

Plug-and-Play Components for Building-Integrated PV Systems

Phase II – Final Report
20 February 2003 – 31 May 2007

D. Rowell
Schott Solar, Inc.
Billerica, Massachusetts

Subcontract Report
NREL/SR-520-43151
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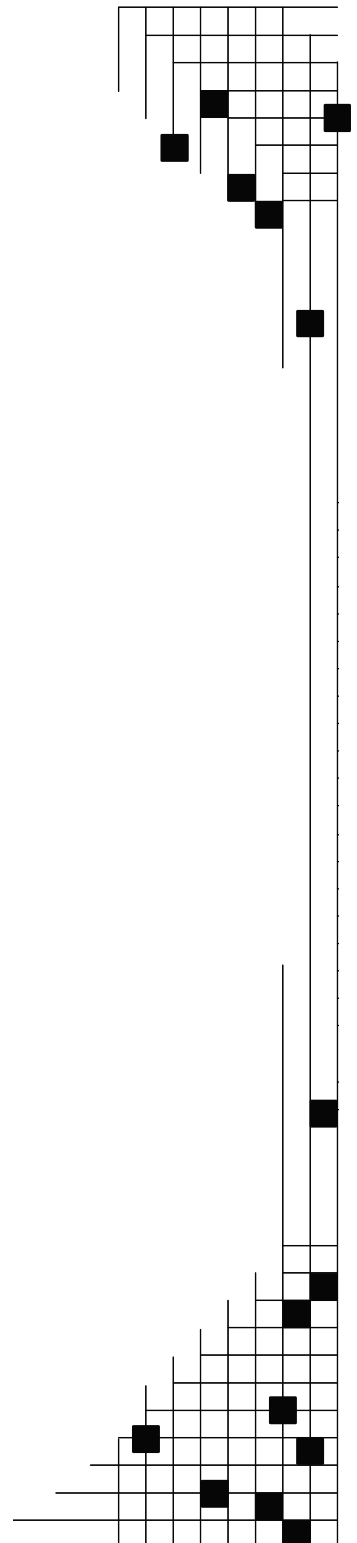
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Executive Summary

Schott Solar, Inc. is developing innovative new products to facilitate the broad use of its PV modules 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 consisted of development and testing of a novel new flat-roof PV array mounting system, development 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. The second, expanded phase of this work is reported here and is summarized below:

- The meter interconnect device (MID) was revised and then deployed in five residential PV installations. The MID was approved for use in these installations by National Grid, the largest electric utility in Massachusetts. No further development of this device is planned.
- The FS mounting system (Figure 1), pioneered by Schott Solar was subjected to further laboratory and wind tunnel scale-model testing. The design of some components evolved to improve performance and reduce cost. New application guidelines have been developed for the FS mounting system and it continues to be a popular solution for mounting modules without requiring penetration of the roof.
- Investigations of dark I-V curves as a way to unearth problems with PV module strings led to the design of portable equipment for this purpose and numerous initial measurements. The equipment allows dark I-V curves to be taken automatically and, with modest post-processing, to be displayed for diagnosis. Schott Solar intends to continue its development and experimentation with the dark I-V capability for potential integration on the module manufacturing floor.
- A new 24-Volt version of the company's flagship ASE-300 PV module was developed. The new model was tested and it achieved UL listing. The key to the approval of this ASE-300/34 PV module was the development of a custom diode circuit board and heat management system.
- The company's photovoltaic source-circuit protectors (PVSCPs), originally UL listed in 1996, were updated with new components. This line of custom junction boxes achieved a new UL listing and remains a companion product for the company's FS mounting system.

As NREL understands, several tasks included in Phase 2 of the contract were terminated and not taken to completion. Specifically, work on the AC module, the rafter-jack residential mounting system, and the second-generation SunTrack were eliminated, as market and company conditions changed over the past two years.

Schott Solar, Inc. has two principal offices. Headquarters in Billerica, MA, is the location of the PV module manufacturing facility. Sales and marketing are located in the Roseville, CA office, near Sacramento. The company manufactures and sells the 300-Watt ASE-300 PV modules and supports its customers, key value-added-resellers, with PV modules and the unique FS mounting system hardware.



Figure 1. The free-standing (FS) system developed under this contract is the flagship PV array mounting system offered by the company. Wind-tunnel testing and extensive analyses were made possible by the project to help establish the applicability of the FS mounting system.

1.0 Introduction

Schott Solar has successfully completed the development of key innovations for the company during this second phase of the contract. A brief overview of the specific developments is provided below:

- The meter interconnect device (MID) was revised and then deployed in five residential PV installations. The MID was approved for use in these installations by National Grid, the largest electric utility in Massachusetts. No further development of this device is planned.
- The FS mounting system pioneered by Schott Solar was subjected to further laboratory and wind tunnel scale-model testing. The design of some components evolved to improve performance and reduce cost. New application guidelines have been developed for the FS mounting system and it continues to be an industry-leading solution for mounting PV modules without requiring penetration of the roof.
- Investigations of PV module dark I-V curves as a way to unearth problems with PV module cell-strings, led to the design of portable equipment for this purpose and numerous initial investigatory measurements. The equipment allows dark I-V curves to be taken automatically and, with modest post-processing, to be displayed for diagnosis. Schott Solar intends to continue its development and experimentation with the dark I-V capability for potential integration on the module manufacturing floor.
- A new 24-Volt version of the company's flagship ASE-300 PV module was developed. The new model was tested and it achieved UL listing. The key to the approval of this ASE-300/34 PV module was the development of a custom, cost effective, diode circuit board and heat management system.
- The company's photovoltaic source-circuit protectors (PVSCPs), originally UL listed in 1996, were updated with new components. This line of custom junction boxes achieved a new UL listing and remains a companion product for the company's FS mounting system.

