

# **PowerGuard<sup>®</sup> Advanced Manufacturing**

**PVMaT Phase II Technical  
Progress Report  
1 July 1999–30 September 2000**

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*PowerLight Corporation  
Berkeley, California*



**NREL**

**National Renewable Energy Laboratory**

1617 Cole Boulevard  
Golden, Colorado 80401-3393

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Contract No. DE-AC36-99-GO10337

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Prepared under Subcontract No. ZAX-8-17647-12



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## **Executive Summary**

PowerLight Corporation (PowerLight) has completed the second of three phases of its Photovoltaic Manufacturing Technology (PVMaT) 5A1 subcontract, "PowerGuard<sup>®</sup> Advanced Manufacturing," addressing the U.S. Department of Energy's PVMaT goals of manufacturing improvements directed toward innovative, low-cost, high-return, high-impact PV products. PowerLight's patented PowerGuard building-integrated PV roofing tile is the product upon which cost reduction efforts have been focused.

The objective of this subcontract over its three-year duration is to continue the advancement of PowerLight's PowerGuard manufacturing improvements in order to reduce PowerGuard system costs, increase PowerGuard tile fabrication capability to 16 MW/year, and stimulate an increase in manufacturing of PV laminates, within the United States, by 2 MW/year.

### ***During Phase II, PowerLight has addressed these goals through:***

- Implementation of an automated tile manufacturing facility exceeding 16 MW/year capacity;
- Continued improvement of the PowerLight manufacturing plant in Berkeley, CA incorporating new portions of the automated design;
- Continued development of the PowerGuard tile and system, including obtaining Underwriters Laboratories (UL) listing for several versions of the PowerGuard tile.

### ***During Phase II, these accomplishments have resulted in:***

- Greater than 400 PowerGuard tiles per shift (20 MW/year) manufacturing capacity;
- 57% cost reduction for PowerGuard tile;
- UL listing for four additional PowerGuard tiles;
- Improved quality of finished goods due to improved tooling and processes in PowerGuard manufacturing which also simultaneously improved throughput and lowered cost.

### ***Patents related to this project:***

In part as a result of this work, PowerLight will likely file for two patents and will list the U.S. government accordingly.

### ***In Phase III of this contract, PowerLight will continue efforts to improve the manufacturing processes for PowerGuard. Specific performance objectives during phase III are as follows:***

- Demonstrate system cost reduction from \$3.80/Wp to \$3.05/Wp;
- Establish or assess the performance of dedicated PowerGuard PV plant capacity of 2 MW per year;
- Complete wind tunnel testing of all design refinements;
- Produce an installation manual and training program for installing PowerGuard systems;

- Establish performance of manufacturing modifications based on assessment of commercial systems which incorporate the new features and processes;
- Finalize UL, International Conference of Building Officials (ICBO), and international listings of PowerGuard improvements.

***This will result in a lower cost, higher impact PV product, as sought by this program.***

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## **1.0 Background**

PowerLight's patented PowerGuard building integrated roofing is the product upon which PVMaT efforts have been focused. A PowerGuard tile consists of a flat plate PV laminate mounted onto a flat, rigid, extruded polystyrene (XPS) board. Two edges of the XPS board are routed into a tongue profile and the other two edges are given a groove profile, allowing PowerGuard tiles to be assembled adjacent to each other in an interlocking fashion. Adjacent tiles are connected electrically through electrical connectors supplied on each PV module, thus creating a string of PV modules. One or more strings are then tied together electrically at a remote location creating a solar electric array (PowerGuard system). The resulting DC current from the array is passed through a DC/AC inverter and transformer before being tied into the building's electric service.

Through this subcontract, "PowerGuard Advanced Manufacturing" seeks to introduce incremental improvements to PowerGuard system components and manufacturing processes to significantly reduce the costs of a PowerGuard system. This will result in a lower cost, higher impact PV product, as sought by PVMaT.

## **2.0 Objective**

The objective of this subcontract over its three-year period is to develop and implement component and manufacturing improvements in order to reduce cost, increase capacity, and maximize throughput, and, in addition, to improve accessibility by providing PV systems which incorporate financing options. Program end goals include cost reduction of PowerGuard system by 46%, increased manufacturing capacity to 16 MW/year, and stimulation of an expansion of PV laminate manufacturing, in the United States, by 2 MW/year.

PowerLight will address PowerGuard system cost reduction through the following:

- Improvements in manufacturing technology related to system (non-PV) components;
- Product design enhancements;
- Increased production capacity;
- Enhanced system reliability and performance;
- Strategic alliances to leverage PV module technical improvements and cost reduction.

### 3.0 Scope of Work - Phase II

**During Phase II, PowerLight continued efforts to improve the manufacturing process for the PowerGuard product. The following specific performance objectives were established:**

- Demonstrate system cost reduction from \$4.80Wp to <\$3.80Wp;
- Increase PowerGuard BOS component production capacity from 8MW/yr to 16MW/yr (10W/sf for PV);
- Complete the updating of the manufacturing layout master plan for integration of automated component stations;
- Complete design, development, and production-based assessment of automated, integrated XPS processing, PV placement, and materials handling between stations;
- Develop methods of packaging which lower packaging and shipping costs by 25%;
- Complete improvements to PowerCurb™ (RT) housing, harness assemblies, and source circuit combining circuitry, resulting in cost reductions (materials and labor) of 50%;
- Complete wind tunnel testing of RT securement, sloped tile assembly, and field assembly system to establish wind zone design guides;
- Submit modified system to UL and international organizations for listing and certifications of PowerGuard improvements;
- Develop design software to facilitate physical and electrical system design, system QA/QC, code conformity, permitting and bidding;
- Develop modular and standardized packages to reduce the cost of small systems;
- Evaluate commercial demonstrations which incorporate the new features and processes; and
- Complete comparison testing of inverter under motor induction load to Institute of Electrical and Electronic Engineers (IEEE) 929/UL1741 standards.

### 3.11 Assembly Layout and Integration

#### *Objectives*

Under this task, PowerLight continued efforts initiated in Task 1, Phase I, to complete design and development of equipment for cost-effective, integrated automation of the PowerGuard tile manufacturing line. Specifically, the redesigned production was to meet the following criteria, and in so doing result in a system cost reduction of 20%:

Criterion:	Existing:	Expected improvement
Production Rate (boards/day)	200	100% more
Throughput (minutes/tile)	3	40-60% faster
Number of Operators	8	20-30% fewer
NEPA, OSHA compliance satisfied.		

## ***Results***

**Summary:** System costs were reduced 57%. The production rate improved more than 100%. Throughput time was reduced 80%. We are in compliance with NEPA and OSHA. The number of operators rose 50%: we learned that to lower the cost of finished goods, maximizing throughput is more important than minimizing labor.

### **Discussion:**

PowerLight has completed numerous improvements to the PowerGuard manufacturing line at the PowerLight production facility at 815 Heinz Street, Berkeley, California. Advanced automation has been incorporated which has improved throughput and product quality. Advanced equipment automation developed and implemented under Tasks 13, 14, 16, 25B, 25C, and 25D is discussed in those sections.

At the beginning of Phase II, PowerLight engineers identified priority issues to be addressed in order to achieve cost and throughput objectives. Timing and quality studies completed at the end of Phase I indicated problems with applying the coating and cutting the XPS spacers that posed production bottlenecks. As a result, engineers designed and implemented coating equipment additions and redesigned the spacer cutting process as part of the redesigned production line outlined under this task.

The first design for the coating distribution hopper proved to have many flaws. Though these flaws did not affect the quality of the coating mixture, they increased the labor required for setup and cleaning and limited the throughput of the coating process. The initial design of a system to deliver coating mix to the hopper also did not work as anticipated. Two different mixing machines were tried before an appropriate solution was found. No commercial product was produced with the first machine. The second machine produced a good quality mix, but required several workers to operate and was prone to jam. The mixing machine now being used delivers a consistent coating mix to the distribution hopper with minimal labor. The original distribution hopper also had inadequate mixing power to handle a large volume of coating mixture in the hopper thus limiting throughput. Additionally, it was difficult to clean and adjust. A new hopper was designed and installed. It provides a removable chute on one end into which the coating mix falls as it comes out of the mixing machine. The hopper is designed to disassemble in just a few minutes with a minimum of tools, greatly decreasing the cleaning time. Additionally, all adjustments are retained when the hopper is disassembled, so that setup for the next run takes only a few minutes. The quality of the coating on the boards has been improved and is much more consistent since installation of this new hopper.

PowerLight engineers experimented with several different tools for making spacers. In most cases, the accuracy and repeatability of the cutting process were not sufficient. In addition, many of the proposed processes were labor intensive and required dedicated space within the manufacturing facility. Engineers determined that with the addition of custom made bits, the computer numerical control (CNC) router could be used to cut spacers. With minimal modification to the router, manufacturing personnel are now able to cut spacers with less waste and greater accuracy. In addition, a worker can set up the stock, start the cycle, and then do other work while the router runs, returning at the end of the cycle to reload. The router is shown cutting spacers in Figure 1.



**Figure 1: Spacer Cutting with CNC Router**

At the program’s onset, the PowerGuard production process required 8 workers and had a throughput of one tile every three minutes. The current process requires 12 workers, but has a throughput of one tile every 38 seconds. This results in an improvement of 57% in the cost of the finished tile. (An improvement of 40% to 70% was anticipated.) The greatest improvements in the cost of finished goods were originally expected to come from both an increase in throughput and a simultaneous reduction in the size of the labor force. However, through the process of developing this improved production line, we learned that to lower the cost of finished goods, it is more important to maximize throughput, even if the labor requirement increases somewhat.

Inspections took place during the last year to insure compliance with the Occupational Safety and Health Administration (OSHA) and National Environmental Protection Act (NEPA). PowerLight has satisfied all issues of compliance. (Reports from those inspections were submitted and reported on under Task 22.1.)

