Subcontractor Report

July 2004 • NREL/SR-520-36246

# Plug and Play Components for Building-Integrated PV Systems

## Phase I—Final Report
## 20 February 2002–19 February 2003

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*RWE Schott Solar, Inc.*
*Billerica, Massachusetts*

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Operated for the U.S. Department of Energy
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Prepared under Subcontract No. NDO-2-30628-05

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## Executive Summary

RWE Schott Solar, Inc. is developing innovative new products to facilitate the broad use of its PV systems in the current markets. This report summarizes the progress made by the company in these developments. This work was conducted under NREL's PV Manufacturing R&D Project, subcontract No. NDO-2-30628-05. The project is a two-phase effort. The first phase consists of development and testing of a novel new flat-roof PV array mounting system, development and UL listing of new PV array source circuit combiner boxes for the company's PV systems, testing and evaluation of fasteners used to secure mounting brackets to residential roofs and the development of a simplified PV system interconnection device for residential applications. Significant progress has been achieved.

A major focus of this effort has been the development of the company's new free-standing (FS) system for mounting large PV arrays on flat-roof buildings. Advantages of the FS mounting system include:

1) No penetrations of the building roof are required, except as may be required for routing wiring from the PV array into the building,
2) The weight of the PV array and mounting equipment is at or below 3 pounds per square foot, keeping the added loading on the building to within the limits of typical construction,
3) The FS mounting system is adaptable for use with individual large-area PV modules and assemblies of PV modules,
4) PV modules are deployed at a non-zero tilt angle to benefit annual energy production,
5) PV modules are open on all sides and underneath for ambient air circulation and passive cooling, to the benefit of module efficiency, energy production, life expectancy; and to promote evaporation of water from roofs,
6) The FS mounting system can be deployed on a flat roof of any type construction,
7) The FS mounting system contains features to expedite field installation labor and simplify PV array wiring,
8) The FS mounting system provides space between rows for easy access to PV modules for service; all modules can be easily accessed for inspection, repair, and replacement,
9) PV modules can be readily moved for roof inspection or repair, and
10) The FS mounting system with its dynamic feature automatically responds to high-velocity wind, allowing modules to reduce horizontal blockage by pivoting to a shallower tilt angle, and thereby reducing or eliminating uplift forces.

The patent-protected penetration-less FS mounting system was wind-tunnel tested at the Massachusetts Institute of Technology, achieved its design and performance goals and was introduced in late 2002. Progress on this and the other important elements of this contract are presented in the following sections.

Figure 1. The free-standing (FS) system developed under this contract is the flagship PV array mounting system now offered by the company. Wind-tunnel testing and computational fluid dynamics analyses were made possible by the PV Manufacturing R&D Project to help document the performance of the system in high winds.

## 1.0 Introduction

This section of the report provides an overview of RWE Schott Solar and the background of the development of the FS mounting system.

RWE Schott Solar, Inc. was formed in 2002/3, bringing together the system design, engineering, marketing and sales of the former Schott Applied Power Corporation and the PV module manufacturing of the former ASE Americas. The company has two principal offices, shown in Figure 2. Headquarters in Billerica, MA, is the location of the PV module manufacturing facility and the product development group. Sales, marketing and project engineering are located in the Rocklin, CA office, near Sacramento.


Figure 2. RWE Schott Solar, Inc. headquarters is located in Billerica, MA (left). Sales, marketing and project engineering are located in Rocklin, CA (right).

RWE Schott Solar manufactures and sells the 300-Watt ASE-300 PV module (shown in Figure 3) and through the merger with Schott Applied Power in 2003, now also provides complete photovoltaic system engineering, design, and turnkey PV system installation services.

RWE Schott Solar, Inc. (RSS) has many years of experience designing PV arrays and installing them on flat-roofs and pitched roofs, and had plans to improve these designs. Specifically, wind tunnel testing and analyses were needed for the new flat-roof PV array mounting system that avoids roof penetrations. In addition, in order to simplify large grid-tied PV systems for flat-roof applications, the company's line of wiring junction boxes needed to be updated with new components and higher-power multi-circuit configurations. For pitched-roof residential applications, testing was planned to determine the holding power of three different fasteners in a wide range of wood sheathing types found in residential construction, to help optimize fastening methods. A device for connecting PV to the grid at a meter socket was innovated and is also being developed. The following sections describe the tasks and the progress made.

## 2.0 Task 1: Wind Force Determination and Mounting System Optimization

The systems team at RSS has a long history of design and installation of grid-tied PV systems for both pitched-roof residential applications and flat-roof commercial applications. In the early 1990s, company principals pioneered a ballasted mounting system using trays filled with gravel or paving blocks to anchor PV modules at a 25-degree tilt angle. This original ballasted design was used successfully to install dozens of small PV systems, between 2kW and 25 kW, primarily on schools and flat-roof electric utility buildings in many locations around the country. As the market for PV systems on rooftops evolved from research and demonstration projects to a truly commercial market, the need for a lighter and less costly mounting system became apparent. In addition, the commercial requirements for PV installations became rigorous and PV system designs needed to be fully tested and certified for compliance with commercial building codes.

Building upon the experience gained in the years of research and demonstration with the ballasted mounting system, a new design began to take shape. RWE Schott Solar's new free-standing (FS) PV array mounting system preserves the desirable attributes and features of the original ballast-tray design, however, there is a new paradigm in the PV marketplace and this reality is fully reflected in the FS system.

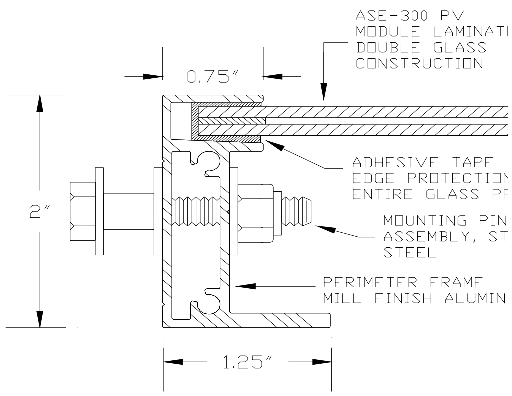
The scope of this task was to conduct wind tunnel testing of the new mounting system, in support of gaining certification of the system's compliance with building codes and wind loading design requirements. In addition, prototypes were built, installed and evaluated.

### 2.1 Description of the FS System

The penetration-less free-standing (FS) mounting system is shown in Figures 4 and 5. These figures show plan and elevation views of an example FS PV array using ASE-300 PV modules and the FS mounting system components are identified. Note in the figures the four basic components of the mounting system: the PV module or module assembly, base plate, taller RoofJack, and shorter RoofJack. These components are further described below.

### 2.1.1 PV Module or Module Assembly

The mounting system is designed to work with the ASE-300 large-area PV module (300 Watts dc, 74.5” x 50.5”), as well as assemblies of typical 140 – 165 W PV modules, such as the SAPC165 and Shell Solar SP140/150. Whether used with the large module or a module assembly, the panel must be equipped with the standard RWE SS mounting pin assembly (see detail below). Figure 3 illustrates the mounting pin assembly affixed to the frame of the ASE-300 PV module.