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2.0 Task 3.7: Meter Interconnect Device Demonstration Systems

The market for residential-scale photovoltaic systems that can operate in parallel with existing grid electricity supply and that can be safely and simply installed in homes is growing rapidly in the United States. The *Meter Interconnect Device* (MID) is a device that can be used to connect such sources of electric power, intended to operate in parallel with grid electricity supply, to the premises wiring at the socket of a kilowatt-hour meter. The MID is depicted conceptually in Figure 2-1. Kilowatt-hour meters are the instruments permanently installed on customer premises by the grid electricity provider, to record the usage of grid electricity for billing purposes.

A meter socket, such as those found on the premises of typical grid electricity customers, contains terminals to which the grid electric service conductors are secured, and terminals to which the premises wiring conductors are secured. The terminals in the meter socket are metallic “jaws” laid out in standardized patterns to receive the “blades” of the kilowatt-hour meter that records energy flowing from the grid to the customer. The MID is based on a meter extender concept. A meter extender is a product designed to plug into a meter socket in the very same manner as a kilowatt-hour meter. One side of the meter extender has “blades” and the other side has socket-like “jaws” to receive the kilowatt-hour meter. Thus, the meter extender inserts itself between the meter socket and the kilowatt-hour meter.

The MID is a meter extender that has been equipped with pre-wired terminals to which the conductors from a parallel source of electrical power can be secured. The MID also provides over-current protection for the conductors from the parallel source of electric power. The conductors from the parallel source of electric power are pre-wired to connect to the premises-wiring side of the meter socket, resulting in a so-called “net metering” arrangement, or they can be pre-wired to connect to the grid electric supply side of the meter socket.

The MID also includes a pre-wired, integrated, manually-operated, lockable disconnect switch, allowing the parallel source of electrical power to be isolated from the grid electric supply and premises wiring.

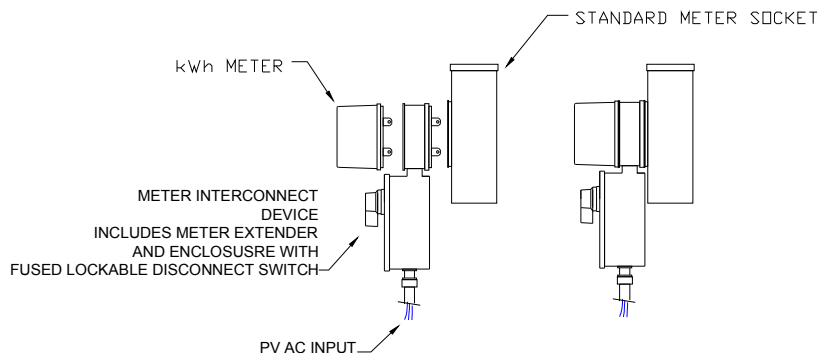


Fig. 2-1. Depiction of the Meter Interconnect Device

Specifications of the MID are presented in Table 1.

Table 1. Meter Interconnect Device Specifications

| Parameter | Specification |
|------------------------------------|---|
| Voltage Rating of switch | 600 Volts AC |
| Weatherability rating | NEMA 3R, IP 54 |
| Maximum fuse rating and fuse class | 30 Amps AC, Class CC fuse |
| Maximum PV input wire gauge | 10 AWG (6mm ² max), copper only |
| Equipment ground lug – internal | Tin-plated copper |
| Equipment ground lug – external | #14 - #1/0 wire |
| PV system interconnection voltage | 240 Volts AC |
| PV system interconnection location | Customer/load side (standard) Utility/supply side (optional) |
| PV system input rating, max | Approx. 5.7 kWac (0.8 x 30 Amps x 240 Vac) |

The MID was designed to mate conveniently with the predominant styles of electrical service in residences and provide a simplified connection to the grid for interactive photovoltaic systems. Other features of the MID include:

1. Works with ring and ring-less style meter sockets.
2. Accommodates the AC output of any grid-tied PV system up to 24 Amps AC at 240 Volts AC, or about 5.7 kWac.
3. PV input 240 Volts ac: ac line 1, ac line 2 and equipment ground.
4. Fused switch is lockable in the “off” position.
5. Enclosure lockable and taggable.
6. Internal and external equipment ground lugs.

2.1 Photographs of the Meter Interconnect Device

The following photographs show the MID prototypes and some details of its construction and features.



Fig. 2-2. The interior of the meter interconnect's custom enclosure houses the fused disconnect switch. An interior ground lug is provided and all live parts are fully protected from touch. A shaft into the body of the switch extends through the cover to the handle on the outside. A gasket seals the door against the box.



Fig. 2-3. The black C-shaped handle (see Fig. 2-2) opens the fuse door in the switch, allowing safe access to the fuses for convenient and safe insertion, inspection or replacement.



Fig. 2-4. The switch handle is shown in the “on” position, which prevents the door from opening. Rotating the switch handle 90 degrees ccw into the “off” position allows the switch to be locked and the door to be opened. A captive fastener secures the hinged lid. A spare hole in the tabs is provided for a padlock or tag.



Fig. 2-5. A jumper through the back of the meter extender carries the equipment ground from the enclosure. This ground wire is shown with a spade terminal. A free length of wire with a mating spade terminal would be secured to the neutral lug in the meter socket.