**3.12 Task 12 intentionally omitted**

**3.13 Automated Spacer Attachment (Flat Tile)**

***Objectives***

Under this task, PowerLight was to design, specify, install and test equipment to adhere XPS spacers to the XPS backerboard. The following criteria were to be met by this equipment:

Criterion:	Existing:	Phase II Objective
Throughput (seconds/tile)	90	45
Number of Operators	N/A	1
Position Tolerance	+/- 1/4”	+/- 1/16”
NEPA, OSHA compliance satisfied.		

## ***Results***

**Summary:** Throughput improvement exceeded expectations, increasing to 20 seconds or less per tile. Two operators are required for this station. Position tolerances stayed at ¼", which is acceptable, as it does not affect product quality. We are in compliance with NEPA and OSHA.

### **Discussion:**

In Phase II, engineers addressed the various objectives of this task through equipment design and development. Various methods to completely automate the positioning of spacers were investigated, but they proved prohibitively expensive. However, it was shown that the objectives for throughput and position tolerance could be met with a semi-automated system.

To insure that spacers are placed on the coated boards in a consistent manner, a semi-automated stop bar and alignment jig have been installed on the production line. An optical sensor detects the presence of a coated board at the alignment jig. One worker pushes the board against the alignment jig. A projector is mounted above the spacer placement station. This projects an image onto each board in the alignment jig showing clearly the positions of the four spacers with four bright rectangles. This allows the workers to position the spacers quickly and accurately. If a board is detected at this station, the stop bar at the spacer placement station will not rise up to allow another board to enter. As long as the press station is clear, when the worker at the spacer placement station pushes the button, the stop bar will rise, allowing the board with spacers to move downstream to the spacer press. When the board clears the optical sensor, the stop bar automatically drops into position to wait for the next board.

Proprietary equipment was developed will be reported on at a later date following patent filings. The new equipment enables a cycle time of approximately 10 seconds. This system produces a much more consistent result than the previous manual method.

Our initial throughput objective was an increase from 90 seconds per tile to 45 seconds per tile. We have exceeded this goal with the equipment we have installed. The workers at the PV attachment station can process boards consistently in less than 20 seconds per tile. We have achieved this by automating part of the process and simplifying the manual part of the process.

### **3.13a Automated Spacer Attachment (Sloped Tile)**

It was originally expected that when the design work was finished for the sloped version of PowerGuard, special equipment would be required to place the sloped tile spacers on the backerboards. However, with the final design, the method of spacer attachment will be the same as for the flat tile PowerGuard.

The spacers for the sloped tile consist of three long metal strips shaped to provide the base of the sloped tile. These would be placed on the coated boards using the same equipment as that used for the flat tile, but the projected image would be changed to match the three long metal spacers.

### 3.14 PV Module Placement

#### *Objectives*

Under this task, PowerLight was to design and evaluate PV module placement equipment which would apply adhesive and accurately position the PV module on the backerboard, and eliminate the need for curing racks by stacking the modules directly onto a shipping carton or pallet base.

The objectives of this task were a 50% throughput improvement, a reduction of labor, and a 50% improvement in positioning accuracy.

#### *Results*

**Summary:** Throughput improved by more than 50%, while positioning accuracy was increased. Labor increased from 1 to 2 workers; overall, this improves throughput and reduces costs. Completed tiles are stacked directly onto shipping pallets for curing.

#### **Discussion:**

During this task, engineers learned a great deal about optimizing the production process. Per the advancements discussed under Task 13, the production method for spacer and PV attachment changed so that spacers are first attached to the coated backerboards. The PV panels are then attached to the tops of the spacers after the coating has cured. The result is an improved process and better throughput. This also allows for the expensive and relatively fragile PV panels to be handled only once.

Several methods to place the PV modules onto PowerGuard backerboards were investigated. A conveyor line was set up in PowerLight's Berkeley factory to test out the method of attaching PV panels to the spacers. In the first stage of equipment development, an alignment jig with a pneumatically powered articulated stop bar was placed on top of the conveyor. A backerboard with spacers is positioned in the alignment jig. Glue is applied to the top of the spacers, and the PV panel is laid on top. Operators wait for the glue to cure, then raise the stop bar and push the completed tile to the end of the conveyor where the tile is lifted and stacked on a pallet. When this pallet is full, weight is applied to the top until the glue has cured. The pallet is then wrapped for shipment.

This system was used for several production runs, and the quality of the PowerGuard tiles was consistently good. However, throughput was less than optimal.

The second stage of equipment development specifically addressed throughput. Engineers determined that most issues could be addressed using two custom jigs with integrated rollers to provide easy positioning of the backerboard. Each jig is only slightly bigger than the PowerGuard tile, which allows easy access to all sides. A vacuum hoist has been installed to allow one operator to handle the PV laminates.

A cured backerboard with spacers is placed on an alignment jig. Glue is applied to the spacers on the backerboard. The operator then maneuvers the vacuum hoist over to an alignment jig and places the PV laminate on top of the waiting backerboard (Figure 2). That operator then retrieves another backerboard, places it on the other alignment jig, and then retrieves another PV laminate. At the same time, another operator moves between the alignment jigs with the glue dispensers. Once the PV laminate has been attached to the backerboard and the glue has cured, the tile is removed from the jig and stacked on the shipping pallet. Two stacking jigs have been constructed where one was used before. This allows the operators to continue without interruption. Once they have completed one stack, they move to the second stack, instead of waiting for the pallet to be removed from the jig and replaced with an empty one.

Using one alignment jig, workers were recently able to process PowerGuard tiles at the rate of one per minute. By using two jigs simultaneously, the throughput is doubled.



**Figure 2: PV Laminate Placed on Backerboard**

An additional jig was designed and constructed for handling PV laminates prior to adhesion to the tiles (see Figure 3). The laminates are removed from their packing crate and set in the v-shaped jig if they need to be turned over. In this flip jig, the laminates can be leaned one way or the other, and then easily lifted using the hoist.



**Figure 3: PV Prep-and-Flip Jig**

### 3.15 Advanced Packaging

#### *Objectives*

Under this task, PowerLight was to specify and evaluate packaging for PowerGuard tiles. Goals were to maximize shipping efficiency, reduce costs, and provide easier handling, rigidity for product protection, and cost-effective return shipment to the factory. PowerLight was also to explore the use of recycled materials. Expected results were an increase in shipping volume to 90-100% and overall cost savings of 30-50%.

#### *Results*

**Summary:** Shipping volumes did not change, as an increase was not cost-effective. None of the alternatives to the present pallet was cost-effective. Improvements were made to reduce breakage during shipment. Because breakage was unpredictable, it is difficult to estimate cost savings.

#### **Discussion:**

To increase shipping volumes, PowerLight experimented with filling more of the potential shipping space (e.g. in a transport truck). However, this caused loading and unloading to take longer, increasing labor costs. Current shipping volumes are more cost-effective.

Regarding pallets, historically, PowerLight has stacked and shipped PowerGuard Tiles on wooden pallets. The tiles were stretch-wrapped with protective cardboard edging on all 4 corners. The pallets were either returned by truck to the factory or disposed of at the destination.

Based on our studies, the best off-the-shelf replacement for wooden pallets were plastic stackable pallets, which would be returned by truck to the factory. These pallets would consume less space than wood pallets during return transit and in storage at the manufacturing facility, and they would be more roof friendly because they lack protrusions, splinters, and nails.

The best plastic pallet for PowerLight's needs is made from high-density polyethylene and can be recycled at the end of its life cycle, which is 20+ shipments of product depending on damage sustained during shipping. It can be moved by a pallet jack or forklift. Use of these pallets would still require stretch wrap with corner protection.

Cost comparisons are as follows for the lifecycle of the plastic pallet:

	WOODEN PALLET	PLASTIC PALLET
Size	48" x 40"	48" x 40"
Uses per unit	1	20
Cost of Pallet	\$4.80	\$16.00
Weight of pallet	N/A	35 lb.
Cost of return shipping	Not returned	\$17.50 (\$.50/lb rate)
Total cost for 20 shipments	\$96	\$348.50
Cost per shipment	\$4.80	\$17.43

The shipping cost to return the pallets overwhelms any advantage that reusing them may provide.

PowerLight also investigated the possibility of making pallets with the styrofoam dust created by the cutting processes in the factory. A sample of the dust was sent to a company specializing in molding pallets out of reused material. A prototype was created, but the finished pallet weighed 80 lbs. This would make the use of these pallets in the factory very cumbersome.

Based on this information, wooden pallets still seem the best option for PowerLight at this time.

PowerLight has also made some packaging improvements to reduce breakage of PowerGuard tiles made with thin-film PV laminates. Thin-film PV laminates are made with untempered glass, and thus are more easily cracked or broken by rough handling. During shipping, some laminates had been broken in a way that indicated that they had been subject to flexing during shipping, and this seemed a result of the laminates not being supported at the edges. To address this problem, a foam and cardboard insert was created to help support the edges during shipping. The insert is made from an open-cell foam cut to conform to the PowerGuard tiles as they are stacked for shipping. The foam insert is shown in Figure 4, and the assembly is shown inserted into a stack in Figure 5.

Test pallets of PowerGuard incorporating thin-film laminates were packaged with these new foam inserts and shipped across the country to determine if the new inserts reduced the amount of breakage. While breakage was not eliminated completely, there were no flexing failures as had been observed in previous shipments. These inserts will be used when PowerLight ships PowerGuard tiles made with thin-film laminates.