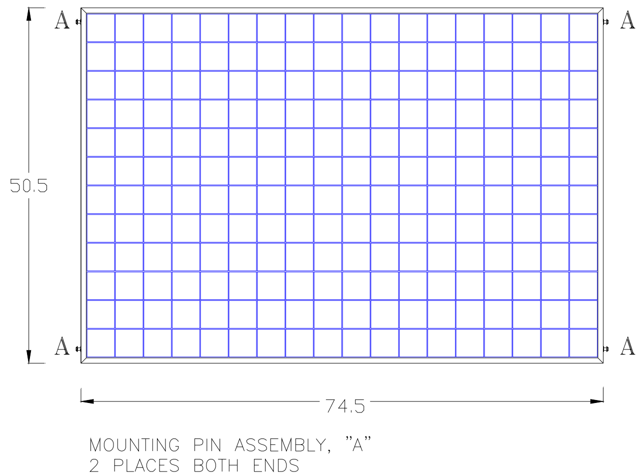




Figure 3. ASE-300 PV Module and Mounting Pin Assembly Detail

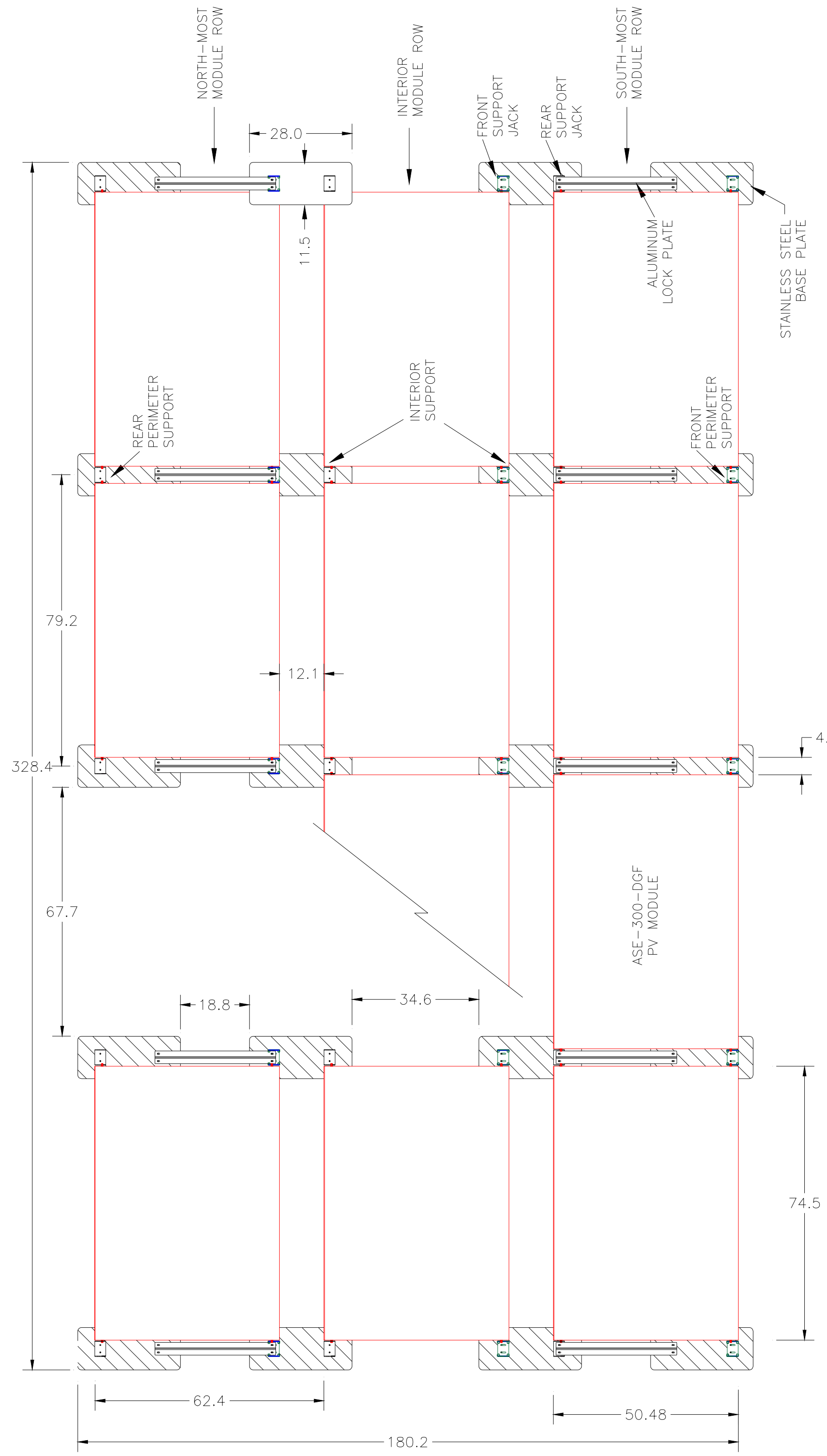
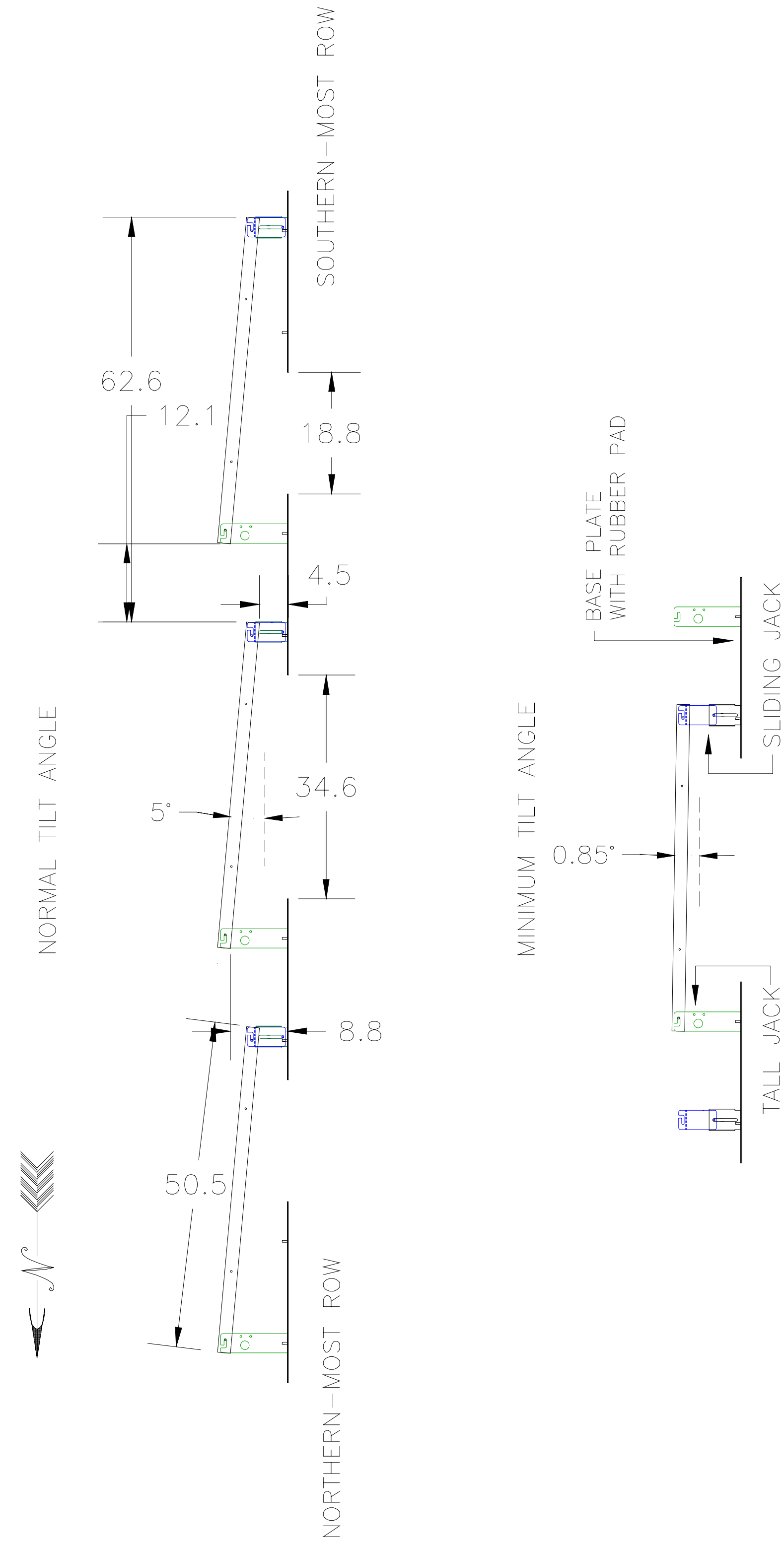