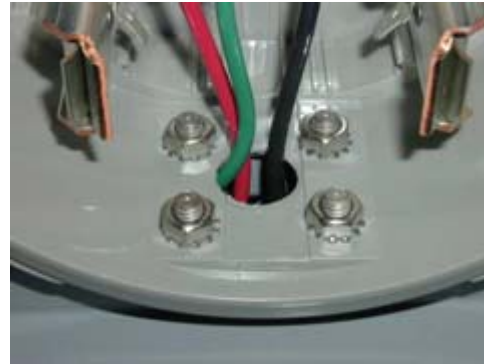


Fig. 2-6a and 2-6b. Factory wiring emanates from the output of the fused switch and passes through a hole in the enclosure and meter extender. The meter extender is equipped with spade terminals riveted in the factory to the metallic sockets. The ac wiring from the switch is factory wired to these spade terminals in the meter extender.



Fig. 2-7. The clear plastic shield prevents inadvertent contact with the factory wiring and sockets in the meter extender.



Fig. 2-8a and 2-8b. To use the Meter Interconnect Device with a ringless style meter socket, there is a second, shallow extender that goes in place first. The bottom photo shows the MID in place with a ringless meter socket.





Fig. 2-9. The Meter Interconnect Device installed in a ringless style meter socket.

2.2 Demonstration PV Installations

In order to gain market feedback on the MID, five residential PV systems were installed using this device. These installations were done with the cooperation of National Grid, the parent company of the retail electric suppliers in a large portion of the Commonwealth of Massachusetts. The PV systems are all identical and use 8 ASE-300 PV modules and a 3.3kW Fronius inverter. The modules were mounted using RoofJacks that stand the modules a few inches above, but parallel-planar to the existing roof pitch. The main components of the systems were supplied to the participants in the demonstration project. Lesser components, such as field wiring, mounting materials and mechanical fasteners were sourced and supplied as needed. Specifications of the systems are shown in Table 2 below and a diagram of the system's electrical configuration is shown in Figure 2-10.

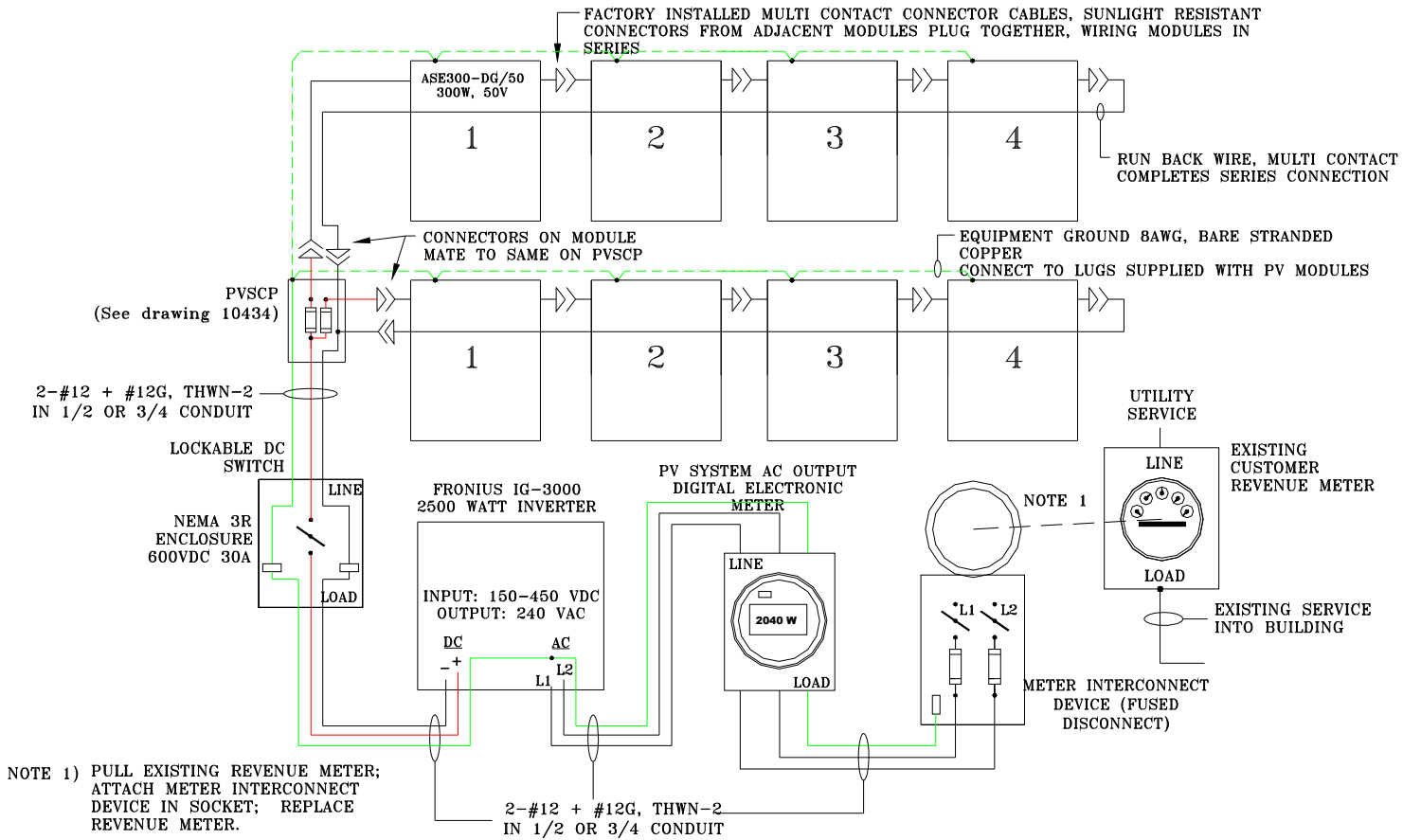
Table 2. PV System Specifications

| | |
|------------------------|------------------------|
| PV Array | |
| Modules | 8 ASE-300 DG/50, 285 W |
| Configuration | 4 series by 2 parallel |
| Rated Power, dc stc | 2,280 Watts dc, stc |
| Open-circuit voltage | 240 V dc, stc |
| Maximum power voltage | 208 V dc, stc |
| Short-circuit current | 12.0 A dc, stc |
| Maximum power current | 11.0 A dc, stc |
| PV System | |
| Rated power | 1820 Watts ac, stc |
| Maximum current output | 11.25 A ac, stc |
| Output voltage | 240 V ac, stc |

A meeting was held with Dr. John Bzura of National Grid to review the design of the meter interconnect device, its intended usage, and the details of the NREL project. After some discussion and review of prototypes, Dr. Bzura agreed to allow the meter interconnect to be used in the National Grid service territory specifically for this project, despite the fact that it is not UL listed.