**Figure 4: Packaging Insert for PowerGuard with Thin-Film Laminates**



**Figure 5: Packaging Insert in Use**

### 3.16 Materials Handling Between Stations – Task 16

#### *Objectives*

During Phase II of this project, PowerLight and its lower-tier subcontractor were to develop additional motorized conveyors and equipment to integrate the various stations of the PowerGuard assembly process into a seamless production line with an even throughput. Experience indicated that some additional production stations were necessary to ensure fully automated conveyance of the feedstock. These stations were to be fully integrated with the conveyor assembly and were to include these processes: loading boards into the conveyor line, cutting boards to proper dimensions prior to routing, scoring board surfaces for improved adhesion of the coating under the spacers, and separating boards following the coating station. Expected results were continuous, station-to-station operation, and a 50% reduction in operators.

#### *Results*

**Summary:** PowerLight has implemented a continuous, station-to-station operation. The number of operators has been reduced from 4 full time workers to one worker ½ time, which represents an 87% reduction in labor.

#### **Discussion:**

The machinery implemented in Phase II of this project was designed as an integrated system. All of the machinery is controlled by one programmable logic controller (PLC), and a series of sensors track the position of the material as it is processed to coordinate the movement of the machinery. In part due to improvements discussed in this section as well as improvements to other parts of the production line, PowerLight has been able to produce as many as 440 tiles in a single shift, which includes preparing the line prior to production and cleaning up after production.

The board stock is delivered to the PowerLight factory in large stacks of either 48” x 96” boards or 128” x 50.5” boards. A stack of boards is set on the input conveyor for the panel loader. The input conveyor has two rows of rollers and a central powered belt. An optical sensor in the middle of the input conveyor senses the presence of a stack. The belt is turned on by the PLC to move the stack forward. A second sensor is triggered when the stack is close enough to the de-palletizing lift, and the belt is turned off. A second stack of boards can then be loaded onto the input conveyor to be automatically moved into position when the first stack is depleted.

Four vacuum cups on an articulated arm pick up the top board on the stack. The arm then moves over the production line and down to a drop position. The board is then dropped through two sloped guides onto a belt. The arm then returns to the position to pick up a new board from the stack. The board that has been dropped onto the belt is moved forward toward two saw stations.

The first saw station is the rip saw, which cuts the board to the required width. The saw is stationary and cuts the board as the board moves past it. Scrap is dropped down onto a set of rollers slightly below the level of the main conveyor where it gathers until an operator clears it away. The position of the rip saw can be adjusted via a hand wheel attached to a screw. The position is adjusted, depending on what size PowerGuard tile is being manufactured, and held in place by a clamp.

The original production line specification called for a set of groove cutters to cut ¼” wide grooves along the boards to a depth of ¼”. These grooves would be located under two of the four spacers and would improve the adhesion of the coating to the backerboard. These groove cutters were designed and built with the intention of mounting them between the rip saw and the cross

cut saw. However, adhesion testing done by PowerLight and UL showed that the bond between the coating and the backerboard without the grooves was sufficiently strong. Thus the use of the groove cutters was eliminated to simplify the system and reduce the quantity of foam dust created.

The board then moves to the cross cut saw, which cuts the board into shorter sections for the router to cut the tongue and groove profile.

The cut boards are next delivered to the tongue and groove router. An operator loads the boards onto the router, which cuts the tongue and groove profile into the boards. They are then ready for the coating process.

The automated coating station was implemented in Phase I of this project.

### **3.17 PowerCurb Housing – Task 17**

#### ***Objectives***

Under this task, PowerLight was to evaluate in-house capability to fabricate the PowerCurb housings while reducing cost per linear foot of curb and increasing quality assurance and quality control (QA/QC). Results were to include an assessment of unit cost and a 50% labor reduction.

#### ***Results***

**Summary:** Three methods were assessed based on cost goals; see discussion. None of the methods proved to be cost effective at our current production volumes. We are pursuing the molding method in anticipation of larger production volumes in the future.

#### **Discussion:**

Several different methods of manufacturing curbs have been investigated. The possible methods considered were molding, extruding, and stamping. Each method involves certain tradeoffs.

Initially, research indicated that molding would be the most financially and qualitatively beneficial method. Two methods of molding curbs were investigated. Both methods involved fabricating plastic molds which would be filled with a modified cement mixture. One method involved using a durable mold, which would be used several times. The curbs would be taken out after they had cured. The other method used a much thinner mold, which would become the outside surface of the curb. Final costs were similar for each method.

After initial tooling outlays, molding could produce curbs at the target price per foot. However, engineers determined that the cost of dedicating the large amount of factory space needed for curing would push curb costs above target.

Extruding appears to be the lowest cost method, though it has turned out to be problematic in practice. Prototype equipment was tested in the PowerLight facility. It was set up on a conveyor so that the extruded material would move along the conveyor and could then be cut to length and moved to curing storage.

Tooling costs for extruding are much less than for molding. However, as with molding, full production would require setting up an assembly line and would likewise require a large amount of dedicated factory space. Costs, while lower than molding, were still at the top of the target range.

In addition, extruding proved to be difficult to control to the required tolerances. The consistency of the mix going into the extruding machine had to be controlled very carefully or the material would be too wet and would slump or it would be too dry and would crumble when cut to length.

It was also difficult to produce a curb sufficiently straight without complicated fixturing. Additionally, the surface of the extrusion needed to be finished by hand, and it was easy to deform the extrusion during this process. Even with the mix controlled very carefully, the cuts were never clean and always had to be dressed by hand. This increased the labor requirement significantly and slowed down the process, making the actual costs much higher.

The final method investigated was stamping. Concrete stamping is commonly used for making cinder blocks and patio bricks. Large numbers of identical parts can be turned out very quickly. Stamped parts are often used in outdoor applications, so it seemed that they should be well suited to the needs of PowerGuard curbs. Stamping machines are very large and generally have very high capacities. A single stamping machine could produce enough curb material for PowerLight for a typical year's production in 9 to 10 hours. Cost outlays for this method would include the fabrication of a fairly expensive mold. However, this is the one method with the potential to bring the cost of the curbs comfortably within PowerLight's target range.

Further analysis, however, regarding curb longevity, showed that while molding and extruding yielded curbs with very good freeze/thaw resistance, the stamping process yielded curbs that performed much more poorly in freeze/thaw tests. We believe that the application of a coating material would improve the life expectancy of stamped curbs, but this would raise the cost above the target range. Uncoated stamped curbs could be used if they were replaced every ten years, but this raises the long-term curb cost.

After substantial research, engineers have determined that the two possible choices at this time are molding or stamping. Molding involves committing considerable resources and factory space to the manufacturing of curbs. Stamping involves considerable setup expense and requires further experimentation to find a mixture with sufficient resistance to freeze/thaw damage. Though it seemed that a practical solution had been found for a new curb design at lower cost, the subsequent investigation of manufacturing methods showed that further research is needed to identify a new curb design to satisfy cost needs and to identify a suitable manufacturing method for that design. It is PowerLight's intention to continue this research beyond the scope of this phase of this project.

### **3.18 PowerBus Harness Assembly – Task 18**

#### ***Objectives***

Under this task, PowerLight had the following objectives:

- Assess options to lower the costs of assembling wire harnesses which connect AC PowerGuard tiles in parallel, and high-voltage DC tiles in parallel;
- Research and evaluate T-harness splice technology to find a preferred vendor;
- Work with the selected vendor to develop a two cavity T-mold fully encapsulating and environmentally sealing the splice;
- Perform environmental exposure testing of sample harnesses;
- Evaluate harness performance with system installations.

The revised wiring harness design is expected to reduce unit costs by 80 to 90%. The wiring harness design is to be submitted to UL for listing.

## ***Results***

**Summary:** The preferred option, after rigorous testing proved inadequate. This has resulted in a delay in finishing this task as PowerLight reassesses the options.

### **Discussion:**

Working with a wire splicing equipment vendor, PowerLight has developed a T-splice design. A splicing machine was equipped with special tooling for our needs. A series of prototype splice connections were made by the equipment vendor and tested at PowerLight. The first splice connections were covered with a mastic tape. A complete harness was constructed in this way and was installed in the field on a PowerGuard installation. This system is being monitored for long-term performance.

Samples of the splice connection were subjected to resistance testing. The measured resistance was compared with a length of plain copper wire. Initial results were very favorable.

Prototype T-splice harnesses have been made by the equipment vendor for evaluation purposes. The lead time associated with the vendor's operation lengthens the time required for each testing cycle. PowerLight has brought the splicing and molding machinery in house so that testing can continue at an accelerated pace to address the issues of mold material.

## **3.19 Modular Source Circuit Combining Circuitry (SCCC) – Task 19**

### ***Objectives***

Under this task, PowerLight had the following objectives:

- Design and develop an integrated board to replace the discrete components of PowerLight's array j-box;
- Design and develop a modular scheme for field connecting the array j-boxes to system combiner boxes;
- Design and develop a system combiner box with integrated circuitry components.

The result was to be the assessment of a newly standardized Source Circuit Combining Circuitry scheme with integrated circuitry, modularity with system size, and integrated components. Costs were to be reduced by 30 – 50% and installation time of SCCC components reduced up to 50% for larger systems.

### ***Results***

**Summary:** The revised design has cut material costs by 60% and labor costs by 80%. Installation time of SCCC components has been reduced by 90%.

### **Discussion:**

The revised modular SCCC design incorporates two boxes. A terminal box on the roof provides a weatherproof transition from outdoor grade wire to less expensive indoor grade wire. Wire gage can be upgraded at this point to accommodate voltage drop considerations. A combiner box near the inverter provides over-current protection and parallels strings prior to entry into the inverter DC disconnect.

