensure that the lateral load carrying capability was not diminished.

Figure 30 shows the test setup for measuring the lateral load transfer ability of the new design. This same setup was used in carrying out a similar test on the previous design. The goal was to make sure that the failure load was at least as high as it was with the previous design. In this case, the test had to be performed several times because the test apparatus kept failing without bringing about a failure of the unit under test. The new design proved to be much more robust than the old design. In the old design, under extreme loads, the support for the top of the wind deflector would rotate and then lose contact. The support for the wind deflector in the new design cannot rotate in the same

way, so this failure mode has been eliminated. The actual failure load was not determined because the PV module itself failed before the mounting system failed. This was considered a very successful result.



Figure 30: Lateral load test on RFT10 universal design.

Results

Wind Testing and Wind Design Tools

The wind tunnel test results provided a failure velocity and failure mode for each configuration that was tested. A safety factor was applied to all failure velocities. PowerLight reviewed the results extensively to identify worst-case conditions and to identify the dominant trends in the data. The results were then incorporated into a series of charts to be used as guidelines for array design.

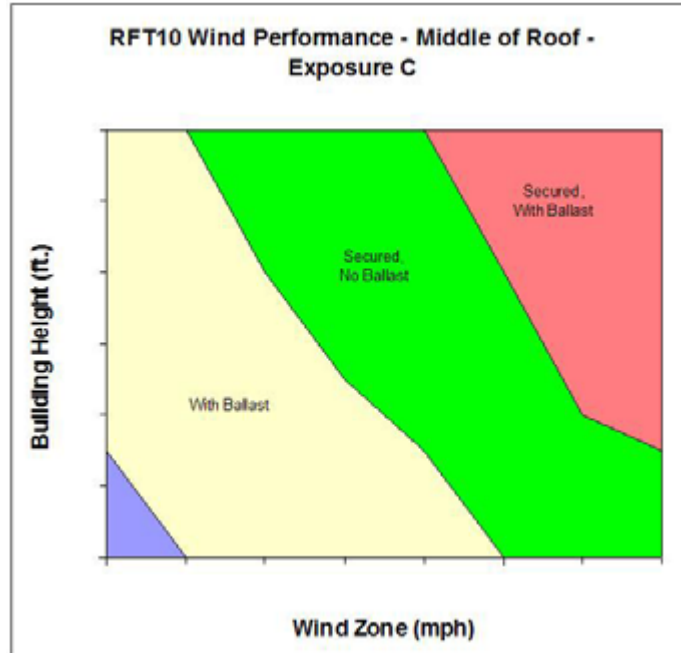


Figure 31: Wind design chart for RFT10 arrays in the middle of the roof in Exposure C.

A sample chart for the middle roof position, Exposure C terrain is shown in Figure 31. To use this chart, the designer first determines the building height, , type of surrounding terrain (Exposure A, B, C, or D), and the 3-second gust design wind speed for the location as defined by ASCE. Additional charts were generated for edge and corner locations on roof. The designer can then determine which level of securement is needed for the particular system. The securement types are defined as follows:

1. No ballast: the system may be installed without any additional ballast or securement.
2. With ballast: additional weight needs to be installed.
3. No ballast, with securement: perimeter penetrations need to be installed.
4. With ballast and securement: additional weight and perimeter penetrations need to be installed.

With the launch of the universal design, the wind design charts were replaced with an interactive spreadsheet-based wind performance calculator. This provides the required array weight and ballast (if needed) for the site conditions that are entered into the spreadsheet.

Structural Testing

The wind tunnel test results discussed above show that for sites in high wind zones, the array must be secured to the building. In these cases, anchor points will be placed around the perimeter of the array. The lateral load testing showed that under these conditions, the structure of the array must be augmented so that lateral loads can be transmitted through the array without deforming the individual structural elements. This additional structure is needed only for the north-south direction. In the east-west direction, the standard structure is sufficiently strong to transmit the loads. PowerLight

designed a connector that will tie each support piece to the adjacent north and south support, as discussed in Section 2.2.1. This will be used only in sites where positive securement of the array is required.

Ground Testing

Results of the grounding tests indicated that the RFT10 assembly meets all safety requirements. A UL listing for the RFT10 clips was obtained, as stated above.

Seismic Testing

The friction test results were provided to the seismic modeling consultants, who used the data to complete their model of RFT10 behavior. The model predicts the maximum displacement of the array in a severe seismic event. The model showed that the maximum displacement of the array in a severe event was less than the standard offset from the array to the edge of the roof. Thus, with the standard offset, no section of the array will become dislodged during seismic activity based on the current model. This ensures that the array does not pose any threat to public safety.

2.3.4 ICC Certification

Background

At the inception of this project, PowerLight planned to obtain an Evaluation Report (ER) from the International Code Council (ICC), with the goal of streamlining the permitting process.

An ICC-ER for PowerLight's ballasted PV roofing products would demonstrate that the products comply with the International Building Code (IBC), including sections pertaining to fire safety, structural integrity, long-term durability, and wind safety. These concerns are among the most commonly raised questions from building inspectors.

Approach

PowerLight completed an extensive test program for all roof products, as discussed above, and initiated communications with ICC. An application package was submitted with engineering drawings, installation guidelines, and a sample Evaluation Report as requested by ICC.

PowerLight's expectation was that ICC would respond with a list of documentation and testing requirements, and that the test requirements could be easily met.

Results

On further evaluation, PowerLight determined that pursuing ICC certification would provide little additional value to the end customer. The expected benefit of having an ICC-ER is to facilitate permitting, and PowerLight has found that this is no longer needed. Recently, questions from building officials during the permitting stage have decreased drastically. There are two reasons for this change: (1) the quality and comprehensiveness of PowerLight's submittals to building departments have improved significantly through continuous improvements based on feedback received from building inspectors; and (2) PowerLight's portfolio of successfully completed projects has increased, bringing a new level of assurance to building officials. In many cases, the building departments have worked on prior PowerLight projects and, therefore, are more familiar with the technology.

In addition, ICC responded with a list of testing and documentation requirements, including documentation of wind resistance. Initially, this did not appear to present a challenge. However, more in-depth discussions with ICC revealed that because the wind testing of PowerLight's products were not performed in an ICC accredited laboratory, the wind testing would need to be repeated under the supervision of ICC staff. PowerLight estimated that this would cost an additional \$100,000 for the ICC wind requirement alone. This additional cost combined with the lack of need to facilitate permitting has led PowerLight to decide not to pursue an ICC certification at this time.

2.4 Quality System Improvements: Tasks 4 & 11

The objective of this task was to implement a supplier quality assurance program with the goal of achieving a 99% first-time acceptance of select supplied products and/or services. In Phase I, PowerLight established a supplier quality program for PV suppliers. In Phase II, PowerLight worked to enhance PV supplier quality by establishing accurate performance expectations and auditing procedures for PV manufacturing facilities.

Background

For PowerGuard, all tile components pass through PowerLight's factory. PowerLight has the opportunity to inspect all incoming material. However, such inspections are clearly non-value added activities. It is far more efficient to establish quality systems at PowerLight's suppliers to make sure that non-conforming material never leaves the supplier.

For products other than PowerGuard, all materials are shipped directly to the job site. For these products, it is vital that PowerLight's suppliers maintain adequate quality assurance systems to ensure that non-conforming material is not sent to the job site. Defects in the field result in much higher costs than those found in the PowerLight factory or during fabrication. As such, PowerLight's supply chain department creates partnerships with suppliers to establish quality systems that will be effective in minimizing and detecting non-conforming material before it is shipped. To accomplish this, a supplier quality standard is needed.