Four of the five demonstration PV systems were offered to selected residential customers in Massachusetts by Berkshire Photovoltaic Systems (BPVS). BPVS is a long-time system integrator and has prior experience installing the ASE-300 PV modules on residential roofs. BPVS generated a complete package when presenting the opportunity to residential customers. The package included the turnkey quotation which included an incentive from the Massachusetts Technology Collaborative, under their Small Renewables Rebate program. The rebate reduced the price by \$2.50 per Watt ac. The fifth demonstration PV system was installed by Fandreyer Electric, an electrician familiar with PV, in the town of Phillipston, MA.

The residential PV installations using the meter interconnect device are located in the following towns in Massachusetts: Gloucester, Phillipston, North Egremont, Easton and Lanesville.



| FRONIUS IG-3000 | | | | | | | |
|----------------------------|---------|------------------|---------|---------------------------|----------|-----------------------|--------|
| PV SYSTEM AC RATING AT PTC | | | | PV ARRAY DC RATING AT STC | | | |
| RATED POWER | 1820 W | OUTPUT FREQUENCY | 60 HZ | RATED POWER | 2.3 kWDC | SHORT-CIRCUIT CURRENT | 12.0 A |
| OUTPUT VOLTAGE | 240 VAC | MAX CURRENT | 11.25 A | OPEN-CIRCUIT VOLTAGE | 240 VDC | MAX-POWER CURRENT | 11.0 A |
| | | | | MAX-POWER VOLTAGE | 208 VDC | | |

Figure 2-10. Electrical design of meter-interconnect PV systems.



Figures 2-11 and 2-12. The residential PV system installation in Gloucester, MA.





Figures 2-13 and 2-14. The residential PV system installation in Lanesboro, MA.





Figures 2-15, 2-16, 2-17 and 2-18. The residential photovoltaic system in North Egremont, MA.

2.3 Lessons Learned

1. Code Considerations

The meter interconnect device was reviewed with John Wiles of the Southwest Technology Development Institute, wearing his national-electrical-code-expert hat. Note that the PV interconnection made by the meter device is on the customer side of the kilowatt-hour meter, but on the utility side (or supply side) of the main service disconnect located in the customer's distribution panel. National Electrical Code article 690.64(A) allows a PV system to be connected on the supply side of the service, as permitted in article 230.82(6). The connection of a PV system on the supply side of the service is essentially connecting a second service to the premises and the interpretation of the code is that the rules for service entrance equipment would apply. Two of the basic functions of the meter device are manual disconnect and overcurrent protection. For example, section 230.79(D) requires that the disconnect switch have a minimum rating of 60 amps. Presently the meter device uses a 30-amp class disconnect switch.

For a small residential PV system of the type installed for the demonstration systems, with 240 Volt ac output and requiring a 15 amp overcurrent protection, the requirement above would dictate a 60 amp rated disconnect but with a 15 amp fuse. This would require a complete

change of the meter device equipment, and availability of higher ampacity equipment of the same type has not been investigated. Technically the combination could be achieved using fuse adapters to allow the smaller format fuse to be used in the higher-current fuse holder. Other related concerns would exist in regard to conductor sizes and conductor routing to maintain the highest level of fault protection.

From a code perspective, the meter device concept is possible, but would need significant modification to meet the service entrance code requirements.

2. Patentability

A provisional patent application was filed on the meter interconnect device in 2001. In 2002 the company's legal counsel for patent activity began a search to determine the feasibility of a full patent application. Several concepts similar in nature but not identical were identified. Legal counsel suggested that award of a patent on the meter interconnect device was unlikely. As a result, and in consideration of the shifting company focus away from the residential market, no further patent activity was undertaken.

3. Mechanical Considerations

The meter interconnect device is designed such that the enclosure hangs suspended beneath the meter extender portion of the device, and the meter extender makes the mechanical connection to the meter base. There are two weaknesses in the basic mechanical design of these connections.

First, when the meter interconnect device is used in a ring-less style meter base, a narrow extender is snapped into the meter jaws first, to bring a set of jaws outside the door of the housing. The meter interconnect device is then mated to the narrow extender, without opening the door of the meter base (see Fig. 2-19 below).



Figure 2-19.

Note the separation between the narrow extender that makes the transition through the cover of the meter base, and the deeper extender that is part of the meter interconnect device. While the jaws and sockets mate very firmly, the plastic surfaces of these two extenders simply do not mate solidly. This allows one to “rock” the meter interconnect once it is in position, and this is not desirable. In meetings with the manufacturer of these components, the message was that the particular application we have developed was not envisioned. No solution was immediately obvious or available to improve this mechanical connection.

The second basic mechanical issue is in regard to the cantilevered enclosure that hangs below the extender portion of the meter interconnect device (see Fig. 2-20). Once in place the enclosure can act as a lever to dislodge the blades from the jaws. In the field conduit is routed and connected to the bottom face of the enclosure that stabilizes the enclosure’s position. Further consideration should be given to the mechanical rigidity of the installed meter interconnect device. This might be most easily achieved with a brace from the box to the wall behind it. No further design work on the mechanical attachment has been undertaken.