Figure 4. PV Array Plan View Layout Illustration with ASE-300 PV Modules

Figure 5. Elevation views of ASE-300 PV array at initial 5-degree tilt angle and at fully wind-relieved 0.85 degree tilt angle



### 2.1.2 Base Plates

The rectangular stainless steel base plate is shown in Figure 6. The base plate's longer dimension differs with the module type being installed.

A ¼-inch thick pad of sponge neoprene rubber is adhered to the bottom side of the base plate. Plate corners are rounded. Stainless steel threaded studs are pressed into the base plate at both ends during fabrication. The taller and shorter RoofJacks are secured to these studs, as described below.

Figure 6. Top and Bottom Views of Base Plate

The base plates rest directly on the building roof surface or on an approved interface material, depending on the specific roofing system and requirements where installed. The plates are laid out in rows and columns as required for the size and geometry of the PV array to be mounted. The base plates define a fixed separation between PV module rows and also link together mechanically all the modules within the PV array.

### 2.1.3 Taller RoofJack

Figure 7. Taller RoofJack supporting an assembly of SAPC-165 PV modules

The taller RoofJack bolts to one end of the base plate. This RoofJack is equipped with three defining features: the mounting pin slot, large holes for a PVC pipe nipple used as a wiring pass-through, and the smaller holes for attachment of the company's UL-listed wiring junction box. The taller RoofJack supports one end of the PV module assembly as shown in Figure 7 below. Adjacent panel assemblies at all internal positions within the PV array share the RoofJack.

### 2.1.4 Shorter RoofJack

Figure 8. View of baseplate with both RoofJacks supporting PV module assemblies.

The shorter RoofJack, Figure 9, attaches to the opposite end of the base plate. As seen in the drawing of Figure 5 and the photo in Figure 8, the PV assembly spans from the taller RoofJack on one base plate, to the shorter RoofJack on another base plate. In fact, a PV module assembly is supported by RoofJacks on four separate base plates. Similarly, each baseplate internal to an array (not one of the baseplates around the perimeter) supports a corner of four different modules or module assemblies.

Figure 9. Panel assembly resting in the lower RoofJack.

A PV module assembly is lowered into the L-shaped slot of the taller RoofJack (Figure 7) and slid forward until the mounting pin rests at the bottom of that slot. The lower end of the PV module assembly is then dropped into the L-shaped slot of the shorter RoofJack (Figure 9) and this RoofJack is slid back on the base plate (using the slotted mounting holes) and tightened into position, “trapping” the mounting pins of the PV assembly. This prevents the PV assembly from being removed from the mounting brackets without the use of a tool.

### 2.1.5 Theory of Operation

The function of the shorter RoofJack is to support the lower end of the PV module assembly and provide for the free, limited upward movement of this trailing edge of the PV module assembly as a means to limit upward forces on the PV assembly under design wind extremes. As wind speed increases and forces tending to lift the shallow-tilted PV assembly grow, the vertical sliding elements of the shorter RoofJack are free to glide upwards in the bracket, to maintain a balance between the wind uplift forces and the dead load of the PV module assembly. The PV module assembly begins at a nominal 5-degree tilt angle measured from horizontal. With wind from any northern direction, a PV module assembly can experience uplift forces that are counteracted by the dead load of the PV modules and associated mounting hardware. The sliding supports of the shorter RoofJack allow the PV module to pivot at the support point of the taller RoofJack and rotate upward to a shallower, near-horizontal tilt angle, as needed to balance the vertical components of forces on the PV modules. The ultimate effect of this feature is to limit wind uplift forces on the PV module assembly.

### 2.1.6 Wind Force Analysis

RWE Schott Solar conducted detailed studies of wind forces on roof-mounted solar arrays. The primary objective of this study was to investigate the company's new PV array mounting method as a way to limit pressure differentials across the solar panels. PV arrays located on rooftops of low-rise commercial buildings interact with oncoming wind developing both positive (tendency to lift the panels off the roof) and negative lift (tendency to force the panels down on the roof). The angle of incidence of the solar panels is similar to that produced by airfoils in which flow tends to accelerate across the top of the panel causing regions of reduced pressure that result in a positive lifting force on the panel. Three approaches were taken: basic force analysis, wind tunnel testing and numerical analysis.

The exhaustive analyses completed with computational fluid dynamics modeling allowed a multiplicity of configurations to be analyzed and the resulting differential pressure distributions over multi-row PV arrays to be quantified. For example, Figure 10 below (case 9-P1) shows the pressure differential for an assembly of three PV modules mounted at a fixed 5-degree tilt angle, in a nominal 8 column by 10-row array on a 30-foot high building roof, with wind from the north at a speed of 90 mph. The figure shows that the maximum differential pressure created by wind at 90mph anywhere in the PV array, not taking into consideration the dead load of materials that counter this uplift force, is approximately 165 Pascals (Pa), or 3.45 psf, acting on the 3-module assembly. In the chart negative values indicate downward (toward the roof) forces. Negative values occur for the first several rows of PV modules, owing to the effect of the building on the airflow over it.