PowerLight maintains a technology neutral position concerning PV module supply. This means PowerLight procures PV material from a variety of suppliers in order to diversify supply and to drive competitive evolution of the corresponding technologies. Because each PV supplier presents the technical descriptions and expectations of their products differently, PowerLight has sought to normalize the supplier data, so that different PV products can be valued using the same metrics. One of the most important specifications for PV modules in this respect is the peak Watt (Wp) power rating at Standard Test Conditions (STC). This value dictates the base performance expectations of the module under normalized operating conditions and is the basis for our energy simulations and customer expectations.

Approach

Historically, PowerLight's most costly quality issues have been related to PV modules. Therefore, PowerLight primarily concentrated quality efforts on the PV suppliers. PowerLight worked with PV suppliers and independent testing facilities to establish meaningful and quantifiable quality metrics for PV modules. This appeared to be a straightforward undertaking at the outset. However, it quickly became much more

complex. For example, discrepancies exist in test results from one test lab to another, further complicating this effort. In conjunction with work being done under Task 1 and 8 to improve system performance, PowerLight embarked on a program to quantify the variations in testing results and to create a consistent method for quantifying PV output.

PowerLight became aware of the magnitude of testing discrepancies when comparing the output of suppliers' flash testers with that of independent third-party testing labs. A group of PV modules were tested by a supplier and then sent to an independent testing lab where they were fully characterized. The flash test results provided an indication of the variation in calibration between the different testers but did not establish a benchmark.

PowerLight established a quality standard that defined an initial qualification technique to be used with each supplier. In conjunction with the independent testing lab, PowerLight created a testing protocol that benchmarks module performance in a way that provides an accurate prediction of system performance. Each manufacturer will send representative samples to this lab for this benchmark testing along with their flash test results. This method will provide a comparison between that manufacturer's flash test data and predicted system performance.

For ongoing quality control, each supplier is required to supply flash test data from each module. These data are adjusted based on the stored comparison between the manufacturer's flash tester and the benchmark test. The results can then be used to ensure that the supplier's modules meet PowerLight's specification and that the installed systems will perform as expected.

The method used to establish a nameplate rating varies from one supplier to another. Without a clear understanding of the method used by each supplier, it is difficult to predict the output of a module or entire system with much accuracy. Some suppliers have a wide tolerance on the output of modules within each nameplate rating, while others apply much tighter tolerances. UL standards allow for up to a +/-10% deviation from the stated nameplate. Some companies employ significantly more stringent standards. For example, one manufacturer uses a tolerance of -0/+10% of the nameplate rating. As such, the actual delivered power for any given shipment of PV can vary from supplier to supplier due to the unique yield tolerances employed by the various suppliers. A key facet of our quality assurance system is a catalogue of how the actual delivered power from any particular manufacturer relates to module nameplate rating.

PowerLight starts its quality process with a visit to the manufacturing facility of each PV module supplier prior to purchasing any product. During this visit, PowerLight conducts a detailed investigation of the manufacturing line and quality processes. Of critical importance is the system that the manufacturer uses to characterize the output performance of the PV modules.

PowerLight references the IEC 61215 standard as a requirement for flash test protocol. This is the only published standard that fully defines a calibration protocol, and it is often part of the supplier's certification and qualification program. The IEC standard requires that flash testers be calibrated at least once per day and that the calibration module used is traceable to a third-party calibration lab with corresponding certificate. PowerLight's visit to the facility includes an audit of this station to confirm that a proper calibration program is in place. PowerLight also verifies that a logbook is kept, showing

the calibration time and identifying the reference module. Using this as a benchmark is consistent with industry standards and does not require our suppliers to cater to a custom specification, which could ultimately increase costs.

PowerLight ensures that the flash test is conducted on the complete and final product. Many manufacturers actually test the modules prior to attaching the frame or connecting wires. In some cases, a problem with final processing steps can damage or otherwise compromise the output of the modules after the flash test has been conducted. PowerLight requires that all testing be performed through the interconnection lead wires with the connectors attached. In this way, the test can also capture problems with the junction box, wires, and connectors prior to release.

Flash data is collected by production run and shipment. PowerLight's PV supply contracts stipulate that there must be an opportunity for PowerLight to review the flash data from any particular shipment prior to accepting that shipment. Upon PowerLight's review and approval of the data, a shipment is released. The review process serves two purposes. First, it provides an outgoing inspection of the material to confirm that the average power of the modules coming off the production line is indeed being met. PowerLight reserves the right, in most cases, to periodically visit the manufacturing facility to inspect the calibration records in order to confirm that the data is accurate. Second, it allows PowerLight to adjust system performance predictions if the average delivered power rating deviates from the nominal nameplate expectation. As suppliers become more and more conservative with their module ratings, some have shown a tendency to over-deliver. If the power overages are consistent over time, PowerLight will update the modeling assumptions and value of the product accordingly.

PowerLight uses extensive computer modeling to predict system performance, which is then communicated to the customer. It is imperative that PowerLight provide accurate data for the simulation software as the customer expectations are based on these numbers.

A typical flash test report is organized to facilitate data sorting by module serial number, manufacturing date, ship date, etc., as well as performance characteristics. PowerLight catalogs this data for every PV module purchased for use in our systems. This database allows us to monitor PV performance expectations over time and adjust our assumptions accordingly.

Results

PV module quality is an important factor in the optimization of system performance. The ability to accurately predict system performance requires an accurate rating system, consistent adherence to that rating system by the PV module manufacturers, and assurances that adequate quality control is in place at the supplier's manufacturing facility. PowerLight has implemented a system to ensure consistent module quality with specific attention to output power rating. Additionally, PowerLight has worked to understand and catalog the variations in module rating and testing that exist within the various suppliers. These programs will help PowerLight to achieve the goal of improved system performance under this subcontract.

PV Specification Package – PowerLight has set up long-term supply agreements with key PV suppliers. These agreements detail product expectations beyond what is typically called out in manufacturing cut sheets and specifications. These agreements include specific detail on delivered power requirements. Powerlight insists that the

average power output of the modules in a given shipment are at or above the nameplate rating of the modules. This avoids the uncertainty associated with the manufacturing tolerance on output power. Warranty, certification, packaging, and inspection requirements are also included in these supply agreements. Further quality assurance protocol has been established to ensure that modules are adequately characterized to ensure accurate performance modeling and maximized system performance.

Manufacturing Facility Audits/Visits – PowerLight visits all the manufacturing facilities from which we order PV prior to placing our first order. During this initial visit we review the overall production process and quality protocols. Most facilities are ISO 9000 registered which covers most concerns regarding material traceability. We also verify general conformance to industry standard practices. At this time, our audit form is based on ISO 9000 quality standards. This form is completed, and any areas on non-compliance are reported back to the supplier. These items are usually negotiated with each manufacturer depending on their relative importance to the products we are ordering. As stated above, PowerLight has also trained suppliers whose quality systems have been found to be inadequate.

Source Inspections – PowerLight contracts with local inspection companies to conduct periodic source inspection of outgoing material from the manufacturing facilities. This approach allows us to discontinue incoming material inspections. In so doing, we can ship PV directly to the installation site without warehousing the material.

PowerLight's quality standard for PV modules is currently the most advanced in use by the PV industry. This will benefit PowerLight by ensuring that our installed systems perform at maximum output and satisfy our customers' expectations. Additionally, this standard will provide an example for the industry to follow, benefiting all PV manufacturers, installers, and customers, and leading to improved system performance throughout the industry.