4. Market Considerations

The original inspiration for the meter interconnect device grew from experiences with residential PV systems in the late 1990s in Austin, TX. At that time Austin Energy, a participant in the former Utility Photovoltaic Group’s TEAM-UP program, managed the installation of a dozen or more residential PV systems. The PV arrays were roof mounted. DC wiring was routed along the outside of the building, down to the inverter and related switches mounted outdoors on an exterior wall of the house. The ac output wiring then enters the house and lands at a circuit breaker in the customer’s distribution panel. One of the challenges of dealing with customers is scheduling the visits that require entry into the dwelling. This was seen to delay and complicate the completion of the PV installations. A second concern is with entering the customer’s dwelling to complete the interconnection of the PV array wiring to the breaker in the panel.

In one case the electrical inspector was completing an inspection of a PV installation and saw that other, unrelated ac wiring on the

premises was not up to code. He would not approve the PV installation until this other wiring was corrected and brought in line with the code. As the “deep pocket” involved, Austin Energy saw to the upgrade of the wiring on behalf of the customer, in order to complete the permitting process and finalize the PV installation. Clearly, if the interconnection of the PV system to the grid could be accomplished without entering the customer’s premises, both the logistical and liability problems alluded to above could be avoided. So began the desire for a meter-based installation method.

In the marketplace there are PV installations like the one described above, with the inverter mounted outdoors, where the meter interconnect might be useful. However, it is also commonplace for inverters and associated switches to be mounted indoors wherever possible. Once this equipment is moved indoors, there is no longer an advantage to using the meter interconnect device. The National Electrical Code allows dc wiring to penetrate the roof and run inside the dwelling and New England is an area where PV installations typically involve indoor



Fig. 2-20. The MID installed in a ringless style meter base.

installation of the power electronics. For example, this is the case for all of the MID demonstration systems. Trends suggest that indoor installations will be the norm, as locating inverters indoors can prevent overheating of the power electronics that would otherwise potentially occur in hot environments.

5. Installer Feedback

Berkshire Photovoltaic Systems (BPVS) installed four of the five residential demonstration PV systems with the meter interconnect device. As noted, these installations, all in Massachusetts, have the inverters mounted indoors. Despite this (and the corresponding diminished utility of the meter interconnect device), the meter interconnect device was used to gain initial experience with its deployment. Feedback from this installer is provided below:

- Mechanical: (issues already described in sections above)
- Physical size: if the enclosure were smaller, it would be less intrusive and look better once installed. Also, he encountered a site where the MID could not be used because of interference.
- Inspectors: the device should be UL listed in the future, but inspectors liked the device with its clear external disconnect handle and close proximity to the meter
- Kilowatt-hour Meter Removal: the device requires removal of the kilowatt-hour meter and the utility company allowed the installer to do this for these installations. In other cases this might be an issue for the local utility company that could require their presence on site.
- Installation in Meter Base: the installation of the device proceeds very quickly and easily in terms of plugging into the meter socket. The short extender solves the situations with a ring-less type meter socket.
- Labeling: BPVS provided additional exterior informational labeling for the meter interconnect device; this should be considered in future installations with the product.
- Customers: the customers for these systems received excellent service and were pleased to participate in the NREL project. No specific comments were received on the meter interconnect device itself from customers.

6. Cost analysis

Only a small quantity of meter interconnect devices was fabricated and assembled. Costs for these units and for higher quantities are shown in the table below.

| Component | Manufacturer | Part Number | Quantity | 1 - 10 | 100 | 500 |
|--------------------------|----------------------|-------------|----------|----------|----------|----------|
| Enclosure | J&J Fabricators | 01015 R0 | 1 | \$139.50 | \$ 64.40 | \$ 59.10 |
| Gasket | Manufacturers Rubber | 10420 R0 | 1 | \$ 0.75 | \$ 0.66 | \$ 0.59 |
| High Voltage plate | J&J Fabricators | 01009 R0 | 1 | \$ 9.00 | \$ 3.65 | \$ 3.05 |
| Meter Extender | Ekstrom | EK-4J2F-BPK | 1 | \$ 62.64 | \$ 20.95 | \$ 19.90 |
| Dinn Rail | McMaster | 8961K15 | 1 | \$ 0.61 | \$ 0.61 | \$ 0.61 |
| 30A Switchable Fuseblock | Ferraz/Shawmut | FBCC30CDT | 1 | \$125.70 | \$ 89.96 | \$ 84.34 |
| Handle | Ferraz/Shawmut | H DPRND | 1 | \$ 12.55 | \$ 8.99 | \$ 8.43 |
| Shaft | Ferraz/Shawmut | SD200-5 | 1 | \$ 7.19 | \$ 5.15 | \$ 4.83 |
| Fuse | Littelfuse | CCMR-30 | 2 | \$ 7.65 | \$ 7.65 | \$ 7.65 |
| #10-32 KEPS nut | McMaster | 96278A411 | 2 | \$ 0.08 | \$ 0.08 | \$ 0.08 |
| 1/4"-20 KEPS nut | McMaster | 96278A511 | 6 | \$ 0.13 | \$ 0.13 | \$ 0.13 |
| #8-32 set screw | McMaster | 92311A192 | 1 | \$ 0.08 | \$ 0.08 | \$ 0.08 |