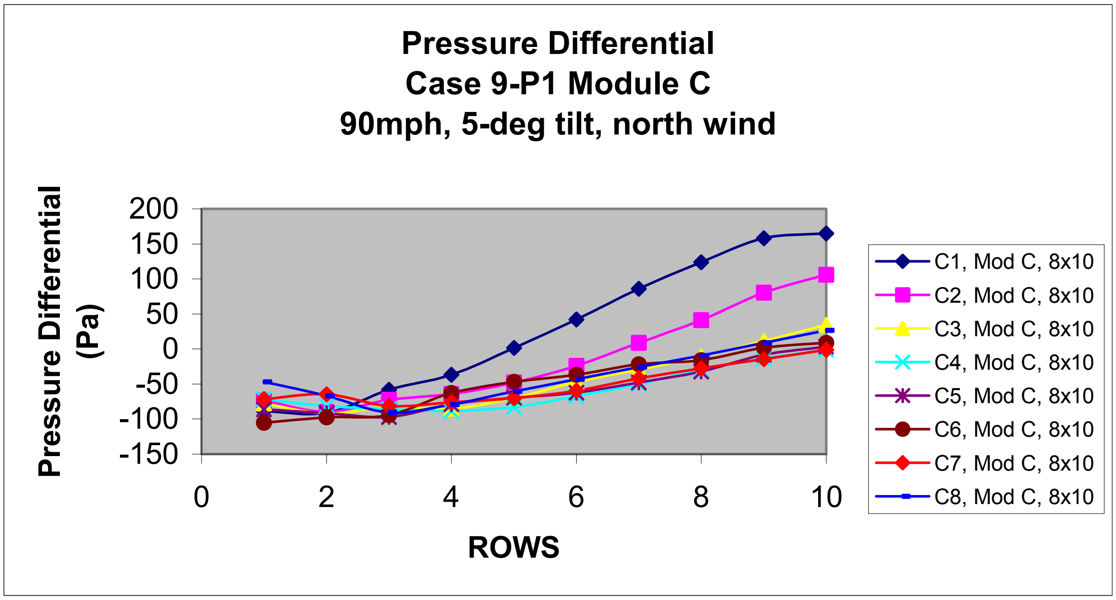



Figure 10. Pressure differentials, 90mph, 5-deg tilt, north wind

Figure 11 (case 7-P1) shows the effect on the results for the same PV array as in Figure 10, but with the wind coming at a 45-degree angle to the roof.

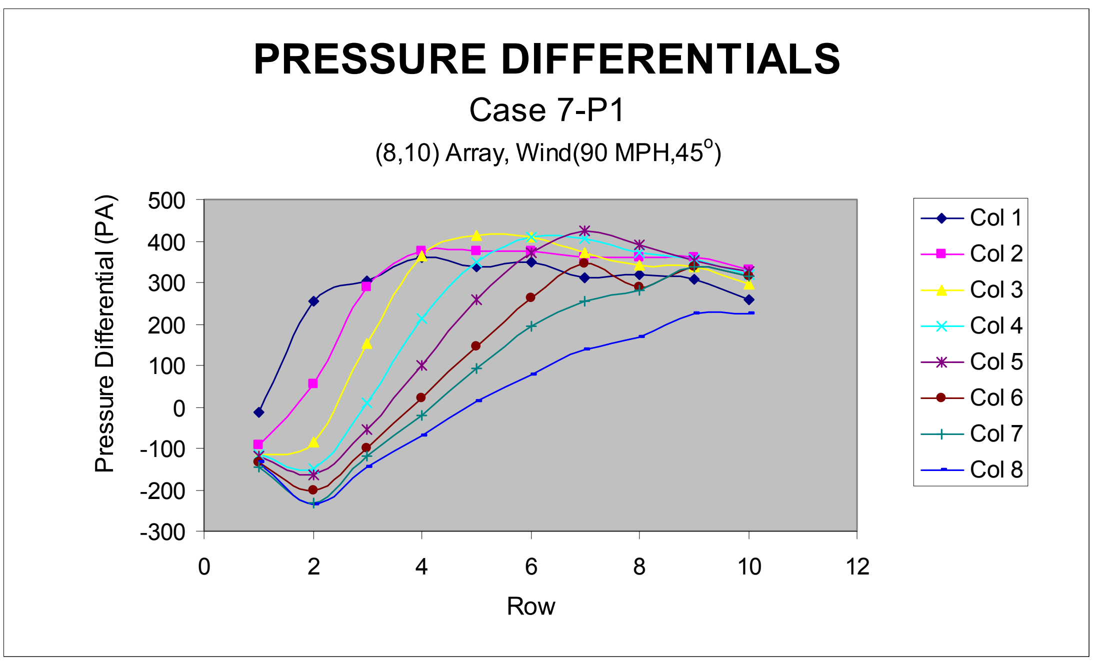



Figure 11. Pressure differentials, 90 mph, 5-deg tilt, northwest wind

The computational fluid dynamics modeling considered various building heights, varying array layout configurations, array locations on the roof, row spacing, module height above the roof deck, module type, the presence or absence of a parapet, wind speed and wind direction and others. Results show that the ability to feather the array angle limits the net uplift forces to a level below the weight of materials

### 2.1.7 Wind Tunnel Testing

The second phase of analysis was conducted at the Wright Brothers Wind Tunnel on the campus of the Massachusetts Institute of Technology in Cambridge, MA. Scale models of two PV panel assemblies were fabricated and tested in the wind tunnel up to speeds of 130 mph. In addition, tests were conducted to quantify and evaluate the functionality of the dynamic feature of shorter RoofJack, which automatically allows the PV panel to adjust its angle. Wind tunnel results were compared with computational fluid dynamic simulation results and good agreement was found. The dynamic feature of the shorter RoofJack was tested repeatedly at half-scale and full-scale and was observed to function as designed and intended in all cases in the wind tunnel

The wind tunnel test does not replicate a large PV array or the flow as it is affected by the building – both of these issues were fully addressed in the computation fluid dynamic modeling. An important validation study was completed to compare the wind tunnel results and the computational wind engineering analysis.

### 2.1.8 Conclusions from Wind Studies

- Basic force analysis defines the pressure differential required to actuate the dynamic feature of the mounting system
- Computational wind engineering modeling shows that actuation of the dynamic feature could occur in an 8-column by 10-row PV array with wind of 90 mph coming from 45-degrees, that is, from the Northwest. Results also show that actuation of the dynamic feature will be partial, and no panels would be expected to rise to the top of their range of travel at wind speed of 90 mph.
- Wind tunnel tests verified the actuation of the dynamic feature of the mounting system. Wind tunnel results also provided case studies for validation of the numerical wind engineering approach.
- The CFD modeling results matched the wind tunnel results to1.4%, which is well within experimental accuracy of the wind tunnel.
- The PV array mounting system, with its ability to respond automatically to increasing wind speeds, has been thoroughly analyzed, modeled and tested for its ability to withstand design winds of 90mph.
- Scaling can be applied to these CFD results for wind speeds higher than 90 mph.

Upon review of all the wind analysis data, including the basic force analysis, the wind tunnel testing, the many different computational fluid dynamics analyses, and the validation of the CFD method with the wind tunnel results, a professional engineering firm has provided a stamped letter certifying compliance of the FS mounting system with ASCE 7-98, *Minimum Design Loads For Buildings and Other Structures*. At present we have certification letters for the FS mounting system in CA, MA and NJ. When the need arises to work in other states, we can obtain the necessary stamped certification letters from the same engineering firm, as they maintain professional licenses in all 50 states.