Because a typical 100-kW installation now requires three boxes instead of twelve, the savings in labor and materials are considerable without applying integrated circuit technology (as was our objective in this task). Also, with the simplification of the components in the boxes, an integrated circuit board is not only unnecessary (since diodes have been eliminated), but would be much

more costly to develop. Each pair of boxes is custom sized for each job, with modular parts. The advantages of the current SCCC design are clear:

- Material cost savings of 60% and labor cost savings of 80% have been realized by reducing the number of electrical boxes, placing the DC circuit surge protector in the inverter, and removing blocking diodes.
- The strings are clearly marked in the combiner box and are easily accessible for diagnostics and voltage checks. The box is near the inverter, which greatly aids troubleshooting. It is possible to measure open circuit voltage (Voc) and operating current for every string of a 100-kW array in 15 minutes.
- The terminal box on the roof significantly cuts down on labor time, since the array wires terminate on the roof. The continuing wires are pulled through the rooftop conduit in a bundle.
- The terminal box allows the transition from outdoor-rated RHW wire to less expensive THHN wire, and provides the opportunity to use larger gage wire, if the voltage drop to the inverter is too high with the 12 gage harness.
- The terminal box provides a weather-tight method of getting wires from outside to inside the building, and provides a transition for conduit attachment.
- Access to boxes does not require disassembly of the PowerCurb, which reduces diagnostic and maintenance labor time significantly.
- Boxes can be assembled in the shop, with wire tie-downs pre-installed to cut down on field assembly time.
- More than one rooftop terminal box can be used for arrays split up around the roof.

### **3.20 Amorphous Silicon Tile Packaging – Task 20**

#### ***Objectives***

Under this task, PowerLight was to deliver a prototype a-Si tile for testing at NREL or Sandia National Laboratories (SNL). The tile design was to achieve a 10-20% reduction in board fabrication costs, while maintaining a 30-year design life and not exceeding laminate temperatures of 90°C.

#### ***Results***

**Summary:** All objectives were met. Cost savings exceeded 30%. The tile has a 30-year design life. It does not exceed laminate temperatures of 90°C.

#### ***Discussion:***

A thin-film module with a 1” spacer was shipped to NREL for testing on May 1, 2000. The a-Si tile may be fabricated using one of two preferred thin-film laminates.

The a-Si tile is constructed identically to the PowerGuard tile, except that 1” tall stand-offs (spacers) are used in the place of spacers that are typically 2” or 3”. Therefore, cost reductions already achieved for the PowerGuard tile are identical for the a-Si tile. PowerLight’s Phase I Final Report to PVMaT (section 3.1.4) documented savings in PowerGuard tile fabrication of 30% or more. Additionally, the reduction in spacer height results in material savings as well as shipping savings due to higher shipping density.

Accelerated life testing already conducted on the PowerGuard tile suggests that it can withstand 30 years or more in a rooftop environment. This testing has been conducted by UL, Arizona State University, Colorado State University (wind tunnel), the manufacturer of the PowerGuard adhesive, and internally by PowerLight. Testing has focused on the bond strength of the spacer attachments, resistance of the coating to freeze-thaw, and wind resistance of the PowerGuard arrays. While the a-Si tile design results in slightly higher PV operating temperatures, field results show that these temperatures remain below 90°C. Because prior accelerated life testing on PowerGuard components included temperature cycling between 90°C and -40°C with no performance degradation, the increased PV temperature should not reduce the life of the a-Si tile. In addition, our measured operating parameters are within the operating range guaranteed by the manufacturer; thus no decline in lifetime is anticipated.

A series of field tests in July and October, 1999, in Sacramento, CA, showed that a spacer height of 1" resulted in peak PV operating temperatures as high as 77°C under open circuit conditions, when the ambient temperature was over 33 °C. However, further research is being conducted to monitor PV and tile temperatures in various ambient conditions. An array of 1" a-Si tiles has been installed for long term monitoring on the PowerLight factory where ambient temperatures greater than 33 °C are expected.

### **3.21 Task 21 – intentionally omitted**

### **3.22 Component Testing, Certification and Safety**

#### **3.22.1 Environment, Health, and Safety**

##### ***Objectives***

The objective of this task is to incorporate applicable Federal and State Regulations into equipment design, operations, worker safety programs, installation manuals, Operations and Maintenance (O&M) manuals, and training programs. PowerLight is to ensure that it is in compliance with all applicable safety and environmental regulations.

##### ***Results***

Federal and State regulations governing the manufacture, installation and operation of PowerGuard PV roof tiles have been reviewed since the beginning of 1998. An assessment was conducted to identify those regulations within Federal and State Codes that apply to PowerLight's activities, and therefore have a bearing on process and equipment design.

PowerLight has ensured that all pertinent environmental and OSHA regulations are being met by initially reviewing these guidelines and incorporating them into equipment design, and by employing an OSHA representative and an environmental consultant to inspect the facility. In addition to these actions, PowerLight has also ensured worker safety by updating the Installation and O&M Manuals to incorporate the latest design and safety practices. These manuals and the initial training programs that PowerLight has begun will ensure that these systems are installed in manner compliant with all OSHA and environmental regulations.

In addition, PowerLight has made a concerted effort to recycle its manufacturing by-products, and has made the reduction of wastes a manufacturing priority.

### 3.22.2 Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels

#### *Objectives*

- Complete additional wind tunnel studies on PowerGuard RT systems;
- Compile data from wind tunnel studies on PowerGuard RT systems into a final report;
- Analyze failure data for PowerGuard RT systems and create final wind design tables;
- Create wind design tables for European and Japanese markets.

Wind tunnel tests are used to fully characterize PowerGuard's unique aerodynamic performance.

#### *Results*

Results of wind tunnel testing over this phase were incorporated into a final report. The final report is considered proprietary. However, results are summarized here.

Pressure tapping was conducted on roof models used in this study to draw comparisons to published data and validate the entire study. This effort was successful in that non-intuitive trends in some of the failure data were explained through the pressure measurements. Peer reviews of the pressure data and failure measurements were positive.

The effects of water on the rooftop, a more accurate model of the RT curb, and extended securement options for RT arrays were studied and included in the creation of final wind tables. A table was created for corrugated metal roofing, as this type of roofing is commonly used on commercial buildings in Japan.

Full-scale testing of the sloped PowerGuard in high winds revealed that the deflector panel experienced large oscillations and needed structural reinforcement. This was accomplished by incorporating a support mechanism at the center of the PV and deflector panel.

The final wind design tables for PowerGuard RT systems are included in Appendix A.

### 3.22.3 Underwriters Laboratories (UL) Listing

#### *Objectives*

During Phase II of this project PowerLight was to continue working with Underwriters Laboratories to expand PowerGuard's original UL listing. This was to include adding additional modules to the PowerGuard system, completing additional fire testing, and adding components to PowerGuard's Accessory File.

#### *Results*

**Summary:** PowerGuard's UL listing was expanded to include four new modules. Additional fire testing was completed. During this period, PowerLight began the process of updating the PowerGuard Accessory file to reflect current practices.

#### **Discussion:**

PowerGuard was originally listed with only the one module. In November 1999, PowerLight submitted an application to list three additional module assemblies – each module from a different manufacturer – as components in the PowerGuard mounting system:

To list these tiles, UL requires that the frameless module be certified as a UL recognized component. Then PowerLight is required to follow the re-test requirements in UL 1703 that are

applicable to mounting structures. These tests include accelerated aging testing, fire testing, humidity testing, mechanical load, temperature cycling, and a voltage current and power test.

Since these tests were completed with the original listing of PowerGuard, UL only required additional mechanical load testing to be completed. Additionally, since these modules are dimensionally similar, UL required that only one of the three be tested and qualified by similarity to the other two.

In December 1999, PowerLight sent a PowerGuard tile with one of the three modules to be listed to UL to undergo mechanical load testing. It withstood 293psf uplift load, which more than surpassed the 45psf required by UL 1703.

In January 2000, PowerLight submitted an application to list an a-Si module with the PowerGuard mounting system. Since this module's backing is glass and not tedlar, UL required us to complete additional adhesive testing. In February, PowerLight submitted samples of XPS adhered to glass with its preferred adhesive to undergo testing. This testing was successful, and in March 2000 this module was listed with the PowerGuard system.

As most modules have only been tested to Class C fire requirements, when PowerGuard was originally listed under Phase I it was tested to these requirements as well. However, during October 1999, PowerLight conducted extensive internal testing, to Class B and A requirements. Through this testing PowerLight found that the concrete coating allowed the product to withstand a Class B burning brand without exposing the roof deck.

In November 1999, PowerLight submitted a PowerGuard tile incorporating a preferred module for Class B fire testing at UL. This testing was successful, and since this module is intrinsically a Class C module, UL listed all PowerGuard tiles that incorporate modules with a Class C fire rating as Class B PowerGuard tiles.

At the same time, PowerLight submitted an additional PowerGuard tile for Class A fire testing, as it incorporated a module that already holds a Class A fire rating. This testing was successful and in December 1999, UL listed this tile as a Class A PowerGuard tile.

When PowerGuard was originally listed under Phase I, PowerLight listed three accessories to be used with PowerGuard. These included PowerBox™, PowerCurb™, and PowerBus™. In the fall of 1999, PowerLight received a quote from UL to submit an updated PowerCurb to the PowerGuard Accessory File to reflect current design practices.

#### **3.22.4 International Certifications**

Under Phase II of this project, PowerLight has continued to work with the International Compliance Services (ICS) department of UL and other organizations to determine applicable standards in the European Union (EU) and Japan. Under Phase II, PowerLight focused on the requirements of the CE Mark, International Engineering Consortium (IEC) and IEEE standards, and the specific requirements of Germany and Japan.

##### **CE Mark**

The CE Mark must be placed on any product exported to Europe; understanding the requirements of this mark, therefore, was a high priority. PowerLight worked with several consultants to determine these requirements and learned that to apply the mark, manufacturers must certify that their product meets all applicable EU Directives, draft a declaration of conformity to the applicable directives, and prepare a Technical Construction File containing product specifications and applicable testing results.