| | | | | | | |
|------------------------|----------|-------------------|---|-----------------|-----------------|-----------------|
| M6x1 set screw | McMaster | 92015A128 | 1 | \$ 0.13 | \$ 0.13 | \$ 0.13 |
| #10-32 Bolt | McMaster | 92314A830 | 4 | \$ 0.14 | \$ 0.14 | \$ 0.14 |
| Ground Lug | Burndy | KPA-4C | 2 | \$ 0.87 | \$ 0.87 | \$ 0.87 |
| Ring Terminal | McMaster | 7113K18 | 1 | \$ 0.09 | \$ 0.09 | \$ 0.09 |
| Spade connector (Male) | McMaster | 7060K77 | 1 | \$ 0.17 | \$ 0.17 | \$ 0.17 |
| Spade Connector (Fem) | McMaster | 7243K69 | 3 | \$ 0.25 | \$ 0.25 | \$ 0.25 |
| Wire 10AWG Red (7") | McMaster | 7587K278 | 1 | \$ 0.20 | \$ 0.20 | \$ 0.20 |
| Wire 10AWG Black (7") | McMaster | 7587K258 | 1 | \$ 0.20 | \$ 0.20 | \$ 0.20 |
| Wire 10AWG Grn (30") | McMaster | 7587K298 | 1 | \$ 0.93 | \$ 0.93 | \$ 0.93 |
| Ground Label | | | 3 | \$ 0.10 | \$ 0.10 | \$ 0.10 |
| High Voltage Label | | | 1 | \$ 0.50 | \$ 0.50 | \$ 0.50 |
| Front Label | | | 1 | \$ 1.00 | \$ 1.00 | \$ 1.00 |
| | | Total Cost | | \$370.48 | \$206.92 | \$193.40 |

At an estimated cost of \$200 for parts in quantities of several hundred, the selling price for the meter interconnect device would need to be on the order of \$300. At that price and given the trend toward indoor locations of power conditioners, the prospects in the market for the meter interconnect device would likely be very limited.

2.4 Conclusions and Recommendations

The meter interconnect device was intended to solve a problem and simplify the installation of residential PV systems. The concept is meritorious and in some situations the device could accomplish its goal of simplifying an installation. However, cost considerations, market conditions and technical design requirements militate against achieving a viable commercial product at this time.

3.0 Task 3.8a: SunTrack Data Acquisition System

The SunTrack data system was a commercial product of the company for many years, as an accompaniment to most every PV installation. After years of experience with the Campbell datalogger and working with our customers, a new version of the SunTrack was conceived. The key elements of the new SunTrack are the Reference Cell Device, to improve the accuracy of our sunlight monitoring, and a very versatile and user-friendly logger in a custom indoor enclosure. Improvements based on years of PV system datalogging experience are embedded in the new SunTrack to make it robust, adaptable to many situations, easy to hook-up and operate, and reasonable in cost.

A succinct summary of the goals for the new SunTrack is provided below.

- Purpose: collect and retransmit PV related data
- Estimated cost \$700
- Functions
 - Communicates with and collects data from devices and/or sensors
 - Reference Cell Device (sunlight and environmental sensor)
 - kWh meters
 - Inverters
 - Stores data and redistributes it to user
 - Local Compact Flash Card
 - Email data to a list of recipients
 - Post data to a web site
- Provides access to sensor for third party hardware
- User configurable
- Functions are generic (Modbus, Ethernet, email, web sites)
- Configurable for new Modbus devices

In recent years the observed trend has been that the company's value-added-resellers (customers for our modules and FS mounting hardware) were taking advantage of the availability of other low-cost datalogging products and services in the market. As a result, the company foresaw a limited market opportunity for the SunTrack and terminated its further development.

4.0 Task 3.8c: Evolution of the FS Mounting System

Schott Solar, Inc. developed its free-standing (FS) mounting system in 2001 to facilitate the broad use of its PV modules in the current markets for PV arrays on large flat-roof buildings. This section provides an overview of the original design of this mounting system, recent refinements and improvements made to the hardware, and the new application guidelines for the FS mounting system.

4.1 Background

The FS mounting system includes the following features:

- 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 three 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 originally at the Massachusetts Institute of Technology, achieved its design and performance goals and was introduced in late 2002.



Fig. 4-1. The free-standing (FS) system developed under this contract is the flagship PV array mounting system offered by the company.

4.2 Description of the Original FS System

The original configuration of the penetration-less free-standing (FS) mounting system is shown in Figures 4-3 and 4-4. 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.

4.2.1 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 mounting pin assembly. Figure 4-2 illustrates the mounting pin assembly affixed to the frame of the ASE-300 PV module.

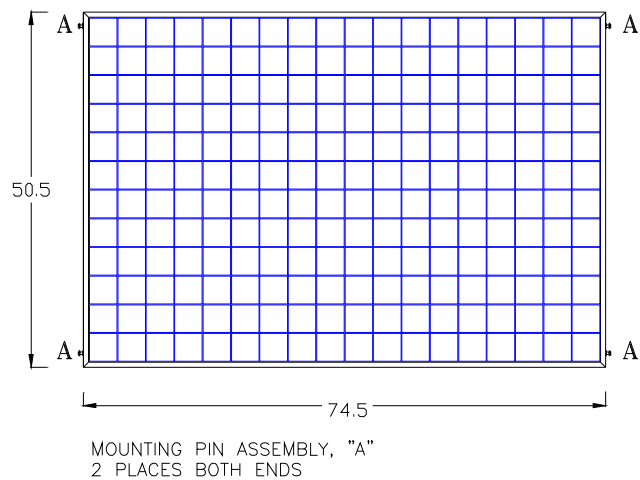
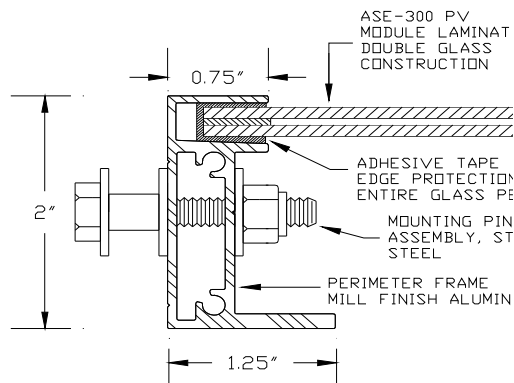