2.5 Manufacturing Improvements: Tasks 5 & 12

The objective of this task is to implement lean-manufacturing techniques in order to maximize yield, improve cost, reduce labor, and reduce inventory levels. The targeted goals of this task include the development of manufacturing tools capable of reducing the labor required to manufacture PowerGuard tiles by 30%, increasing manufacturing yield to 99.9%, and increasing inventory turns to at least eight per year.

2.5.1 Manufacturing Yield Improvement

Background

Over the past several years, PowerLight has been implementing lean manufacturing concepts in the production of PowerGuard. This process is being continued under the current subcontract.

One of the main goals of lean manufacturing is the elimination of waste. Processes for which the customer is not willing to pay are identified as non-value added (NVA) processes. Inspection of parts is an example of one NVA process. Pull manufacturing is another key concept in lean manufacturing. Upstream stations in a manufacturing process only make product when the next station downstream requires them. This method minimizes the amount of work-in-process, which helps to keep costs low and minimizes the risk of damaging parts between stations. Excess handling is eliminated in

the ideal setup, and all inspection is replaced by error-proofing where parts are made so that they can only be assembled the correct way. Waste can also be eliminated through the application of the 5-S principles, as follows:

- *Seiri* (Organization) or Sort- eliminate unnecessary items
- *Seiton* (Order) or Set in order- storage system & layout, provide for easy access
- *Seiso* (Cleanliness) or Shine
- *Seiketsu* (Neatness) or Standardize- continue the first three S's all the time
- *Shitsuke* (Discipline) or Sustain – develop these into a constant habit – this is the most important

Many of these lean concepts are implemented through *kaizen* events. During a *kaizen* event, the workers are asked to create a solution to a particular manufacturing challenge. The challenge can be organization of tools, layout of the workspace, layout of the workflow, improvements in ergonomics, or anything else that affects worker productivity, product quality, product cost, or safety. By involving the workers in the process of continuous improvement, they gain a sense of ownership for the product and the process, and they can be a source of good ideas since they are involved in the manufacturing process every day.

Approach

Improvements in yield were pursued primarily in two areas. The final assembly process has been labor intensive and prone to variable results. By automating portions of this section of the manufacturing line, labor costs could be reduced, yield could be improved, and manufacturing capacity could be increased. The first areas to be automated were the cleaning of the PV modules and the application of a surface treatment process for PET-backed modules prior to assembly into PowerGuard tiles. While the previous process did not produce a large number of rejects, there was no mechanism in place to ensure that these two steps are being carried out properly or to detect rejects. Machinery was specified that would produce consistent, adequate results for these steps.

The second area where yield improvement was pursued was in the mixing of the ingredients for the cementitious coating. Different liquids are mixed together, and then this mixture is combined with dry ingredients to create the coating. In Phase I, the mixing of the liquids with the dry ingredients was improved through the implementation of a new liquid pumping system, which would deliver a preset flow rate to match the flow rate of the dry ingredients. This modification was expected to improve the quality of the coating, as well as reduce the labor requirement by decreasing the amount of monitoring required to operate the coating process.

In Phase II, the focus of improvements was the next process upstream, which is the metering and mixing of the various liquids prior to the addition of the dry ingredients. The existing equipment used a set of peristaltic pumps to meter liquids into a batch barrel. Flow meters in each line provided a feedback signal to the system controller to ensure that the liquids were pumped at the desired rate. A secondary pump and flow meter system measures the liquid delivery to the final mixing machinery.

The existing pumping and metering systems provided accurate, automated fluid delivery as long as the flow meters were kept properly calibrated. The calibration process is time consuming and difficult to perform accurately. The pumps were also subject to frequent wear and maintenance needs.

A data collection system was installed as part of the Phase I improvements to monitor two critical ratios in the mixing process. These are the ratios of water to cement and polymer to cement. It is important to keep these two ratios within a predetermined range to ensure that the coating will have adequate long-term weather resistance and adhesion. The data collection system worked properly, but it required someone to manually download and catalog the data from each coating batch. It proved difficult to ensure that someone remembered to download and catalog the data each day.

The new system replaced the liquid flow meters with a metering system that relies entirely on mass measurement. This system is very robust. The scales used are unlikely to go out of calibration, and the periodic calibration check is very fast and easy to perform. The data collection and storage system has also been improved so that storage of data from each batch is completely automatic.

Downstream of the mixing system, the distribution hopper spreads the coating onto the foam boards that will become the base of PowerGuard tiles. The hopper required frequent monitoring and adjustment to maintain the proper material level and flow. In order to reduce labor and improve consistency, the new system includes an automated hopper level control. This reduces the labor required for the coating process. The person who was monitoring the hopper was moved to the spacer placement station. The hopper must be monitored for a short period during startup, and then it maintains the proper level for the rest of the run.

Results

The greatest impact on the measured yield of PowerGuard tiles was achieved through the implementation of the error-proofed mixing systems. Two parameters are monitored as primary indicators of coating quality: the polymer-to-cement ratio and the water-to-cement ratio. The new monitoring system collects data on material flow and calculates these parameters in real time. A plot of these parameters is then stored for each day of production, providing traceable information for each lot of PowerGuard backerboards made. Figure 32 shows a typical plot from one production run. A solid line is displayed above and below each parameter plot showing the acceptable range for that parameter. The system is programmed to start collecting data when the flow rate exceeds a threshold level. This produces the slight scatter of outlying points each time the system starts and stops.

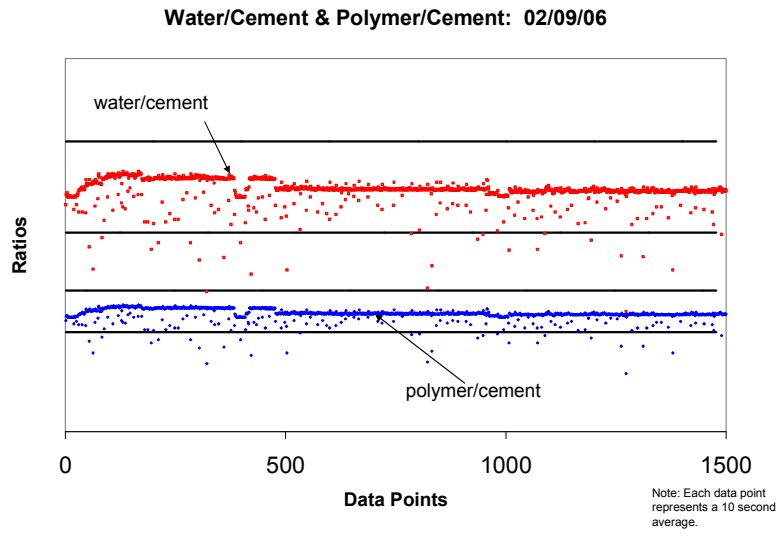


Figure 32: Typical plot from coating monitoring station.

Figure 33 through Figure 36 show the new mixed liquid pumping station that was implemented in Phase I.



Figure 33: New pumping station for mixed liquids.



Figure 34: Control panel for pumping station.



Figure 35: New liquid metering system.



Figure 36: Transfer pumps.

The improvements made to the coating process have resulted in reduced labor requirement and a more consistent process. Yield for the PowerGuard production process has been improved dramatically. Out of nearly 33,000 units, there were only four rejects, giving a yield of 99.99%. This demonstrates the value of the improvements made. Decreasing the number of reject parts reduces the cost of production, leading to a reduced system cost.