PowerLight and its consultant researched each of the EU Directives and found two directives applicable to photovoltaic systems: the Low Voltage Directive and the Construction Products Directive. It was determined that PowerGuard meets the Low Voltage Directive without additional testing. Therefore PowerLight prepared the appropriate Declaration of Conformity and the associated Technical Construction file. These documents were reviewed by consultants to ensure CE compliance.

The Construction Products Directive requires certification to IEC 61215; therefore compliance with this directive is not possible until IEC testing is complete.

### **IEC and IEEE Testing**

Through research on the requirements of EU member countries and the CE Mark, PowerLight learned that certification to IEC 61215 and IEEE 1262 is required to install a photovoltaic system in Europe. PowerLight found that there are three facilities recognized to complete this testing.

PowerLight determined which of the available facilities was the most cost effective and efficient place to complete this testing, and in June 2000, we began fabricating tiles for testing, which began in July 2000. However, due to a misinterpretation between PowerLight and the testing facility about the requirements of IEC 61215, these tiles were inadvertently destroyed in their test chamber.

From July through September 2000, PowerLight worked with the test facility and the IEC technical committee to determine the appropriate tests to certify PowerGuard to IEC 61215 and IEEE 1262. PowerLight, the test facility, and the IEC technical committee have now agreed on these tests, which will begin in October 2000.

### **Additional Testing in Germany and Japan**

Germany and Japan were found to have favorable markets for PowerGuard, therefore under Phase II PowerLight thoroughly researched the specific requirements of these countries. PowerLight has identified a license partner in Japan and has acquired appropriate building and fire codes through the Japanese Ministry of Construction. These codes are currently being updated to conform to IEC requirements. The new standards are expected to be published in January 2001, at which time PowerLight will submit samples for testing.

PowerLight has also researched German requirements for photovoltaic systems. In addition to IEC and IEEE certifications, Germany also requires the TUV safety mark and conformance to fire standards outlined by the Otto-Graf-Institute, Research and Testing Establishment for Building and Construction Products (FMPA). In August of 2000, PowerLight submitted samples to FMPA for B2 fire testing.

### **3.22.5 Inverter Anti-Islanding Testing in a Manufacturing Environment**

#### ***Objectives***

PowerLight worked with lower-tier subcontractor Trace Technologies to develop a load test that includes:

- Motor with inertia (sized for the 10-kW inverter);
- Capacitor bank (capacitance value recorded for unity power factor at 120V);
- Resistive load in addition to the motor load; and

- Time constant (time for the motor terminal voltage to drop by ½ from nominal AC test voltage when R & C are connected).

The effectiveness of this testing was to be demonstrated in a larger unit—up to 120-kW—in a commercial application.

### ***Results***

A test plan as described above was developed and implemented by the subcontractor. The results of the inductive motor load test were evaluated against the requirements of UL1741/IEEE929P. Under each of the test conditions, the inverter detected an island condition and shut down within the allowable time limit. The test procedure is included in Appendix B.

After the anti-islanding circuitry and software was developed and tested, it was installed in a 100-kW inverter connected to a PowerLight commercial demonstration PV system in Hopland, CA. It has been operating for several months in this configuration.

## **3.23 Integrated Design Software**

### ***Objectives***

To simplify the physical and electrical design of PowerGuard systems, PowerLight was to develop custom Integrated Design Software based on an AutoDesk program called Actrix Technical 2000. This software would easily incorporate drawing specifications into Excel spreadsheets, which allow a Bill of Materials (BOM), permit drawings, and quotations to be generated in an expeditious manner.

This software was to be developed with the following objectives in mind:

- Create software that automates the design process, the creation of the BOM, and quotation packages based on the array layout and electrical drawings generated by the user;
- Allow both an experienced AutoCAD user and a person unfamiliar with AutoCAD the ability to create an array layout and electrical drawings needed to design a PowerGuard system;
- Allow a user the ability to import AutoCAD drawings into the software and the ability to export drawings created in the software into AutoCAD.

### ***Results***

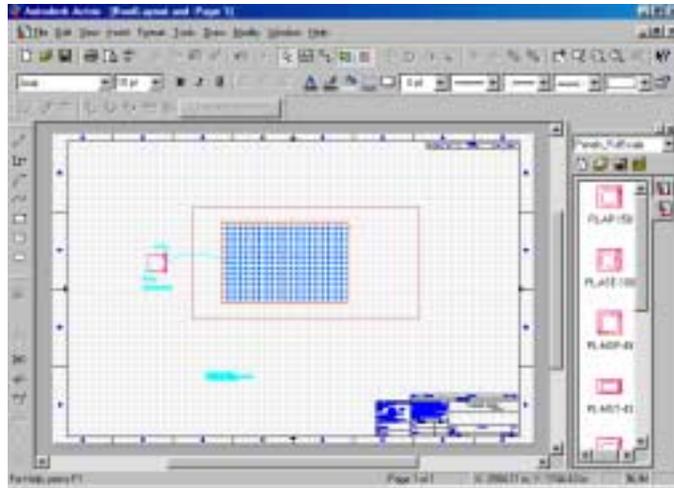
**Summary:** PowerLight has developed integrated design software that meets all objectives.

### **Discussion:**

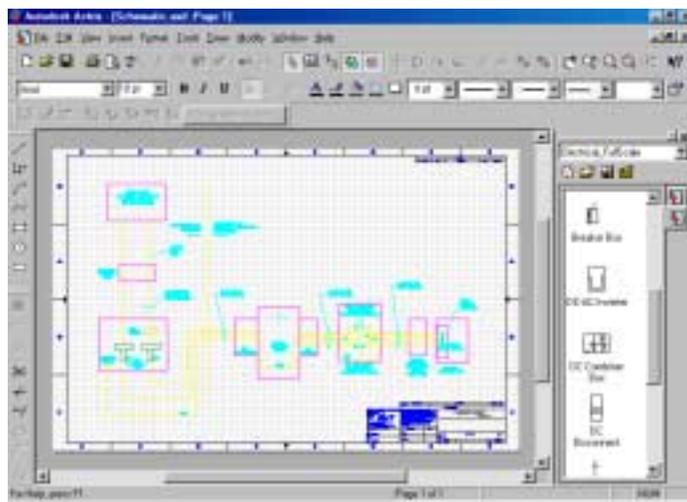
After receiving quotes from qualified consultants, PowerLight chose the one which proposed using an off the shelf AutoDesk software called Actrix Technical 2000. PowerLight found it preferable to use this software because it was developed by AutoDesk, and is therefore inherently similar to AutoCAD. Actrix also has many key features that made it preferable for our purposes such as its ability to create active shapes and its user friendliness.

Engineers found that Actrix can be customized by Visual Basic for Applications to create a user-friendly automated interface.

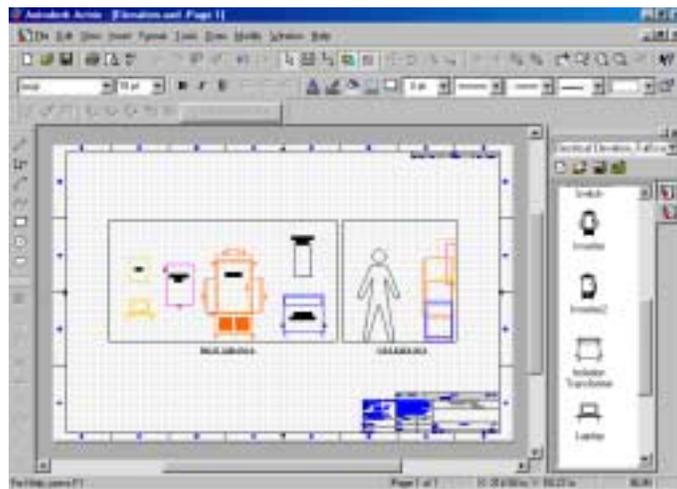
Once Actrix was selected, PowerLight worked with the subcontractor to create three drawing templates (rooftop array layout, electrical schematic, and electrical room elevation) in which a user could create a drawing. Figures 6, 7, and 8 show these templates and a sample drawing created in Actrix using the template.



**Figure 6: Sample Rooftop Array Layout Created in Actrix Technical 2000**

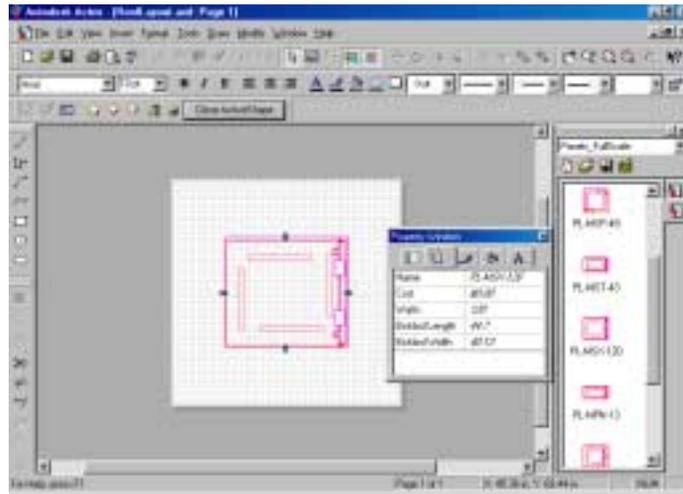


**Figure 7: Sample Electrical Schematic Drawing Created in Actrix Technical 2000**



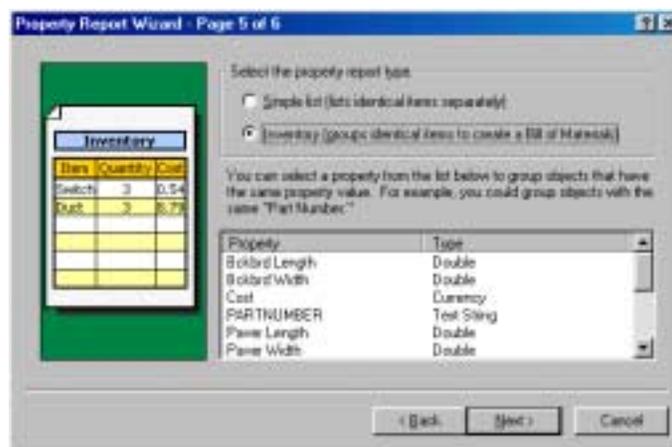
**Figure 8: Sample Electrical Room Layout and Elevation Drawing Created in Actrix**

In each of these templates, active shapes were created that are shown to the right of the drawing field. These active shapes can be placed into the drawing field and have associated properties that will be used in a BOM or quotation package. Figure 9 shows the active shape editor and property window of a selected laminate active shape. As shown in the figure, this shape has an associated cost, power, and backerboard dimension. These properties can be edited and added to over time as the parameters of the selected laminate tile are modified.