## 2.2 Task 2: Fastener Design Improvements

The purpose of Task 3.2 was to determine and summarize information on the applicability of the RoofJack mounting brackets for pitched-roof PV array mounting systems. The issue to be investigated was the adequacy of the pull-out resistance of the fasteners that are typically used to secure the RoofJacks to roofs of various construction. The results of the testing undertaken in this task have been compared with the wind force calculations from Task 3.1 to help refine the design of the RoofJack mounting system and determine the limits on the applicability of the RoofJack mounting system.

The approach taken was to accumulate eight different roof sheathing materials and three different fasteners that are, or could be, used to secure the RoofJack mounting brackets to typical residential roofs. The fasteners were secured in the normal way into samples of the different types and sizes of wood sheathing material. Fasteners were tested individually and also in pairs. In addition, the end and interior types of RoofJack brackets were both tested. The testing was conducted by a certified lab in accordance with the ASTM D1761-88 test procedure.

### 2.2.1 Specifications

<u>Test Procedure</u> -- ASTM D1761-88, “Test Method D1761-88 (1995)e1 Standard Test Methods for Mechanical Fasteners in Wood” test procedure was used for all tests. (This document is copyrighted and cannot be reproduced for this report.)

<u>Fasteners</u> – The 3 fasteners used during testing are listed below.

| Fastener | Description | Size |
|---|---|---|
| Screw #1 | Phillips Head Deck Fastener | #12x2-1/4" |
| Screw #2 | Plated Steel Tapping Fasterer (Type A) | #14x2-1/4" |
| Toggle Bolt | Metal Hilti Toggle Bolt | 3/16" x 2-1/2" |

### 2.2.2 Variables

Six variables were examined during the pullout testing. These variables are described below:

<u>Fasteners</u> – 3 different fasteners were used during the testing. Screw type #1 is the standard fastener currently used to install RoofJacks, and is therefore of greatest interest to the company. Screw type #2 represents what an alternative supplier recommends for the RoofJack application. This screw was also chosen because the manufacturer has conducted their own pullout testing on that screw, and our testing could therefore corroborate their results and ensure that our tests were being conducted properly. Finally, a metal toggle bolt was tested. This toggle bolt fastener was suggested by a local installer for use on steeply-pitched roofs. Whether this fastener may be useful for RoofJack applications remains an open question.

<u>Pilot Hole</u> – The ASTM test procedure calls for a pilot hole to be drilled in the wood sample before securing the fastener and conducting testing. However, the standard screws used for RoofJack installations are self-drilling and no pilot hole is required. We tried both approaches, allowing us to see if drilling a pilot hole before anchoring the screw affected the pullout strength.

<u>Fastener Spacing</u> – It was desirable to determine if a reduction in pullout strength occurs when two screws are near each other (less than 10 diameters apart, for example) and pulled together, as compared to twice the value obtained for an individual screw. Accordingly, a subset of tests looked at

extracting pairs of screw #1 (test numbers 8, 10 and 11). In all other tests screws were pulled one at a time.

Pullout Speed – The ASTM procedure calls for a pullout rate of 0.1 inch per minute when conducting the test. In a real-world situation however, the uplift force would not be a steady pull, but rather would probably result from a wind gust and be very dynamic. We were able to adjust the pull-rate and this variable allowed us to investigate whether a faster pullout rate affected pullout strength.

RoofJack – In an actual installation of the RoofJack system, any uplift forces on the PV modules would be translated to the RoofJack and then in turn transferred to the fasteners securing the RoofJack. Tests were conducted to understand how the RoofJacks themselves affected the pullout strength of the three or four fasteners holding them in place. Both types of RoofJacks were used – the three-hole "end" type and the four-hole "interior" type (see appendix C) – secured to one of the wood sheathing samples. For these tests the uplift force was applied to the RoofJack at the mounting pin slot using a special fixture on the apparatus.

Number of Tests – To obtain a representative result, we conducted multiple tests for each configuration. All results are displayed as an average of the results obtained for the set of tests conducted.

Sheathing Material – Various thickness and types of wood sheathing were tested, representing a sample of what would be most commonly found in new and older homes around the country. A list of these materials is shown in the table below.

| Sheathing Type | Description | Thickness (inches) |
|---|---|---|
| 1 | 3/8 ACX plywood, Douglas fir | 11/32 |
| 2 | ½ CDX plywood, 4-ply yellow pine | 15/32 |
| 3 | 5/8 CDX plywood, Douglas fir | 19/32 |
| 4 | ¾ CDX plywood, southern yellow pine | 23/32 |
| 5 | Waferboard/OSB, 7/16 inch | 7/16 |
| 6 | Waferboard/OSB, ¾ inch | ¾ |
| 7 | Particle board, ¾ inch | ¾ |
| 8 | Premium eastern pine, nominal 1 inch board | 13/16 |

### 2.2.3 Tests and Results

This section describes the tests and what was learned by comparing results from sets of tests.

Tests 1 and 2 – This pair of tests was done to understand which screw (#1 or #2) has the higher pullout strength. Screw #2 has deeper threads with fewer threads per inch than screw #1. The results show that screw #2 slightly outperforms screw #1. The exception was with sheathing type 5, 7/16" OSB material. In this test screw #1 slightly outperformed screw #2. This was most likely because screw #1 has a greater number of threads per inch, which would work more effectively in a thinner wood.