Fig. 4-2. ASE-300 PV Module and Mounting Pin Assembly Detail

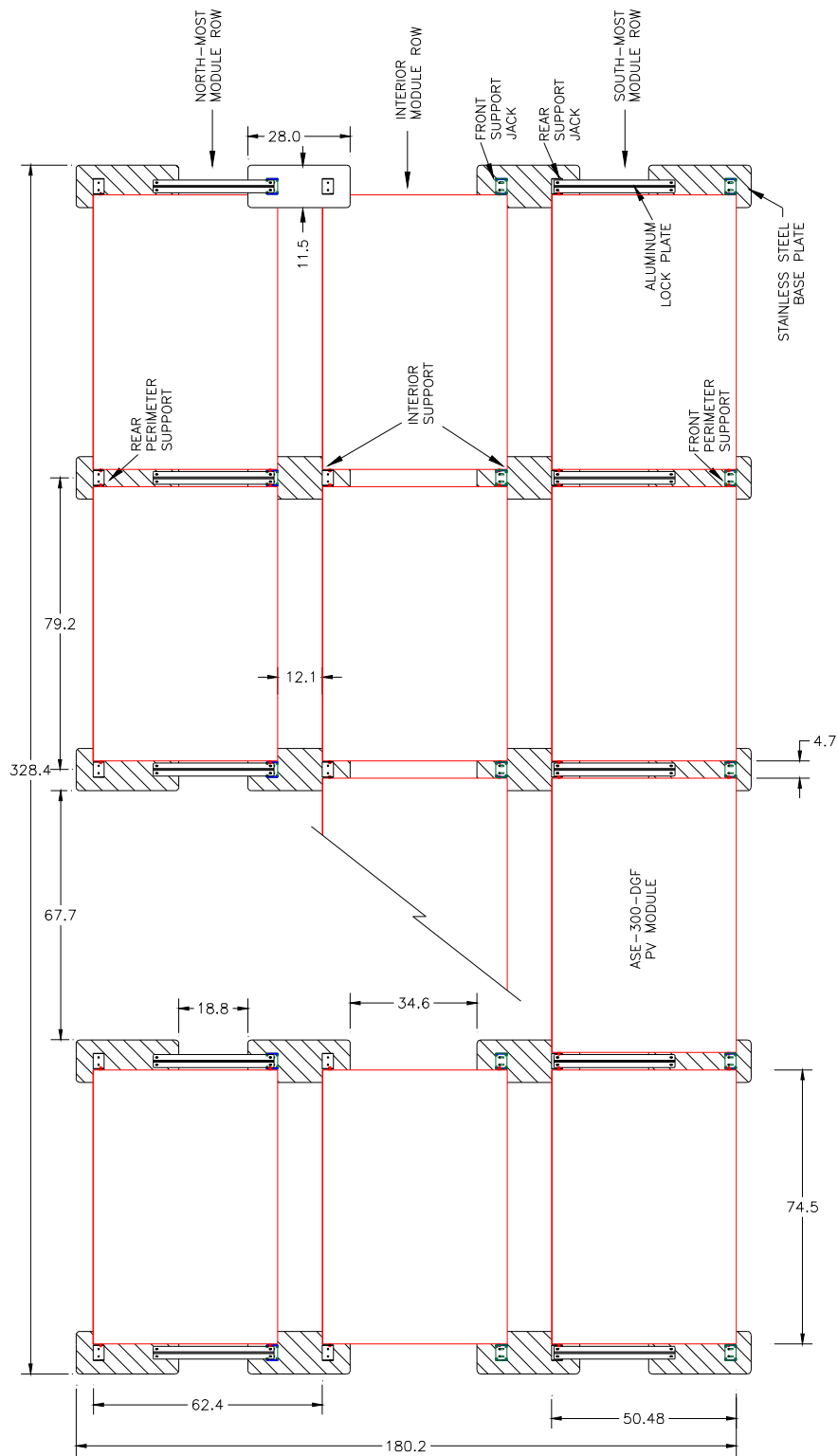


Figure 4-3. PV Array Plan View Layout Illustration with ASE-300 PV Modules

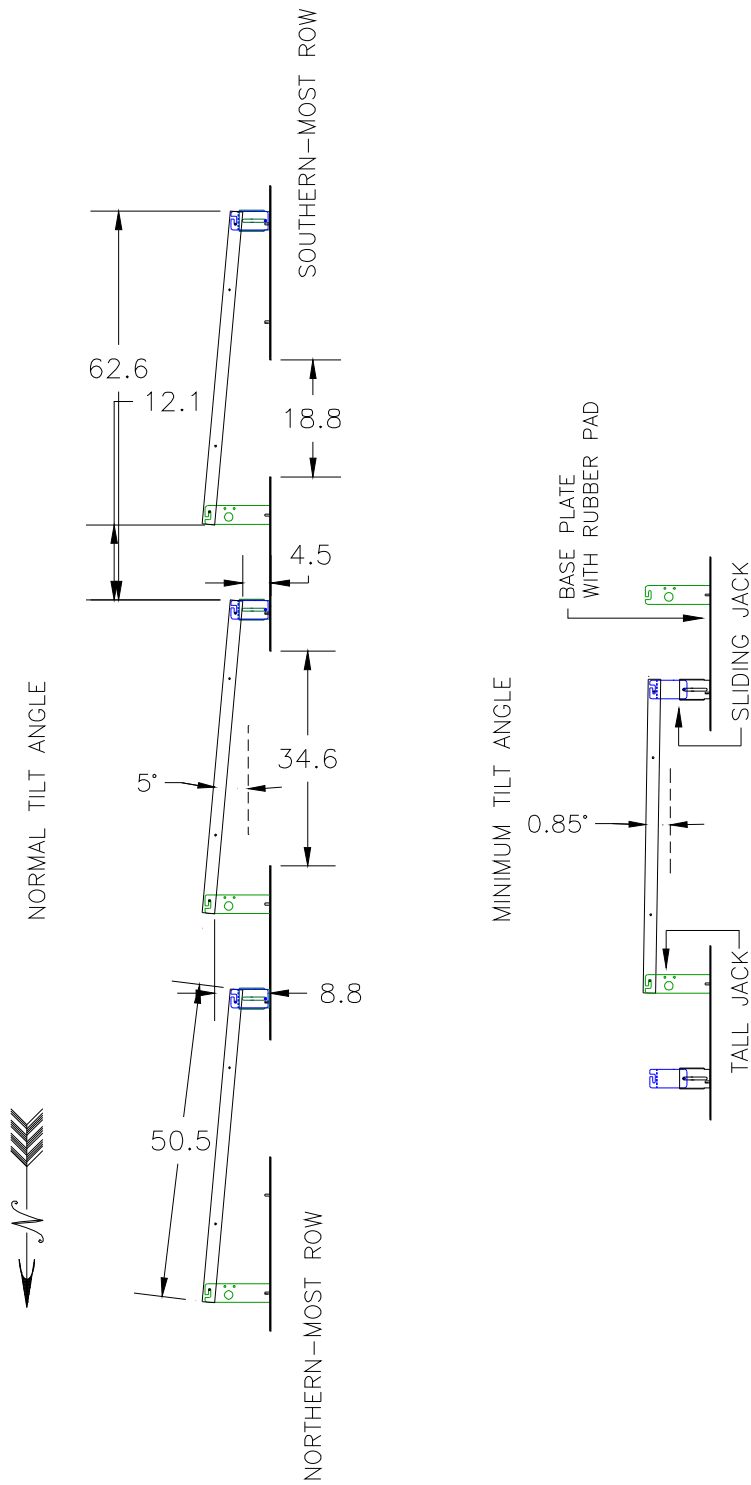


Figure 4-4. Elevation views of ASE-300 PV array at initial 5-degree tilt angle and at fully wind-relieved 0.85 degree tilt angle.

4.2.2 Base Plates

The rectangular stainless steel base plate is shown in Figure 4-5. The base plate's longer dimension differs with the module type being installed.

Originally a ¼-inch thick pad of sponge neoprene rubber was 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 4-5. 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.

4.2.3 Taller RoofJack



Figure 4-6. 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 4-6. Adjacent panel assemblies at all internal positions within the PV array share the RoofJack.



Figure 4-7. View of baseplate with both RoofJacks supporting PV module assemblies.

4.2.4 Shorter RoofJack



Fig.4-8. Panel assembly resting in the lower RoofJack

The shorter RoofJack, Figure 4-8, attaches to the opposite end of the base plate. As seen in the drawing of Figure 4-4 and the photo in Figure 4-7, 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.

A PV module assembly is lowered into the L-shaped slot of the taller RoofJack (Figure 4-6) 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 4-8) 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.