**Figure 9: Selected Laminate Active Shape Property Window**

Once these properties are defined, Actrix has the capability to generate a property report or BOM in a tab delimited (.txt), comma separated (.csv), or Microsoft Excel (.xls) format. This is generated using the property report wizard, which is similar to a Microsoft Excel Chart wizard, in that it allows users to choose the fields to be included in the report. Figure 10 shows the step in this process in which the user specifies the property report type. These reports will be used to generate a BOM and quotation package, and could eventually be linked to a Material Requirements Planning (MRP) system.



**Figure 10: Actrix Property Report Wizard**

Although Actrix has some limitations, PowerLight has found it to be a cost-effective design tool. The customized software allows both experienced and inexperienced AutoCAD users to design a PowerGuard system with ease.

### **3.24 PowerGuard System Packages**

The smaller the project, the higher the \$/watt cost of a PowerGuard installation. This is due to the variety of fixed costs involved in designing, permitting, and installing a PowerGuard system. For relatively straightforward installations, substantial cost savings can be realized if some of the processes associated with fixed costs can be standardized. Much of this work could then be performed once, and results used again and again on multiple projects.

Under this task, PowerLight has created a series of system packages based on economical modular increments. An installation manual was created for the specified systems and was distributed to qualified Value Added Resellers (VARs).

### **3.25 Assessment of Commercial Demonstrations – Task 25**

#### ***Objectives***

Under this task, PowerLight was to assess commercial demonstration projects in order to evaluate the performance of the system, review the cost savings, and assess the effectiveness of changes made during Phase II of this project.

#### ***Results***

**Summary:** PowerLight compared performance and cost of projects manufactured before PVMaT Phase II with projects manufactured and installed after Phase II. System performance has not been compromised, and the quality (e.g. fit and finish) has improved. Overall manufacturing costs were reduced 57%; an additional 74% reduction in materials costs was realized during installation. Labor requirements have been reduced, as demonstrated in recent batch production runs. For example: for a pre-phase II project, it took 6 weeks and 6 workers to manufacture 350 boards. For a post-phase II project, it took 2 days and 8 workers to manufacture 500 boards.

#### **Discussion:**

This report has detailed a number of manufacturing improvements. The following are additional PowerGuard manufacturing and installation assessments of project installations during this period that incorporated advancements made as a result of this program. The aspects considered were: palletizing, roof preparation, handling of materials, materials lift, PowerGuard tile manufacturing router and tile alignment, RT Curb corner design, thin-film parallel wiring connectors, and DC electrical equipment consolidation.

#### **Palletizing with the Stretch Wrapping Sidewinder Machine**

With the addition of the stretch wrapping Sidewinder machine PowerLight has been able to improve packaging by better securing PowerGuard tiles to pallets and to decrease stretch wrapping labor costs with increased wrapping efficiency when compared to previous hand held plastic wrapping tools. The risk of breakage during shipment has decreased because materials are better stabilized when compared to hand wrapped pallets. The stretch wrapping Sidewinder machine has also eliminated onsite re-wrapping of hand wrapped pallets prior to craning to the roof. This in turn has decreased onsite labor costs.

#### **Roof Preparation & Crane Lift**

When PowerGuard tile pallets are lifted, a protective 2” polystyrene board larger than the module needs to be placed on the top to prevent the pressure of the lifting straps from breaking the top

module. The angle of the lifting straps from the edge of the top module to the lifting ball must not be less than 60 degrees to prevent added pressure to the top modules.

### **Router Cutting Improvements**

Router improvements on the manufacturing line have greatly improved PowerGuard tile alignment. This has made the installation of the PowerGuard tiles easier, which in turn has decreased installation time. Improved alignment also has aesthetic benefits. When boards are identical in width, length, and height the mortar edges fit together tightly creating perfect lines throughout the PowerGuard system.

### **RT Curb Corner Design**

With the design of square box RT Curb Corners, the installation of the RT Curb has improved. It is easier to install the corners than to make miter cuts on the RT Curb. The RT Curb Corners are also forgiving in that they minimize the effect of uneven roofs on the RT Curb. The RT Curb Corners are slightly taller than the RT Curb, allowing height differences of the RT Curb to blend into the RT Curb Corner.

### **Parallel Wiring of Thin-Film Strings on the Roof**

On the PowerLight project, parallel wiring harnesses were used with thin-film modules on the roof. This design decreased the number of wire runs from the array to the terminal box and from the terminal box to the DC-fused Combiner box. With this decrease in wires, these two boxes were designed to a smaller size, which in turn allowed consolidation of DC electrical equipment. Without parallel wiring, installers would need to fabricate, in the field, 72 wire runs from the array to the inverter. With parallel wiring, only 16 such “home runs” were required. This resulted in a 74% cost reduction in materials and field labor.

### **DC Electrical Equipment Consolidation**

With a smaller terminal box, it is possible to integrate DC electrical equipment into the RT Curb, eliminating the costs of additional mounting hardware. PowerLight has reduced costs by purchasing smaller, less expensive electrical boxes and decreasing the purchase quantity of electrical components used for internal wiring. A smaller DC-fused Combiner box also makes it easier to locate mounting areas in electrical rooms.

## **3.25A Sloped Tile Refinements and Testing – Task 25A**

### ***Objectives***

A sloped version of the PowerGuard tile will increase the annual energy capture of a photovoltaic array, particularly in higher latitudes. While Phase I work yielded a sloped tile product that performed well in the field, engineers identified design refinements necessary for commercialization. Under this task, PowerLight and its consultant were to address the following design issues:

- Replacement of the hinge mechanism between XPS spacer and the backerboard for improved manufacturability;
- Verification of the chosen hinge mechanism as the best solution;
- Development of an improved clasp mechanism joining the upper edge of the PV with the tile backplate.

In addition, engineers aimed to produce a sloped PowerGuard tile which could be fabricated in a flattened configuration for shipment, but which would not cost much more than a standard PowerGuard tile. It was expected that the resulting sloped tile would be stronger and meet standards for European products.

### ***Results***

**Summary:** Research and field-testing show that the resulting design meets design and performance criteria and will meet European product standards.

### **Discussion:**

The sloped PowerGuard design went through several iterations during this phase. Initially, the design consisted of two wedge-shaped foam spacers attached to hinges which were in turn attached to the coated backerboard. The PV laminate and wind deflector were likewise hinged. The foam spacers supported the PV and the deflector while they were folded down flat. In the field, the PV and deflector were lifted up, the wedge spacers were folded up into an upright position, and then the PV and deflector were set down on top of the spacers and attached to each other at the top.

While this design performed well in the field, it had a large number of parts, all of which needed to be carefully aligned during the fabrication process, making the assembly very costly. The consultant PowerLight hired to improve on this design produced a design largely constructed of sheet metal. Details of the design will be released following patent filing. Cost savings are realized through a reduction in the number of parts and an ability to ship materials flat.

## **3.25B Tile Edge Trimming Station**

### ***Objectives***

The contour of the edge of the coating on PowerGuard backerboards is very important for the fit of the boards, as they are laid out on a roof, and for ensuring tile longevity. If the edge of the coating extends slightly beyond the foam edge of the backerboard, the tiles will not fit together closely, and the tongue and groove profiles will not mate properly. If the coating edge is slightly short of the edge of the backerboard or if it has too much slope, sunlight will penetrate the tongue profile and degrade the foam. These constraints pose a number of quality control and cost and labor reduction problems. The expected results of this task were a semi-automated system that reduced the number of operators needed at this station by 2/3 and improved repeatability and quality of the edge shape.

### ***Results***

**Summary:** The number of operators has been reduced from 6 to 1. Repeatability and quality of the edge shape have been improved.

### **Discussion:**

When the new production line in the Berkeley PowerLight factory was first installed, the edge trimming was done at the end of the conveyor. Each tile was lifted from the end of the conveyor and set on a low table the top of which was slightly smaller than the backerboard. Two workers would trim the four edges of each tile using a hand-held trowel. Trained workers could do this fairly rapidly. However, because the trowel had to be held at a steady angle with just the right amount of pressure, the quality of the edge varied depending on the skill and attentiveness of the worker. To keep up with the speed of the coating process, two tables were set up so that two boards could be trimmed simultaneously. Six workers were required: two to move the coated

boards from the conveyor to the trimming tables and two working at each trimming table. In addition, after trimming and stacking, operators noted some degree of slump in the coating, which in many cases required a second trimming.

Engineers pursued two possible system options to address these issues. The first entailed mounting trowel blades to four rail-mounted carriages which would all move along the board edges and quickly trim the coating. The second entailed designing hand held tools for custom trimming.

The first option seemed preferable, as it could be easily automated. This would provide faster throughput and more consistent, better quality boards. Investigation revealed, however, that this method would be impractical due to the variation in the coating mix caused by ambient humidity and temperature.

The disadvantage of the second option was that it is hard to trim edges with a trowel when tiles are stacked. Since the worker must trim edges at various heights, it is difficult to maintain consistency. Furthermore, trimming with a trowel under any conditions poses repeatability and quality problems. We needed first to improve the trimming tools and then to improve the trimming process.