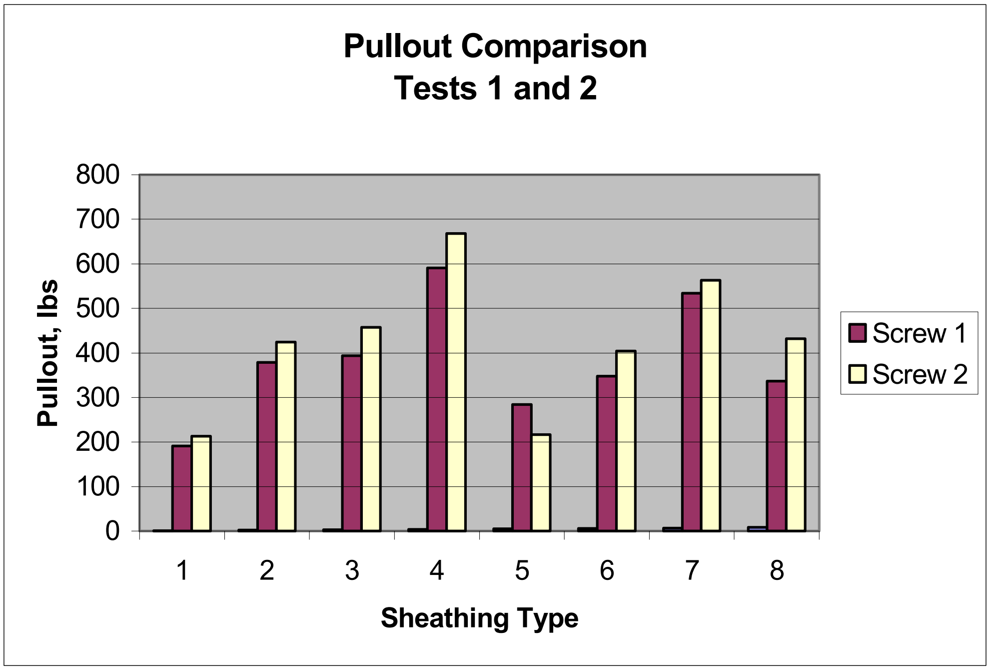
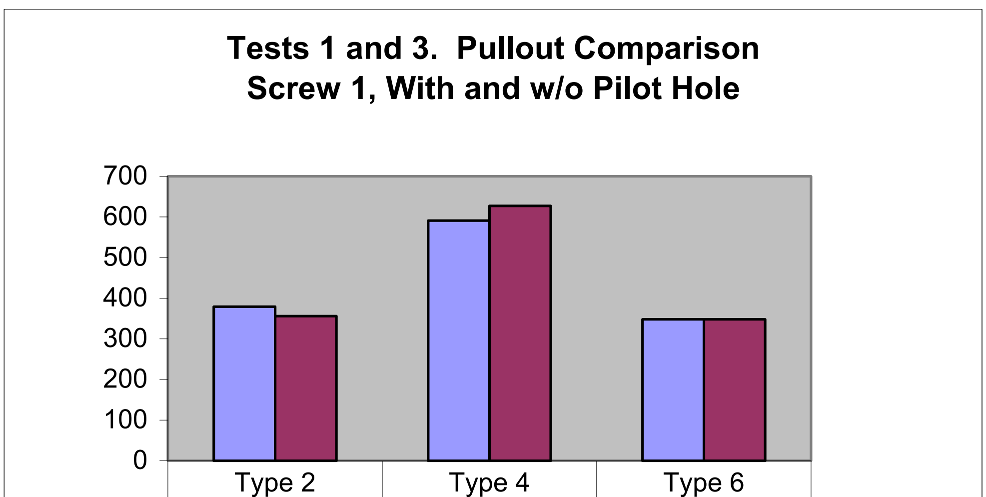



Figure 12. Tests 1 and 2 comparing two screws.

<u>Tests 1 and 3</u> – This pair of tests was done to evaluate how drilling a pilot hole before inserting the screw affected the pullout strength. No significant difference in pullout strength was noticed.




| | Type 2 | Type 4 | Type 6 |
|---|---|---|---|
| w/ Pilot | 379 | 591 | 348 |
| w/o Pilot | 356 | 627 | 348 |

Figure 13. Comparing fasteners installed with and without a pilot hole.

Tests 1 and 4 – This pair of tests was done to understand how the faster pullout rate affected pullout strength.  No significant difference in pullout force was observed in these tests.

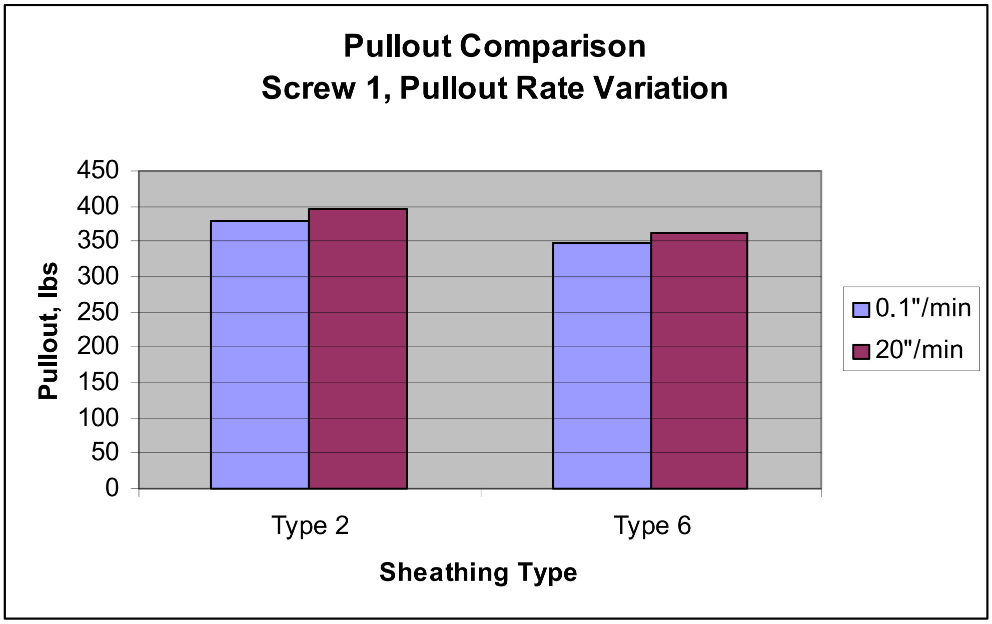



Figure 14. Effect of screw spacing with pullout rate.

Tests 5, 6 and 7 – These tests were done to understand if there was a correlation between how close the screws were placed together and the pullout strength.  No significant pullout strength difference was noticed.

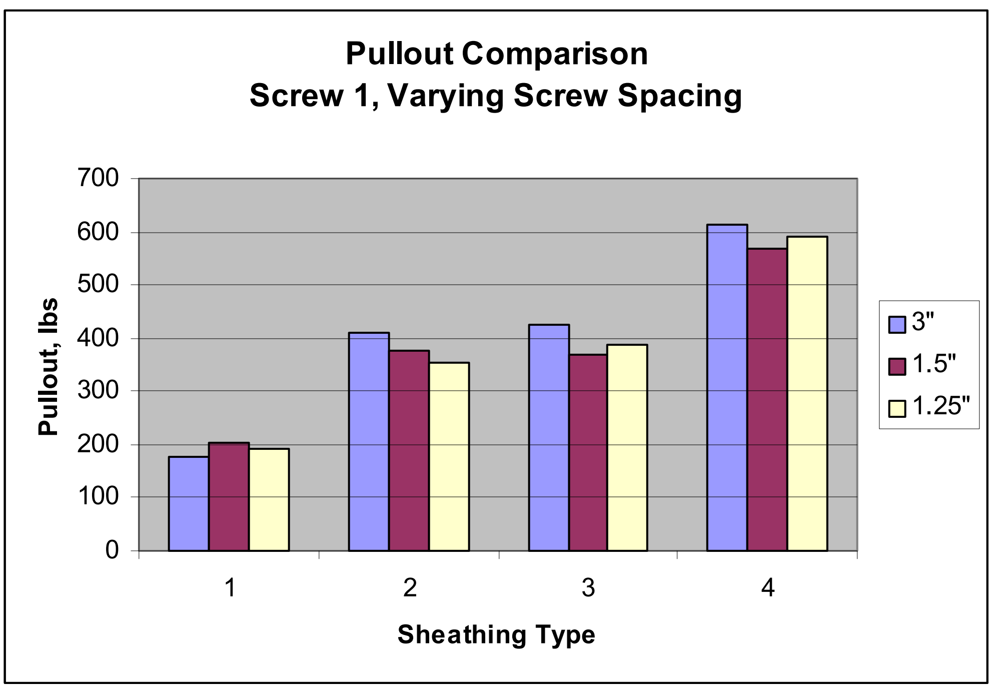



Figure 15. Effect of screw spacing on pullout strength.