2.5.2 Optimization of Inventory Levels

To facilitate reductions in inventory levels, PowerLight formed an interdepartmental team to coordinate manufacturing and installation processes in order to remove unforeseen delays, which result in the storage of finished goods. The continuing goal of this team is to find ways to increase inventory turns to at least eight per year.

By forming an interdepartmental team to study these schedule issues and to look for ways to avoid them, much of the wasted activity involved with storage and extra handling of material could be eliminated. In addition, by increasing inventory turns, the cost of inventory on hand will be reduced.

Results

PowerLight created a team to coordinate manufacturing and installation processes in order to remove unforeseen delays. The team consists of representatives from the following departments:

Projects – responsible for installing product at the job sites

Production – responsible for manufacturing PowerGuard tiles

Logistics – responsible for delivering goods to the job sites

Purchasing – responsible for supplying materials to Production and Projects

Production planning – responsible for scheduling material shipments and production.

2.5.3 Labor Reduction

In order to decrease labor costs, PowerLight was to design new tools for material handling in the PowerGuard manufacturing process. The goal was to design equipment that would enable a worker to move components that are currently too awkward for single-person handling through the factory without assistance from other workers. The expected results of this task included the development of manufacturing tools capable of reducing the labor required to manufacture PowerGuard tiles by 30%.

A portion of these efforts focused on reducing labor costs, improving the consistency of processes, and reducing the amount of material handling during the process of preparing PV modules for assembly into PowerGuard tiles.

Approach

PowerLight has completed the design of a new portion of the assembly line that will change several parts of the PV module preparation process from a series of inconsistent, labor-intensive steps to a controlled, repeatable, and automated continuous process.

PV modules must be cleaned and tested prior to being assembled into PowerGuard tiles. The serial numbers must also be scanned. A surface treatment process is required on modules with polyethylene terephthalate (PET) backskins, and a PowerGuard label must be printed and adhered. The cleaning and surface treatment processes are difficult to control and labor intensive. In order to ensure the quality of the process and to reduce labor costs, a new conveyor line was designed to perform all of these functions. The line was installed during Phase II and is now used in production.

Results

The implementation of new equipment designed in Phase I reduced labor of the final tile assembly process by 37%. The implementation of new mixing and metering equipment provides a reduction of 9% from the labor required for the coating process. This provides a total labor reduction of 29% for the complete project. These changes will also ensure that the critical mixture ratios are maintained and that appropriate records are kept for each batch of product.

The implementation of the new PV preparation line also improved PowerLight's quality control in this area, though it is difficult to quantify the improvement as there was no way to measure the quality previously. The new equipment provides consistent and effective cleaning and surface treatment for the PV modules prior to the final assembly process for PowerGuard tiles. The surface treatment function is used only for modules that have a PET backing material. While the PV modules are being processed, the system also scans and stores the serial numbers so that each module can be tracked to its final installation site. These improvements help ensure that product performance and reliability will be maximized throughout the life of the product. Figure 37 and Figure 38 show the new PV preparation line.



Figure 37: PV preparation line.



Figure 38: PV preparation line, showing operator station and bar-code scanner.

2.6 Environment, Safety & Health: Tasks 6 & 13

The objective of this task is to reduce waste streams from both manufacturing and installation processes, investigate the use and availability of more environmentally friendly materials, and improve the efficiency, ergonomics and general safety of the workspace. As part of this effort, PowerLight was to work with PV module manufacturers to improve packaging practices with the goal of significantly decreasing on-site waste streams. In addition, PowerLight held employee brainstorming and implementation meetings, known as *kaizen* events, to improve manufacturing processes.

2.6.1 Kaizen Events

One of the goals of this task was the implementation of employee-suggested changes that result in improved efficiency, ergonomics, or general safety of the work environment. The tool used to implement these changes is called a *kaizen* event.

Background

Kaizen is a Japanese term that means continuous improvement. During a *kaizen* event, the workers are asked to create a solution to a particular manufacturing challenge. The challenge can be organization of tools, layout of the workspace, layout of the workflow, improvements in ergonomics, or anything else that affects worker productivity, product quality, product cost, or safety. The factory workers are a source of good ideas since they are involved in the manufacturing process every day. By involving the workers in the process of continuous improvement, they can have a sense of ownership for the product and the process.

First Kaizen Event

Approach

The focus of the first *kaizen* event was to address issues concerning the shift to a continuous manufacturing process. Currently, the PowerGuard manufacturing process is not continuous, as batch processing is employed. Once the backerboards are made, the coating must cure before the PV laminate can be adhered. A second curing step is required for the adhesive that is used to attach the PV laminate to the backerboard. When PowerLight first opened the Berkeley factory, the PV laminates were attached to the backerboards during the coating process. At that time, however, the coating process was not sufficiently well controlled to provide a consistent quality in the finished PowerGuard tiles; as such, the processes were separated. The coating process and final assembly process were improved significantly over the course of the next few years. The coating process is now tightly controlled, and the quality of the finished product is consistently very good. In light of this, it seems appropriate to combine the steps again to create one continuous process. This will have the benefit of reduced labor in material handling and improved use of factory floor space, allowing higher weekly production volume.

In order to set up a continuous, combined process, various changes needed to be made to the equipment layout and to details of the process. Hereafter, this process will be called the inline PV attach process.

The event started with a meeting to discuss the issues and come up with suggestions for improvements. The permanent manufacturing employees, the production supervisors, and engineers participated in the event. The following issues were identified at the meeting:

1. Layout of the process: The various pieces of equipment had to be rearranged so that the material could flow continuously. The normal setup had the coating process and the final tile assembly process separated by a large amount of space where the coated backerboards were stacked while the initial curing took place. The workers came up with their preferred layout of the equipment.
2. Spillage of the wet mortar on the conveyor: When the viscosity of the mortar varies, it can fall off the edges of the backerboards and get on the conveyor rollers. During the current process, the mortar is cured by the time that the PV

laminates are attached. Any mortar on the bottom of the backerboards can be cleaned off. Even if it is missed, it will not stick to the top of the PV laminates when the tiles are stacked. With a combined, continuous process, the wet coating can get on the bottom of the backerboards and be transferred almost immediately to the top of the PV laminates. Better control of the viscosity will reduce this risk.

3. Contamination of the PV alignment fixture: The current alignment fixture registers the backerboard by contacting the edges of the coating. With the coating uncured, the alignment fences would quickly become contaminated with coating.
4. Spacers can lose contact with the backerboard when the tiles are lifted for stacking: When long spacers are adhered to the PV laminate, the spacers tend to pull away from the backerboard when the tile is lifted, disrupting the bond between the spacer and the coating.

The following were observed during the run:

1. The new layout proved to be effective for the pilot run. The coating edges must be trimmed after the coating process because they slump a bit during the insertion of the spacers and handling of the backerboards. If the coating edges are trimmed too early, the coating will slump again, requiring the trimming to be repeated. If the trimming happens too late, the coating is too stiff and can break off at corners. The decision was made to trim the coating before the final assembly process. This worked well, though the PV alignment fixture was contaminated with coating as discussed below.
2. One difficulty that was encountered during the pilot run was the fluctuation of the liquid flow during the mixing of the coating. This had to be monitored very precisely in order to ensure that the viscosity of the coating was just right. More care than usual was taken to ensure that there was no spillage of the coating for the reasons discussed above. PowerLight subsequently installed a precise metering pump that controls the viscosity much more consistently, as discussed in Section 2.5.1.
3. As expected, the PV alignment fixture was contaminated with coating during the run. To compensate for this, the PV attach fixture was cleaned regularly during the pilot run. Based on the observations from this run, changes were discussed that would prevent this contamination. If the fences that are used to align the backerboard are moved so that they register against a lower portion of the tongue and groove profile, then the wet coating will not contaminate them.
4. As expected, once the PV laminate was adhered to the spacers, the backerboard was prone to sagging away from the spacers. When this happens, the spacers lose contact with the coating, disrupting the bond. If the coating is very fresh, then the spacer will adhere again when it is pushed back into the coating. However, it would be best to avoid this disruption altogether. Based on these observations, the spacer layouts of PowerGuard tiles are being evaluated to see if they can all be changed to use more short spacers rather than fewer long spacers. This will eliminate the disruption of the bond with the coating.