A series of prototype tools were designed and fabricated which fit snugly into the tongue and groove contour and hold a blade set at a firmly maintained angle to trim the coating. Six prototypes were made with varying blade angles, and an optimal angle was found. With the new tools, trimming board edges after stacking was no longer an inconsistent process.

The initial prototype tools were made of plastic, which worked well, but the tools were a bit heavy and expensive. For the second round of prototyping, a team of industrial designers designed and constructed more than twenty tool models. Of these, a few were developed further. The most promising prototype was a long tool with multiple blades; these qualities would allow the tool to be securely engaged with the tongue or groove profile of the board, with one of the blades extending beyond the edge of the board.

The final version was designed out of sheet metal with a plastic insert to match the tongue or groove contour. Two blades are mounted on the ends of the tool. An ergonomically designed handle is mounted to the outside, making it easy to manipulate and comfortable to hold.

A design study was also done to optimize the mounting of the trimming blade to the tool. An optimal mounting system would mount the blade in a repeatable position to ensure consistent edge contour and allow for a fairly easy blade change when the blade was worn out.

While the initial trimming method, at the end of the production line, required six workers plus another to inspect and clean up the edges later, the new method of trimming stacked boards with the new tool requires only one worker. That one worker can easily keep up with the production line even though production line speed has increased significantly during this phase of the project. In addition, the repeatability of edge shape and the quality of finished product have exceeded minimum performance specifications.

### **3.25C End of Line Lifter/Stacker**

#### ***Objectives***

Under this task, PowerLight was to experiment with end-of-line methods which ensure board straightness and proper stacking and which anticipate semi-automated methods, and then to design the semi-automated equipment for lifting and stacking, preferably from off-the-shelf assembly equipment. The specific objectives were to:

- Reduce labor required by 50%;
- Increase throughput from 60 seconds per tile to 45 seconds per tile;
- Improve quality assurance of bonded parts (spacer to backerboard);
- Eliminate periodic restacking of finished pallets.

### ***Results***

**Summary:** The new stacking system has met or exceeded all objectives. Labor has been reduced 50%. Throughput was increased to 20 seconds per tile. Quality assurance has improved, and periodic pallet restacking has been eliminated.

### **Discussion:**

When the new production line in the Berkeley PowerLight factory was first installed, coated boards coming off the conveyor were lifted up by two workers and set down on a trimming table. The edges were trimmed, and the boards were lifted again and set in a stacking jig on a pallet. This method of stacking caused concern about the integrity of the bond between the spacers and the board coating. The boards flex when they are lifted by hand from each end, which can cause the spacers to pop up out of the coating in the center. This problem was worse when the spacers had been previously glued to the PV laminates. The PV laminate, being very stiff, would hold the spacers rigidly, and the coated boards would sag away from them.

When the production method changed so that spacers were attached to the boards first and the PV laminates were glued to them later, the problem was less obvious, but a new method of stacking the boards was still needed. With the PV in place, the boards would slide easily on top of each other. Without the PV, however, the boards would not slide easily. A method was needed to move the boards into position and then lower them onto the previously stacked boards. Because boards of different dimensions behaved differently, two methods were developed.

For fairly long and narrow boards, sag is only an issue in the long direction. The boards are sufficiently narrow to not sag in the short direction. For these boards, two rails were constructed. They were equipped with handles at each end. The boards are slid onto a narrow table, and a rail is lifted into contact with the board along each of the long sides. The rails are shaped so that they slide in toward the center of the board a consistent amount. On the tongue side of the board, the rail is equipped with alignment brackets. The rail is pushed up against the board to be lifted until the alignment brackets contact the tongue profile on two sides. Two workers then lift the two rails and the board and move it to the pallet on which the boards are being stacked. Alignment brackets on the bottom of the tongue side rail contact the tongue profiles of the top board on the stack, aligning the board held by the rails with the stack. The new board is then lowered into place. Thus the boards are lifted without sagging and are stacked in consistent, straight stacks.

For boards closer to square, sag is a concern in both directions, and a different lifting and stacking method had to be devised. The best approach seemed to be to lift each board with a set of forks which would span the board in one direction and would be spaced at an optimum distance from the center so that the board would not experience significant sag in the other direction. These forks needed to be retractable so they could set a board on the stack, and then move back, either up or down, to the correct height to collect another board and place it on the stack. To accomplish this, a retractable fork assembly was designed and constructed on top of the platform built on the hydraulic lift. Using extruded aluminum rails, a frame was constructed over which the board could slide and which also supported the sliding forks. The board slides onto the fork and frame assembly up to an alignment fence. The forks are then pushed forward. A second alignment fence on the forks pushes against the board. The forks slide forward until a stop

bracket is contacted. The lift is then lowered until the board rests on the stack. The forks are then pulled back until they clear the stack.

The new stacking system has met all the objectives for this task. It has reduced the labor from four laborers to two, a 50% reduction. Furthermore, the four laborers previously required were able to stack boards at a maximum rate of about 50 seconds per board. With the new system, two laborers can consistently stack boards at 20 seconds per board. Quality assurance has been improved: there is now minimal sag of the board and little opportunity for the spacers to pull away from the backerboard. Since the new stacking system moves each board to the same position each time, the boards are stacked neatly and consistently.

### **3.25D Clean-up and Waste Management**

#### ***Objectives***

Under this task, PowerLight was to develop methods to handle and dispose of all primary waste from operations at the factory. We were to develop a cleaning station for the hopper and for the mixing tube of the coating mixer to enable quick spray down of these components into a settling trough for later disposal; research how to dispose of or recycle the polystyrene foam dust which exits the router; and construct an apparatus to manage cement dust at the dry goods silo intake.

The specific objectives were to:

- Reduce cleanup time from 3 hours per day to 1 hour per day, thus increasing plant throughput to 420 tiles/day;
- Reduce the cost of XPS waste disposal by 50 to 75%;
- Capture 95% of the dust at the intake feed of the dry goods silo.

#### ***Results***

**Summary:** Cleanup time is less than 1 hour per day. We have identified the option that will reduce the cost of XPS waste disposal by the target amount, but the equipment has not yet been purchased. Capture of silo dust has not been formally measured; however, with the below-described improvements, the factory is now virtually dust-free.

#### **Discussion:**

##### **Clean-up**

Improvements to many parts of the PowerGuard manufacturing line have reduced cleaning time to less than one hour. Changes to the design of the coating hopper and the creation of a cleaning trough for the mixing shaft of the continuous mixer have significantly reduced cleaning time of the parts of the production line associated with the coating process. Further improvements in the consistency of the coating mixture have resulted in less contamination of the rollers of the conveyor system. This eliminates a time consuming cleaning task.

One of the design priorities for the second generation coating hopper was ease of assembly and disassembly. The original coating hopper was very difficult to disassemble, and when it was disassembled, all adjustments were lost. The new hopper is held together with special clamps so that it disassembles in about a minute or two making cleaning easy and fast. Most parts can be cleaned before the coating has a chance to start setting up, making the cleaning process a wiping down rather than a scrubbing process. Re-assembly of the hopper takes about five minutes since all the adjustments are retained even when the hopper is taken apart. This allows for easy set-up of the line to prepare for the next day's operation.

### **XPS Waste**

The dust collection system for the router has been modified to provide for easier and more efficient removal of the XPS dust from the collection bags. Previously, emptying the collection bags was time consuming, and it was difficult to contain all the XPS dust. New collection bags were fabricated with drawstring closures on the bottom. The system was raised off the floor and a hoop placed under the collection bag to hold a plastic bag. When the drawstring is opened the collection bag empties into the plastic bag. This setup is shown in Figure 11. The plastic bags of XPS dust are sent to the recycler, which also collects the scraps of XPS boards.



**Figure 11: Modified XPS Dust Collection System**

### **Silo Dust**

A vacuum system and dust containment box have been installed on top of the dry goods silo. The vacuum uses a special filter to maximize dust capture. The containment box is shown on top of the silo in Figure 12.



**Figure 12: Dust Containment Box on Dry Goods Silo**

**APPENDIX A**

**PowerGuard RT System Wind Design Tables**

*For PowerGuard Tiles with a 15 Degree Slope on Adhered Membranes*

**A. For Parapet Heights of 0" to 18" (0 to 45.7 cm)**

**Maximum Wind Speed, MPH (m/s)**

<b>System 1 Securement</b>							<b>System 2 Securement</b>					
<b>Middle Roof Position</b>			<b>Corner or Edge Roof Position</b>				<b>Middle Roof Position</b>			<b>Corner or Edge Roof Position</b>		
<b>Building Height, ft (m)</b>	Exposures A + C	Exposure B	Exposure D	Exposures A + C	Exposure B	Exposure D	Exposures A + C	Exposure B	Exposure D	Exposures A + C	Exposure B	Exposure D
15 (4.6)	140 (63)	140 (63)	120 (54)	140 (63)	140 (63)	120 (54)						
30 (9.2)	120 (54)	130 (58)	110 (49)	120 (54)	130 (58)	110 (49)						
45 (13.7)	120 (54)	130 (58)	110 (49)	110 (49)	120 (54)	95 (42)						
60 (18.3)	110 (49)	120 (54)	110 (49)	100 (45)	110 (49)	90 (40)						
75 (22.9)	110 (49)	120 (54)	100 (45)	100 (45)	110 (49)	85 (38)						
90 (27.45)	100 (45)	110 (49)	100 (45)	100 (45)	100 (45)	85 (38)						