Tests 1 and 8 – This pair of tests was done to understand how the pullout strength was affected by pulling out a pair of screws together, spaced 1.25 inches apart, as they would be when securing a RoofJack. In comparison to pulling out a single screw, pulling out a pair of screws approximately doubles the pullout strength. That is, no degradation of pullout strength was observed for the spacing of screws tested.

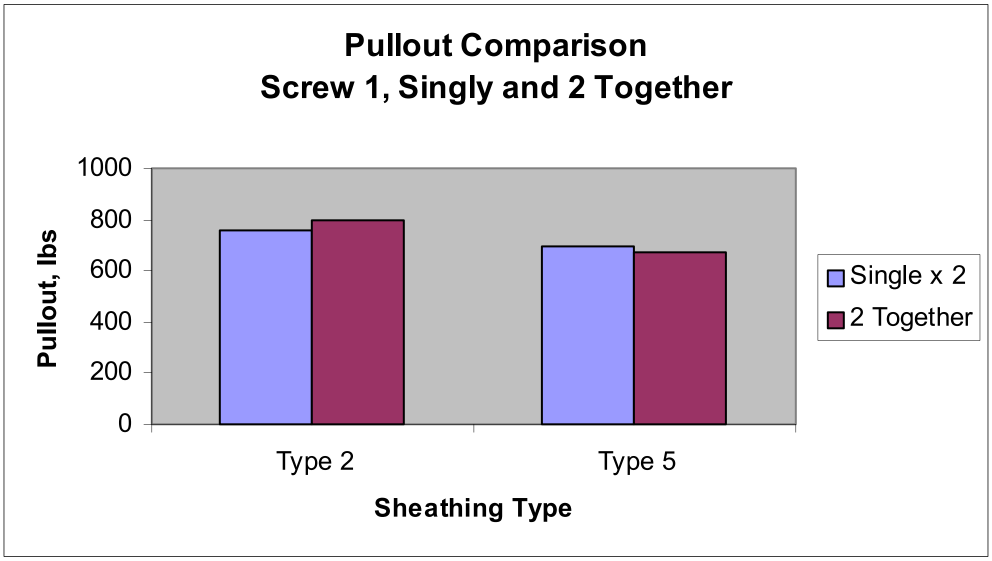



Figure 16. Pullout for pairs of screws pulled together.

### 2.2.4 Applicability of the RoofJack Mounting System

Task 3.1 included simulation of the wind forces on a PV array mounted with RoofJacks on a typical pitched roof. These results are summarized here to allow evaluation of the RoofJack system applicability. The PV array layout was two rows, four modules per row, on RoofJacks, with a 12-inch border of roof all around the array. Roof slopes of 45-degrees (12-on-12 pitch) and 22.6 degrees (5-on-12 pitch) were investigated. The roof has equal and symmetrical sections pitched to the north and the south, with a ridge line running east-west. Wind from the south and also from the north was modeled. Wind from the south produced no uplift forces on the PV array. The results for wind from the north are shown below.

From the chart note that the highest uplift force occurs on the upper row of modules on the shallow pitched roof. The peak uplift is 350 Pascals, which equates to approximately 7.3 psf. Proceeding conservatively, assume that this uplift applies to all 8 modules (which is clearly not the case). Then, the following results are obtained:

| | |
|---|---|
| Area of one module | 26.126 sq. ft |
| Area of 8 modules | 209 sq. ft. |
| Total uplift, at 7.3 psf | 1,526 lbs |

The array is held in place by 8 end-type RoofJacks and 12 interior Roofjacks. From the pullout testing we saw that even though the RoofJacks use 3 or 4 fasteners, they have effectiveness somewhat greater than a single screw, but not as much as that of two screws. Again, conservatively, assume that each RoofJack attachment equates to the pullout resistance of just a single fastener. In this case, each fastener must be able to counteract 76.3 lbs (1526 lbs total upflift divided by 20 fasteners).

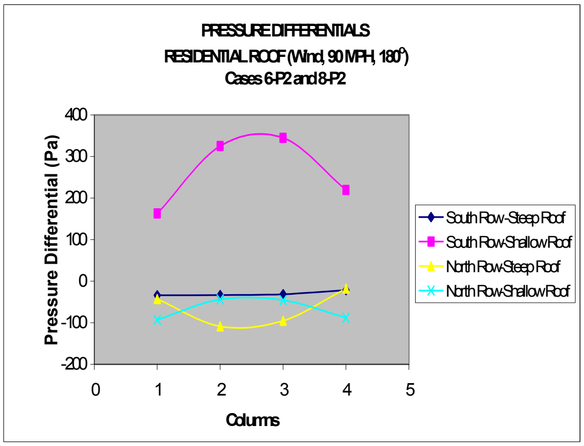



Figure 17. Wind forces on pitched roof.

The minimum pullout force for screw #1 in any of the tested wood sheathing materials, was 191 lbs in 3/8-inch ACX plywood. A comfortable margin of safety exists even for this extremely thin sheathing material. There appears to be broad applicability for the RoofJack mounting system on residential roofs.

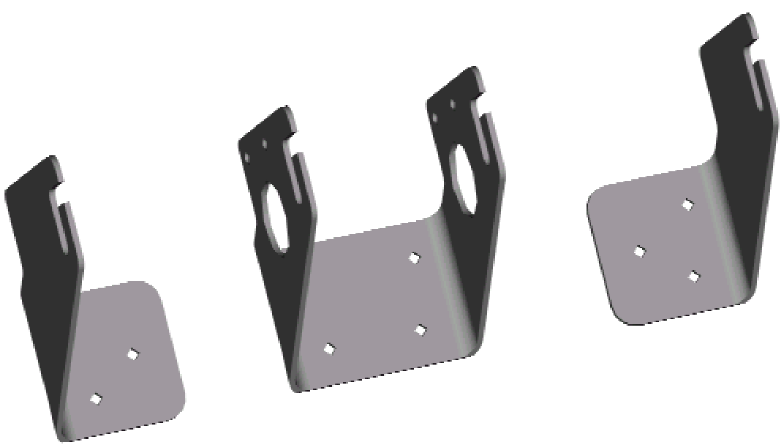


Figure 18. Illustration of the east, west and interior RoofJacks.

### 2.2.5 Conclusion

These tests have given us the necessary test data to understand the pullout force required to remove the fasteners alone, in pairs and most importantly, for RoofJacks secured with multiple fasteners. As a direct result of this important testing, we are revisiting the number of fasteners and their layout pattern in the interior RoofJack and continuing to use screw #1.

## 2.3 Task 4: PV Source Circuit Protectors

The goal of Task 3.4 is to update and expand the company's line of UL-listed PV source-circuit protectors (PVSCPs), achieving cost reduction, and developing a new model with multiple dc inputs for PV arrays and subarrays larger than approximately 20kW. There are two subtasks in Task 3.4. The first deals with re-design and new components for our Basic PV source circuit protectors. The second subtask addresses the development of a Multi-input PVSCP version for use with higher capacity PV arrays.