Second Kaizen Event

The focus of the second *kaizen* event was the design of a new layout for the final assembly stations for PowerGuard tiles. The event started with a meeting to discuss the issues and come up with suggestions for the layout. The permanent manufacturing employees, the production supervisors, and engineers once again participated in the event. Several possible layouts were examined, and it was decided to experiment with a few. The assembly stations and associated equipment are easily moved around, so it was not difficult to rearrange them and try more than one layout.

After trying out several layouts, the workers agreed that one of them worked better than the other options. Once the equipment layout was decided on, the associated electric and pneumatic connections were moved to provide power for the new setup. The final layout is shown in Figure 39.

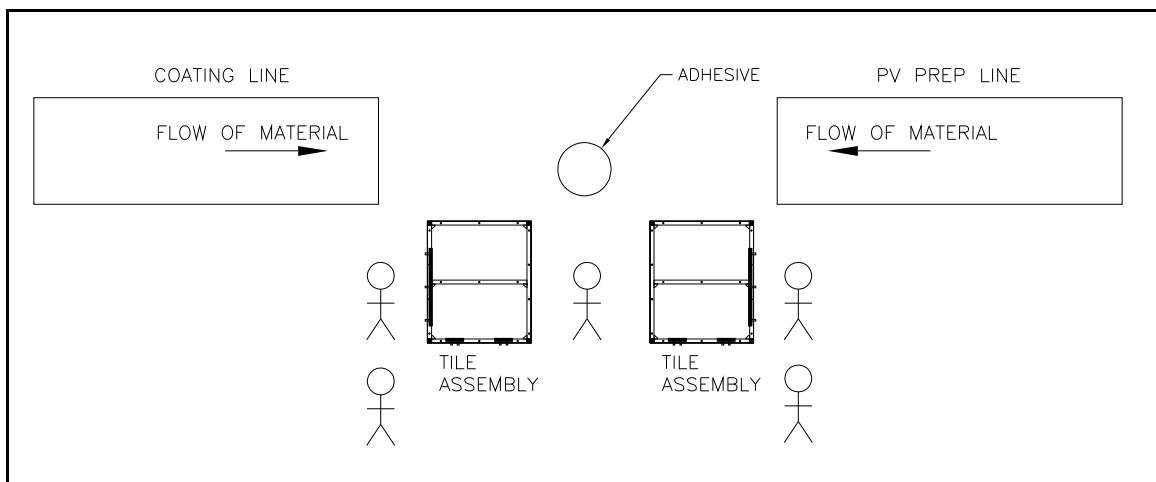


Figure 39: Tile Assembly Layout after Kaizen Event.

Third Kaizen Event

The subject of the third *kaizen* event was the modification of the mortar mixing system for the PowerGuard coating. These modifications built on earlier work carried out during the first phase of this project in which the mix monitoring system was improved. The changes were to automate the level control in the distribution hopper, reducing labor costs associated with this process and improving consistency of the final product. Additionally, the metering system for the liquids was being changed to make it easier to maintain. The previous system used a set of flow meters to measure the liquid proportions. These flow meters required frequent calibration, which was time consuming and labor intensive. The calibration was accurate at one flow rate, but the response was non-linear, making the calibration incorrect at other flow rates. The new system uses mass rather than flow to meter the liquids. As part of this change, it was important to arrange the components in a way that minimized unnecessary movement of material. In order to lay out and test the new equipment, PowerLight held a *kaizen* event with the factory workers.

The event started with a meeting to discuss the issues and come up with suggestions for the layout. The permanent manufacturing employees, production supervisors, and

engineers participated in the event. Several possible layouts were examined, and it was decided to trial a few of them.

Some of the main issues that the workers brought up are listed below:

1. General discussion of plumbing layout.
2. A drain connection is needed to our drain system from every tank for safety and cleaning purposes.
3. Filter locations need to be defined. We need an accurate piping diagram of liquid/tank connections.
4. Tanks should have airtight covers.
5. Secondary containment is needed for all tanks.
6. Safety posts are needed in front of tanks for forklift operators.
7. Shut-off valve locations for the system must be clearly identified for safety.

The final layout is shown in Figure 40.

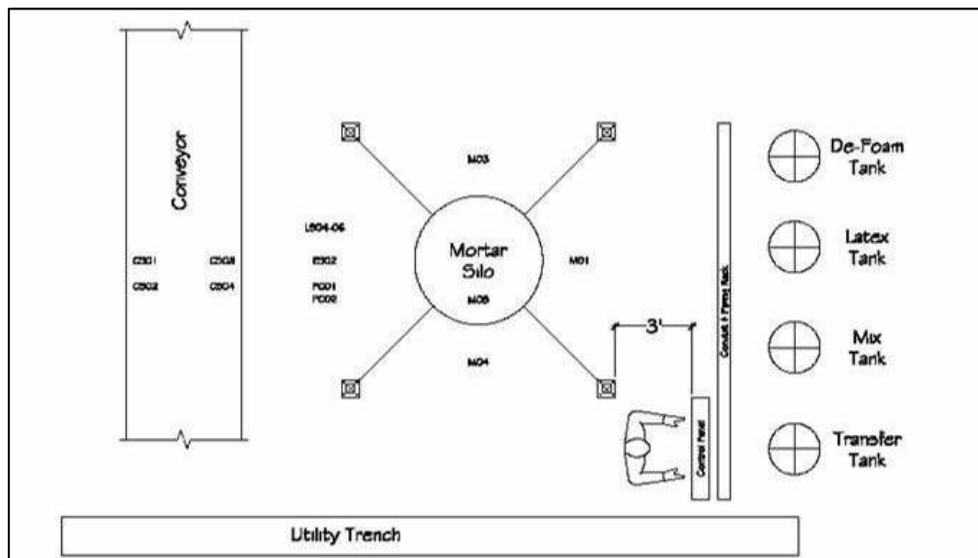


Figure 40: Layout After Kaizen Event.

Fourth Kaizen Event

The first *kaizen* event showed the potential of the proposed process change to a continuous flow. However, there were some portions of the process that were not satisfactory. Because of this, the PowerLight factory personnel decided that it would be beneficial to have another *kaizen* event with the same subject matter to try to improve on the results of the previous event.

The following were the issues that were unsatisfactory from the first *kaizen* event:

1. Spillage of the wet mortar on the conveyor: This was largely due to fluctuations in liquid flow during the mixing process. The improvements made to the mixing equipment during Phases I & II provided a much more consistent viscosity of the mortar. This results in less excess mortar falling off the edges of the backboards and cleaner backboard bottoms during stacking. To protect the

PV from any small amount of mortar that has fallen on the rollers, the operators suggested applying a Teflon coating on the conveyor rollers and a protective sheet on top of each PV prior to stacking the next completed PG. The conveyor rollers can be brushed or wiped clean periodically during the coating process which requires less effort with a Teflon conveyor roller.