**B. For Parapet Heights greater than 18" (45.7 cm)**

**Maximum Wind Speed, MPH (m/s)**

<b>System 1 Securement</b>							<b>System 2 Securement</b>					
<b>Middle Roof Position</b>			<b>Corner or Edge Roof Position</b>				<b>Middle Roof Position</b>			<b>Corner or Edge Roof Position</b>		
<b>Building Height, ft (m)</b>	Exposures A + C	Exposure B	Exposure D	Exposures A + C	Exposure B	Exposure D	Exposures A + C	Exposure B	Exposure D	Exposures A + C	Exposure B	Exposure D
15 (4.6)	140 (63)	140 (63)	140 (63)	140 (63)	140 (63)	120 (54)						
30 (9.2)	130 (58)	140 (63)	120 (54)	120 (54)	130 (58)	110 (49)						
45 (13.7)	120 (54)	130 (58)	110 (49)	120 (54)	130 (58)	110 (49)						
60 (18.3)	110 (49)	120 (54)	110 (49)	110 (49)	120 (54)	110 (49)						
75 (22.9)	110 (49)	120 (54)	100 (45)	110 (49)	120 (54)	100 (45)						
90 (27.45)	100 (45)	110 (49)	100 (45)	100 (45)	110 (49)	100 (45)						

Notes:

- 1 No part of the array may not be closer than 4 ft (1.2 m) to the building or parapet edge.
- 2 The array is in the corner roof position if any part of the array falls within a distance 'a' from two building edges, as defined in note 4.
- 3 The array is in the edge position if any part of the array falls within a distance 'a' from one building edge, a defined in note 4.
- 4 The dimension 'a' is defined as 10 % of the least horizontal building dimension, or 0.4 times the mean roof height (eave height shall be used for flat roofs), but not less than either 4% of the least horizontal dimension or 4 ft (1.2 m).
- 5 Surrounding terrain has an effect on the overall wind exposure of the building. The exposure in which a specific building or other structure is sited shall be assessed as being in one of the categories described in the document ASCE 7-95.
- 6 Roof pitch may not exceed 2 in 12.

# **Anti-Islanding Test Plan For Trace Technologies' Utility-Tied Photovoltaic Inverter (With Induction Motor Load)**

Trace Technologies Corporation  
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Document # PE0####



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<b>Rev. #</b>	<b>Comments</b>	<b>Date Issued</b>	<b>By</b>
1	Initial Release	11/04/99	K. Sheldon



## 1.0 Purpose

This document describes test procedures to verify proper anti-islanding protection and operation of Trace Technologies' photovoltaic utility-tied inverters.

## 2.0 Scope

Due to inverter islanding concerns it has been requested that Trace Technologies perform tests in addition to UL1741 to verify successful inverter anti-islanding protection within Trace's photovoltaic utility-tied inverter line. This document describes the test procedure to be performed at Trace Technologies. The test procedure and method has been adapted from UL1741, section 46. A full record of test results shall be provided.

## 3.0 Test Equipment Required

- Trace Technologies model PV10208 10kVA utility-tied photovoltaic inverter
- Isolation Transformer, 208:480Y/277V, 15 kVA (1)
- 225 kVA Trace Technologies DC Supply
- Isolation Transformer, 480:480Y/277V, 300 kVA (1)
- Voltech PM3000A Digital Power Analyzer (2)
- Tektronix DSA-600 Digital Storage Oscilloscope (1)
- Fluke 87 Multimeter (1)
- Variable Resistive Load Bank, Balanced 3-Phase, 20kW
- Variable Capacitive Load Bank, Balanced 3-Phase, 25kVAR
- Induction Motor, 10 HP 3-Phase

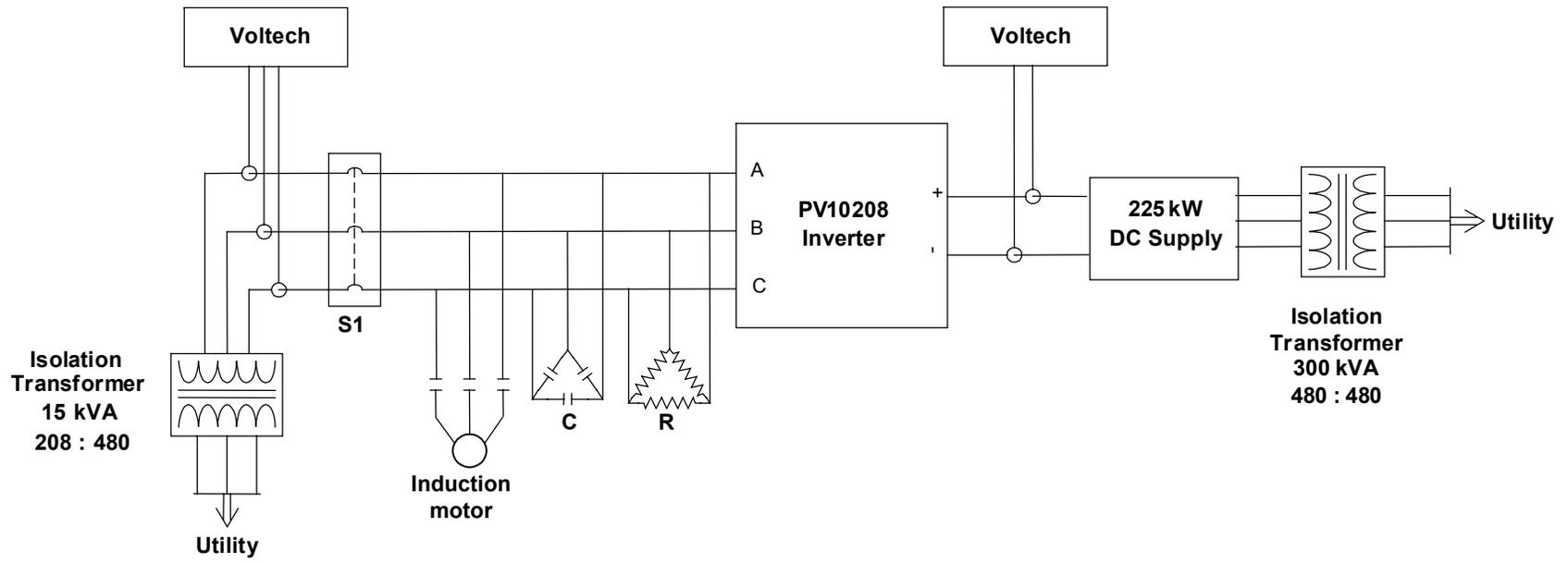
## 4.0 Anti-Islanding Test Procedure

- 4.1 The inverter and isolation transformer shall be connected to a stable 3-phase, 480Vac, 60Hz utility source.
- 4.2 The inverter shall be connected to the balanced load circuit which contains the 3 phase induction motor in place of the U/L required passive RLC load.
- 4.3 The induction motor is run no-load, the resistive load is used to test at different load points and the capacitor bank is used to correct the power factor to values shown in the table below.
- 4.4 Open utility breaker S1.
- 4.5 The inverter shall cease power production to the load within 2 seconds of opening the switch. Record the time required for the inverter to shut down under each trial.
- 4.6 Close breaker S1 after the inverter stops processing power and disconnects from the utility. The inverter shall not start processing power for a minimum of 5 minutes.
- 4.7 Repeat the test 5 times for each condition. Record results for each test in the test record.

Rated Load (%)	Power Factor (%)	Inverter Output (% of rated)
75	95% Leading	75
100	95% Leading	100
75	100% Unity	75
100	100% Unity	100
75	95% Lagging	75
100	95% Lagging	100

## 6.0 Attachment

Test Configuration Diagram



**Attachment 6.2**  
**PV - GTI Anti- Island Test Configuration**

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 2001	3. REPORT TYPE AND DATES COVERED PVMaT Phase II Technical Progress Report 1 July 1999–30 September 2000		
4. TITLE AND SUBTITLE PowerGuard® Advanced Manufacturing, PVMaT Phase II Technical Progress Report 1 July 1999–30 September 2000			5. FUNDING NUMBERS CF: ZAX-8-17647-12 TA: PVP16101	
6. AUTHOR(S) T.L. Dinwoodie and J. Botkin				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) PowerLight Corporation 2550 Benvenue Avenue Berkeley, CA 94794			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NREL/SR-520-30247	
11. SUPPLEMENTARY NOTES  NREL Technical Monitor: Holly P. Thomas				
12a. DISTRIBUTION/AVAILABILITY STATEMENT National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			12b. DISTRIBUTION CODE	
<p><b>13. ABSTRACT (Maximum 200 words)</b> This project introduced incremental improvements to PowerGuard system components and manufacturing processes to significantly reduce the costs of a PowerGuard system. The improvement resulted in a lower cost, higher impact PV product. During Phase II, these accomplishments have resulted in: A production rate of greater than 400 PowerGuard tiles per shift (20 MW/year) manufacturing capacity; 57% cost reduction for PowerGuard tile; UL listing for four additional PowerGuard tiles configurations; Improved quality of finished goods due to improved tooling and processes in manufacturing, simultaneously improving throughput and lowering cost of \$3.80/Wp for large systems.</p> <p>In Phase III of this contract, PowerLight will continue efforts to improve the manufacturing processes for PowerGuard. Specific performance objectives during phase III are as follows: Demonstrate system cost reduction from \$3.80/Wp to \$3.05/Wp for large systems; Establish or assess the performance of dedicated PowerGuard PV module plant capacity of 2 MW per year; Complete wind tunnel testing of all design refinements; Produce an installation manual and training program for installing PowerGuard systems; Establish performance of manufacturing modifications based on assessment of commercial systems which incorporate the new features and processes; and Finalize UL, International Conference of Building Officials (ICBO), and international listings of PowerGuard improvements. These are expected to result in a lower cost, higher impact PV product, as sought by this program.</p>				
14. SUBJECT TERMS PV; PowerGuard system; components and manufacturing process; flat tile; sloped tile; advanced packaging; amorphous silicon; PV system; crystalline silicon			15. NUMBER OF PAGES	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT  UL	