The preliminary specs on these two new combiner boxes are shown below.

**Preliminary Specifications**

| | Model | |
|---|---|---|
| | **PVSCP-2** | **PVSCP-4** |
| Description | 2-circuit combiner with over-current protection | 4-circuit combiner with over-current protection |
| Existing UL listing and file number | 1N39<br>E158823 | NA |
| Voltage Rating | 600 Vdc | 600 Vdc |
| Max Number of Input PV Source Circuits | 2 | 4 |
| Max Input PV Source Circuit DC Current (rated PV dc,stc) | 19.2 A | 19.2 A |
| Max Output Circuit DC Current | 38.4 A | 76.8 A |
| Fuse Size Range and Type | Up to 30 A<br>Class M | Up to 30 A<br>Class M |
| Output Wire Size Range | # 22 – # 6<br>(terminal block rating) | # 8 – # 2/0<br>(terminal block rating) |
| Environment | Outdoors<br>100% RH, -40C to +50C | Outdoors<br>100% RH, -40C to +50C |
| Physical dimensions (approx) | 9" x 4.4" x 3.5" | 11.5" x 9.5" x 3.75" |
| Enclosure Construction | Custom fabricated, 0.080" thk aluminum base and 0.093" thk aluminum lid, with paint finish | |

Prototypes of the two versions were fabricated and used for internal evaluation and review purposes. An initial pass through Underwriters Laboratory was made and some feedback on the PVSCPs was received. Second generation prototypes were fabricated to help address these new comments.

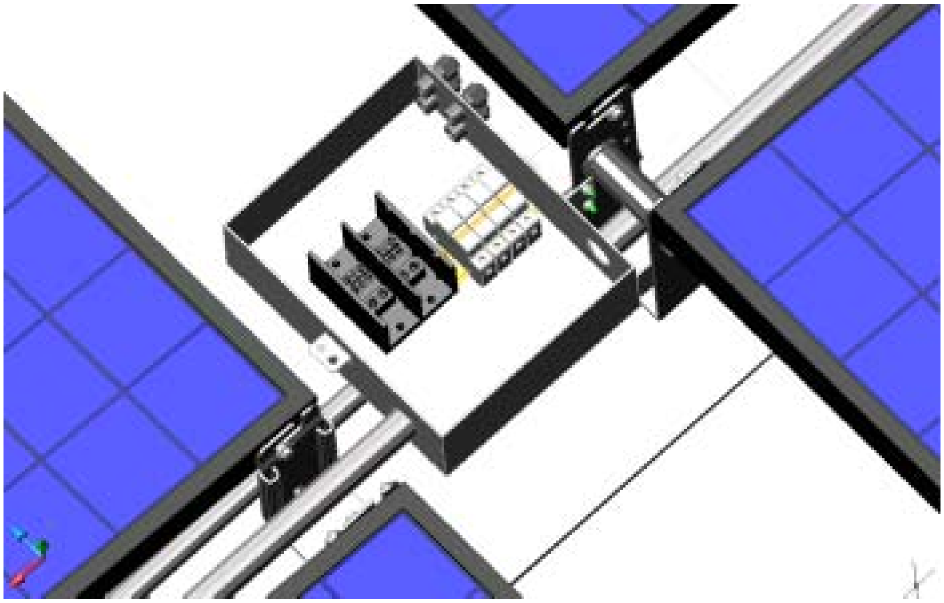


Figure 19. Depiction of the PVSCP-4 installed in an array, viewed from above

Figure 20. PVSCP-4, showing four 2-hole strain relief connectors through which the positive and negative conductors from 4 PV source circuits enter the box. Note external and internal ground lugs for termination of equipment ground wires.

Figure 21. PVSCP-2 with lid in place.  Note knockouts on end and sides.

Figure 22.  PVSCP-2 provides fused landing place for 2 PV source circuits, that are bussed and pre-wired to output lugs.  Source circuit wiring enters through strain relief connectors (not shown) in knockouts  on side of box.

## 2.4 Task 5: Device for Connecting Parallel Sources at a Meter Socket

The purpose of Task 3.5 is to design and develop a device allowing safe, code-compliant interconnection of PV systems to be made at a standard residential kilowatt-hour meter socket. A concept mock-up of this device was assembled and reviewed by four individuals in the PV industry in late spring and summer 2002.

Figure 23. Mock-up of the meter device concept.

The basic meter interconnect device comprises a meter extender section and a junction box below. A meter extender is a housing with “blades” on one side and sockets on the other; it plugs into a standard Form 2S meter socket and a kilowatt-hour meter plugs into it. The output from a PV system would be terminated in the junction box at fused lugs, as shown in the mock-up. Up to two separate ac outputs can be terminated in the junction box, to accommodate large residential systems. An equipment ground lug is provided and the unit is completely pre-wired to the customer side jaws of the meter socket.

The mock-up shown was reviewed and discussed with individuals in the PV and electric utility industry. The comments of these reviewers have been extremely valuable in helping refine the concept. Concerns exist about the very idea of pulling the residential meter and the fact that typically only utility personnel can do that. Other comments and suggestions were in regard to incorporating a switching function in addition to the overcurrent function in the device, and also providing proper sizing and protection for all wiring runs internal to the device. Finally the mechanical aspects need to be improved and all materials evaluated for their UL compliance.

The reviews were most helpful, raising excellent, valid questions and issues that must be fully addressed in the next prototype of the meter interconnect device. We believe these questions and concerns can be resolved, but a significant amount of work still lies ahead with this task.

## 3.0 Conclusions

The major accomplishments in Phase 1 of this contract center around the development of the FS mounting system, which would not have been possible without this support. More than 1.2 MW of PV systems have been installed with this mounting system, starting with the first installation completed in spring 2003. The lesser tasks are all equally beneficial to the company's efforts to refine and optimize its PV system offerings. Work began in Phase 1 on the PV source circuit protectors and the meter interconnect device and will continue toward their completion in Phase 2.

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13. ABSTRACT (Maximum 200 words): This report describes the development by RWE Schott Solar, Inc., of innovative new products to facilitate the broad use of its PV systems in the current markets. RWE manufactures and sells the 300-watt ASE-300 PV module and also provides complete photovoltaic system engineering, design, and turnkey PV system installation services. RWE Schott Solar has many years of experience designing PV arrays and installing them on flat roofs and pitched roofs, and had plans to improve these designs. Specifically, wind-tunnel testing and analyses were needed for the new flat-roof PV array mounting system that avoids roof penetrations. In addition, to simplify large grid-tied PV systems for flat-roof applications, the company's line of wiring junction boxes needed to be updated with new components and higher-power multi-circuit configurations. For pitched-roof residential applications, testing was planned to determine the holding power of three different fasteners in a wide range of wood-sheathing types found in residential construction to help optimize fastening methods. A device for connecting PV to the grid at a meter socket was innovated and is also being developed.

14. SUBJECT TERMS: PV; thin film; solar cell; manufacturing; module; array mounting systems; grid-tied; free-standing mounting; base plate; device; building-integrated PV

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