2. Contamination of the PV alignment fixture was a problem during the First Kaizen event. This time, the fixtures were brushed or wiped clean preventing any mortar drying on the fixtures. The employees recommended using a Teflon coating on the alignment fixtures.
3. Previously, there were problems with spacers losing contact with the surface of the fresh coating during the stacking process. This time, spacers did not lose contact with the backerboard when the tiles were lifted for stacking because the spacers are now shorter and standardized. For a permanent solution, the employees suggested a hydraulic drop built at the end of the conveyor. The weight of each backerboard would drop the lift at the same level as the conveyor line in order to slide the next complete unit on the lift. With the hydraulic lift process, the movement of the spacers is at a minimum.

The following were observed during the run:

1. Trimming of coating edges was improved over the previous trial. The coating edges are trimmed after the coating process and no slumping of the edges was noted during the insertion of the spacers or the handling of the backerboard. The trimming quality was maintained. The trimming of the coating was made before the final assembly process. The alignment equipment was contaminated but the suggestion of a Teflon-coated fixture would reduce any curing of the mortar.
2. In order to explore the use of Teflon during mortar coating, the manufacturing group attached sheets of Teflon on the stacking jig. The coating run was processed without any edging prior to stacking. It was found that the mortar gradually slipped off the Teflon. Heavier amounts of mortar had to be brushed off the sheets.
3. The PV laminate adhered to the spacers and the backerboard was not prone to sagging away from the spacers because smaller spacers were used for this run.

2.6.2 Waste Stream Reduction

One of the expected results of this task is the development of an improved shipping method for PowerGuard tiles that would reduce shipping costs and site waste by at least 20%. At the start of this project, PowerLight expected to achieve this goal through the implementation of reusable shipping containers that maximize shipping density to the installation site and collapse for return shipment. In addition, PowerLight planned to investigate means of incorporating recycled materials into the design, when developing these reusable containers.

Approach

PowerLight has looked for ways to reuse shipping containers in the past, but the cost has always been prohibitive due to the transportation cost associated with returning the containers to the factory. Prior to the start of this project, new analysis had shown that the cost of the return shipment could be offset by maximizing shipping density to the installation site. For example, by building containers that double shipping density and

then collapse for return shipment, the total number of trips to or from the site would be reduced.

The first step in this process was to evaluate the cost of different types of shipping containers. The preferred solution would be containers that are completely reusable. However, if that was not feasible, PowerLight wanted to investigate alternatives that would reduce site waste and environmental impact by increased shipping density and the use of recycled material.

PowerLight looked into a variety of materials for both reusable and single-use packaging, including recycled plastic and recycled cardboard. If a reusable container has a life of five trips and costs \$100, it will provide a 28% savings in packaging/transportation costs for large installations. As system size goes down, the benefit is reduced. For a 200-kW system, no cost savings is realized.

A primary obstacle to implementation of reusable containers was the variety of sizes of PowerGuard tiles. PowerGuard tiles are sized to conform to the size of the PV module being used, and it is an advantage to be able to use the standard sizes offered by a variety of manufacturers. Even with a small number of sizes (three or four), the number of reusable containers that would need to be on hand at any one time would be prohibitively large, especially in the context of additional storage costs.

Since reusable containers proved infeasible at this time, PowerLight looked for ways to increase shipping density and, thereby, achieve the site-waste and cost reduction goals. PowerGuard tiles were generally stacked 12 high on each pallet. This was primarily done to allow workers to stack the tiles easily in the factory and to unstack them easily at the job site. A stack of twelve PowerGuard tiles is approximately 60 inches high. Shipping containers would allow a stack as high as eight feet, but unstacking a pallet this high becomes nontrivial. PowerLight investigated the possibility of taking two pallets with stacks of PowerGuard tiles and placing one on top of the other for shipping. When the stacks were unloaded from the truck, the two pallets could be separated either prior to lifting to the roof or after they had been lifted to the roof. PowerLight investigated the use of corner supports that were strong enough to support the second stack on top of the first one. Corner supports were found that were made from recycled plastic bags and were easily strong enough to provide the needed support. Figure 41 shows an initial test of these supports.



Figure 41: Test of corner supports in double stacked pallets.

Unfortunately, the cost of the stronger corner supports and the second pallet was too high to be economically feasible.

The final approach was to increase the stack height as much as possible without adding a second pallet. With some experimentation, we found that the workers were able to stack and unstack up to 15 tiles. This reduces shipping costs, as well as the associated site waste by up to 20%. The main issue with this approach was the compressive strength of the spacers of the bottom tiles. Shipping tests were carried out with accelerometers mounted on the top and bottom of stacks of various heights.

PowerLight explored reducing the amount of packaging used for PV modules that are shipped directly to the job site. The packaging methods for the various PV suppliers varies dramatically. Several manufacturers use one cardboard box with many inserts for every two modules. Other manufacturers use only corner guards and stack modules on pallets. This second arrangement is much better for PowerLight. With one box for every two modules, one full-time worker is required just to get all the cardboard off the roof and into recycling bins on a typical project. PowerLight approached the manufacturers who use large numbers of boxes to try to gain their cooperation in reducing site waste. Unfortunately, this effort has been largely unsuccessful. The burden of dealing with the packaging does not have any impact on the PV supplier. It also appears that the money that the supplier would save by eliminating the packaging is not sufficient to motivate

many suppliers to change their methods. Two of the manufacturers have very effective corner-guard packaging. It is hoped that eventually, other manufacturers will see the benefits of this system and implement it.

PowerLight also investigated the availability of an alternative, environmentally friendly foam for PowerGuard. The foam used in PowerGuard is extruded polystyrene. A blowing agent creates the small bubbles in the foam as it is extruded. The blowing agent in use in the United States is a hydrocarbon. PowerLight's foam supplier manufactures a similar foam in Europe with a carbon dioxide-based blowing agent, which is much more benign. PowerLight would prefer to use this foam, but it is not yet available in the United States. The foam supplier has said that they are working on a non-hydrocarbon blowing agent for the U.S., but this still may not be the same as that used in Europe. The expected availability date for this new foam is still one to two years away. None of the states has a mandate for switching this blowing agent, so there is little perceived demand. PowerLight will continue to push the supplier to make this alternative available, but until that happens, PowerLight will continue to manufacture with the standard foam.

Results

PowerLight was successful in reducing packaging waste by the increase in stack height for PowerGuard tiles from 12 to 15 tiles. This solution reduces the amount of packaging by 20% as well as reducing the number of truck trips required by 20%.

Unfortunately, PowerLight was unable to reduce the packaging of PV modules, so this continues to be a problem. Likewise, PowerLight was unable to secure a supply of foam that uses a carbon dioxide blowing agent. PowerLight will continue to push suppliers to minimize packaging on their product for PowerLight's large-scale projects.

2.7 Commercial Demonstrations: Tasks 7 & 14

The objective of this task is to use commercial demonstration projects to assess the efficacy of the modifications implemented during the course of this project. A total of 2000 to 4000 PowerGuard tiles, totaling at least 500 kWp, was to be used at commercial demonstration sites for this assessment during each phase. The performance of these commercial demonstration projects was to be monitored to quantify improvements in system performance, and the costs were to be collected to evaluate the results of cost reduction efforts.

2.7.1 System Performance

Approach

Improvements in system performance and reliability were measured by comparing new systems, which have improved monitoring and diagnostic equipment with historical data from a range of existing systems. The "control" sites, listed in Table 4, were existing sites that we used for comparison with the new sites.

Table 4: Existing Systems for Comparing System Performance

System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability
System 1	Control	Los Angeles, CA	4/30/2003	115.1	98%	100%
System 2	Control	Hayward, CA	1/8/2004	261.0	95%	100%
System 3	Control	Hayward, CA	2/14/2004	101.8	95%	100%
System 4	Control	Hayward, CA	3/24/2004	114.0	101%	98%
System 5	Control	Hayward, CA	1/5/2004	243.3	106%	100%
System 6	Control	Hayward, CA	1/5/2004	279.7	105%	95%
System 7	Control	San Francisco, CA	10/18/2003	234.5	97%	99%
System 8	Control	San Francisco, CA	10/18/2003	234.5	99%	100%
System 9	Control	San Francisco, CA	2/27/2004	207.0	102%	99%
System 10	Control	Walnut Creek, CA	1/30/2003	93.6	108%	100%
System 11	Control	Healdsburg, CA	6/18/2004	258.3	96%	99%
System 12	Control	Healdsburg, CA	6/18/2004	199.1	106%	100%
System 13	Control	San Mateo, CA	1/27/2003	233.7	94%	96%
System 14	Control	Sacramento, CA	2/3/2004	201.4	96%	94%
System 15	Control	Sacramento, CA	2/3/2004	201.4	95%	93%
System 16	Control	Rohnert Park, CA	1/29/2003	96.0	95%	100%
System 17	Control	Torrance, CA	2/6/2003	37.1	98%	96%
System 18	Control	Torrance, CA	2/5/2003	124.7	105%	100%
System 19	Control	Torrance, CA	2/5/2003	124.7	100%	100%
System 20	Control	Torrance, CA	2/5/2003	124.7	101%	100%
System 21	Control	Torrance, CA	2/5/2003	124.7	97%	100%
System 22	Control	Vallejo, CA	3/14/2003	107.8	89%	100%
System 23	Control	Vallejo, CA	3/14/2003	224.0	95%	98%
				Average	98.8%	98.6%

Table 5 lists the “test” sites that were installed during the course of this project with new monitoring and diagnostic equipment.

Table 5: Test Systems for Comparing System Performance

System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability
System 24	Test	Oakland, CA	6/9/2005	100	N/A	N/A
System 25	Test	Oakland, CA	7/28/2005	265	N/A	N/A
System 26	Test	Oakland, CA	7/28/2005	265	N/A	N/A
System 27	Test	Oakland, CA	7/28/2005	252	N/A	N/A
System 28	Test	Oakland, CA	7/28/2005	121.8	N/A	N/A

Results

Performance Index and Availability figures are shown in Table 6 for the control group of sites for two periods: September 1, 2004 - August 31, 2005 and February 1, 2005 - January 31, 2006. This data is shown for the test group for the periods from February 1, 2005 - January 31, 2006 only; data for Test System 24 are available from June 2005 and figures for Test Sites 25 through 28 include data from September 2005. Data for Systems 25 through 28 prior to September 2005 were excluded because of manual shutdowns associated with the project installation. Energy from these systems was tracked via the data acquisition system, but measures of availability and performance index for the site are slightly skewed by the frequency and duration of shut-downs related to breaker installations and other site work. During the period February 1, 2005 - January 31, 2006, twenty of the twenty-four control sites were off at some point during the year for planned maintenance or because of an unplanned outage (utility outage or inverter failure). None of the test sites suffered inverter outages during this period, and none were shut down for planned maintenance.

Table 6: Results of system performance monitoring

System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Metrics for 09/01/04 – 08/31/05		Performance Metrics for 02/01/05 – 01/31/06	
					Performance Index	System Availability	Performance Index	System Availability
System 1	Control	Los Angeles, CA	4/30/2003	115.1	98%	100%	95%	98%
System 2	Control	Hayward, CA	1/8/2004	261	95%	100%	91%	100%
System 3	Control	Hayward, CA	2/14/2004	101.8	95%	100%	95%	100%
System 4	Control	Hayward, CA	3/24/2004	114	101%	98%	98%	99%
System 5	Control	Hayward, CA	1/5/2004	243.3	106%	100%	101%	98%
System 6	Control	Hayward, CA	1/5/2004	279.7	105%	95%	102%	94%
System 7	Control	San Francisco, CA	10/18/2003	234.5	97%	99%	95%	100%
System 8	Control	San Francisco, CA	10/18/2003	234.5	99%	100%	95%	100%
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System 12	Control	Healdsburg, CA	6/18/2004	199.1	106%	100%	108%	99%
System 13	Control	San Mateo, CA	1/27/2003	233.7	94%	96%	92%	94%
System 14	Control	Sacramento, CA	2/3/2004	201.4	96%	94%	93%	94%
System 15	Control	Sacramento, CA	2/3/2004	201.4	95%	93%	93%	95%
System 16	Control	Rohnert Park, CA	1/29/2003	96	95%	100%	92%	100%
System 17	Control	Torrance, CA	2/6/2003	37.1	98%	96%	96%	96%
System 18	Control	Torrance, CA	2/5/2003	124.7	105%	100%	104%	100%
System 19	Control	Torrance, CA	2/5/2003	124.7	100%	100%	98%	100%
System 20	Control	Torrance, CA	2/5/2003	124.7	101%	100%	99%	100%
System 21	Control	Torrance, CA	2/5/2003	124.7	97%	100%	102%	100%
System 22	Control	Vallejo, CA	3/14/2003	107.8	89%	100%	87%	100%
System 23	Control	Vallejo, CA	3/14/2003	224	95%	98%	92%	97%

					Performance Metrics for 09/01/04 – 08/31/05		Performance Metrics for 02/01/05 – 01/31/06	
System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability	Performance Index	System Availability
				Average	98.8%	98.6%	97.2%	98.4%
System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability	Performance Index	System Availability
System 24	Test	Oakland, CA	6/9/2005	100	N/A	N/A	106%	100%
System 25	Test	Oakland, CA	7/28/2005	265	N/A	N/A	106%	100%
System 26	Test	Oakland, CA	7/28/2005	265	N/A	N/A	111%	100%
System 27	Test	Oakland, CA	7/28/2005	252	N/A	N/A	97%	100%
System 28	Test	Oakland, CA	7/28/2005	121.8	N/A	N/A	103%	100%
				Average	N/A	N/A	104.5%	100.0%

Performance Index and Availability figures are shown in Table 7 or the control group of sites for two periods: September 1, 2004 - August 31, 2005 and October 1, 2005 – March 29, 2007.

Both the performance index and availability for the test sites were higher than for the control sites at the end of Phase I. This was due in part to the implementation of more advanced monitoring systems at these sites. However, these data are not sufficient to fully validate the more advanced monitoring. Availability and performance index are impacted by many factors, only one of which is the rapidity of PowerLight's response to a problem. For instance, the availability of System 6 is quite low because of an extended inverter outage at this system. Although PowerLight responded to the outage within 24 hours using our existing monitoring system, the inverter manufacturer was unable to diagnose the problem and fully repair the unit in a timely fashion; the inverter was down and/or running at half power for over two weeks. If such an outage had struck one of the test sites, availability would have been impacted similarly; although more advanced monitoring will help PowerLight respond to problems more quickly, it cannot change the amount of time that a system is off once a problem is discovered.

At the end of Phase I, we concluded from this data that the test sites were operating at higher levels of performance index and availability than the control sites, but a longer measurement period was necessary to give us confidence in the role that our advance monitoring systems had played in this improvement.

Table 7: Results of system performance monitoring

PVMR&D Data Table					Performance Metrics for September 1, 2004 - August 31, 2005		Performance Metrics for October 1, 2005 - March 29, 2007	
System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability	Performance Index	System Availability
System 1	Control	Los Angeles, CA	4/30/2003	115.1	98%	100%	98%	100.0%
System 2	Control	Hayward, CA	1/8/2004	261	95%	100%	95%	99.9%
System 3	Control	Hayward, CA	2/14/2004	101.8	95%	100%	95%	99.9%
System 4	Control	Hayward, CA	3/24/2004	114	101%	98%	95%	98.9%
System 5	Control	Hayward, CA	1/5/2004	243.3	106%	100%	95%	97.8%
System 6	Control	Hayward, CA	1/5/2004	279.7	105%	95%	110%	99.6%
System 7	Control	San Francisco, CA	10/18/2003	234.5	97%	99%	94%	98.7%
System 8	Control	San Francisco, CA	10/18/2003	234.5	99%	100%	92%	99.0%
System 9	Control	San Francisco, CA	2/27/2004	207	102%	99%	96%	97.0%
System 10	Control	Walnut Creek, CA	1/30/2003	93.6	108%	100%	104%	99.9%
System 11	Control	Healdsburg, CA	6/18/2004	258.3	96%	99%	99%	95.7%
System 12	Control	Healdsburg, CA	6/18/2004	199.1	106%	100%	104%	99.6%
System 13	Control	San Mateo, CA	1/27/2003	233.7	94%	96%	99%	99.8%
System 14	Control	Sacramento, CA	2/3/2004	201.4	96%	94%	84%	93.6%
System 15	Control	Sacramento, CA	2/3/2004	201.4	95%	93%	88%	99.7%
System 16	Control	Rohnert Park, CA	1/29/2003	96	95%	100%	88%	100.0%
System 17	Control	Torrance, CA	2/6/2003	37.1	98%	96%	103%	100.0%
System 18	Control	Torrance, CA	2/5/2003	124.7	105%	100%	109%	99.7%
System 19	Control	Torrance, CA	2/5/2003	124.7	100%	100%	105%	99.7%
System 20	Control	Torrance, CA	2/5/2003	124.7	101%	100%	108%	100.0%
System 21	Control	Torrance, CA	2/5/2003	124.7	97%	100%	103%	99.6%
System 22	Control	Vallejo, CA	3/14/2003	107.8	89%	100%	80%	99.5%
System 23	Control	Vallejo, CA	3/14/2003	224	95%	98%	84%	99.2%
Averages, Control Systems					98.8%	98.6%	96.9%	99.0%
System 24	Test	Oakland, CA	6/9/2005	100	N/A	N/A	107%	99.9%
System 25	Test	Oakland, CA	7/28/2005	265	N/A	N/A	107%	99.0%
System 26	Test	Oakland, CA	7/28/2005	265	N/A	N/A	112%	99.9%
System 27	Test	Oakland, CA	7/28/2005	252	N/A	N/A	105%	100.0%
System 28	Test	Oakland, CA	7/28/2005	121.8	N/A	N/A	108%	99.4%
Averages, Test Systems							108.0%	99.6%

Monitoring of these parameters continued during the latter part of Phase I and throughout Phase II. In **Error! Reference source not found.**, data for the 18 months beginning in October 2005 and ending on March 29, 2007 is shown for each system and is compared to data for the 12-month baseline period from September 2004 – August 2005. The table shows that the average availability of control group sites increased slightly from the baseline period to the 18-month test period, while average performance index fell slightly. Both the availability and performance index of the test sites was better than that of the control sites during the test period. The average Performance Index of the test sites was 11% better than the control sites and the availability was 0.7% better than the control sites. The availability of both the control and test sites was very good.

2.7.2 Cost Reduction

Approach

The cost reduction activities involved modifications to standard PowerGuard tiles as well as improvements to PowerLight's newly introduced sloped product, RFT10. The sites that were used for these assessments are shown in Table 8.

Table 8: Sites for Cost Reduction Assessment

Site ID	Location	Product	Inception Date	Current Rated Power (kWp)
Phase I				
Site 1	Oakland, CA	PowerGuard	Aug. 2005	262
Site 2	St. Helena, CA	RFT10	Aug. 2005	229
Site 3	Napa, CA	RFT10	Sept. 2005	195
Phase II				
Site 4	Fresno, CA	RFT10	Nov. 2006	1000

Results

In August 2005, PowerGuard tiles with reduced coating thickness were installed at a demonstration site in Oakland, California. This was PowerLight's first opportunity to observe the quality of a large number of production tiles made with the new coating thickness, a cost-saving improvement implemented under Task 2. It was also the first opportunity to install these tiles and confirm that the durability was not compromised. The array was constructed with 500 tiles that had the reduced coating thickness and approximately 1,300 tiles that had been made with the standard coating thickness. This allowed for a side-by-side comparison.

The workers appreciated the lower weight of the new tiles, which made them easier to handle. Figure 42 shows the array with the reduced coating thickness during installation. Figure 43 shows a close-up of the difference in coating thickness between a standard PowerGuard backerboard and the new backerboard.



Figure 42: Demonstration array with reduced coating thickness during installation.



Figure 43: PowerGuard tile with reduced coating thickness (on right).

The reduction in coating thickness, increased stacking height, and reductions in labor resulted in a reduction in backerboard cost of 17.8%.

Commercial demonstration projects with RFT10 were installed in Phase I and Phase II. In September 2005, PowerLight completed the installation of the first large-scale arrays of RFT10, as shown in Figure 44. Lessons learned during this installation were used in the development of the universal RFT10 design, as described previously in Section 2.2.



Figure 44: Phase I commercial demonstration project.

The Phase II changes made to the RFT10 product were extremely well received by the installation crews. The new mounting method was easier to install, and it made it easier to maintain array alignment. The installation was subject to several delays and problems unrelated to the array design itself. However, these problems made it difficult to obtain an accurate measurement of installation labor. The impression of the installers was that the new design could be installed in a lot less time than the previous design. Subsequent jobs that have been installed in February and March of 2007 have confirmed this impression. Photos of the project under construction and completed are shown in Figure 45 and Figure 46.

Changes to the wind deflectors reduced part cost and also improved the ease of installation by making it easier for the array to conform to roof contours. Changes to the support pieces of the deflectors also made the design more robust and less likely to get skewed as the array was installed. The new design made for a more intuitive installation process. There were a few issues with workers not taking sufficient care to ensure proper alignment of parts prior to tightening bolts. We will need to look for ways to further error-proof this process.



Figure 45: Commercial demonstration site under construction.



Figure 46: 1-MWp array completed.

In addition to reducing installation labor and making the installation easier, the new design reduced overall balance-of-system cost. The mounting hardware cost was reduced by 70% compared to the commercial demonstration projects that were installed during Phase I of this project. This is a far greater improvement than hoped for. Overall system cost was reduced by nearly 10% from the Phase I commercial demonstration. PowerLight is very proud of the success that we have had with this new product.

3 Acknowledgements

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14. ABSTRACT (Maximum 200 Words) During this PV Manufacturing R&D subcontract, PowerLight Corporation made significant progress toward reducing installed costs for commercial-scale, rooftop PV systems. PowerLight worked to reduce operating costs by improving long-term reliability and performance developing more sophisticated tools used in system design and monitoring. Additionally, PowerLight implemented design improvements with the goal of reducing cost, while maintaining and/or improving product quality. As part of this effort, PowerLight also modified manufacturing and shipping processes to accommodate these design changes, streamline material flow, reduce cost, and decrease waste streams.					
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