4.3 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.



Fig. 4-9. An example FS installation with the original hardware.

In response to field experiences with the first 100 installations, Schott Solar began an engineering review of the FS system. Field observations found that in many situations the actuation of the PV modules was constrained as a result of workmanship problems such as intrusion of conduit that would prevent actuation. Quality control on the short jack fabrication was also a concern, as it could inhibit the jack from actuating smoothly. In addition, the installers found it difficult to install the FS hardware properly and it became clear that improvements were needed. The engineering review resulted in revision of the short jack (that allows the actuation of the module), and included further wind tunnel testing to re-affirm the applicability of the design.

4.4 New Design Features

The new look of the FS system is depicted in Figure 4-10 below. Several changes have been made to the hardware to address various deficiencies of the original version. The first change in the FS hardware is to the short jack that supports the lower edge of the PV module. The original design with the plate sliding inside a sleeve has been replaced by a bracket that forms a resting surface.

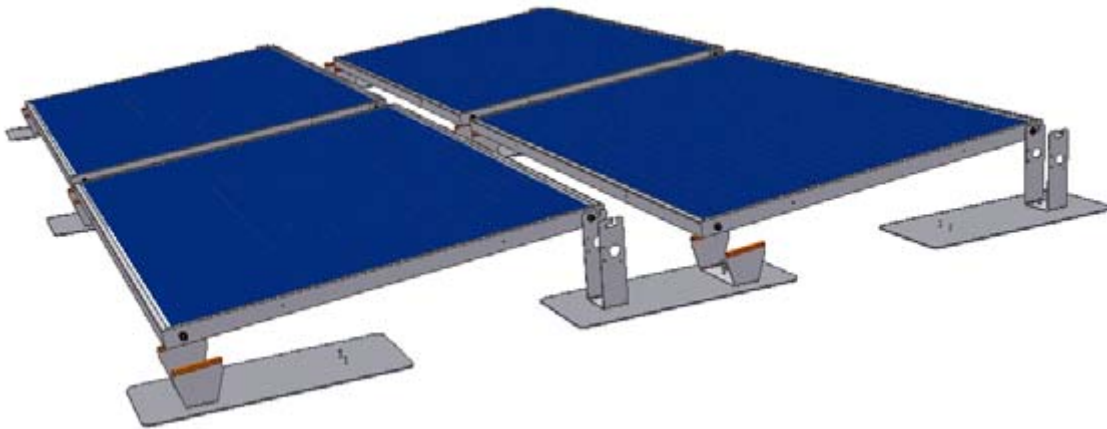


Fig. 4-10. Rendering of the new design of the FS mounting system.



Fig. 4-11. New short jack

The photographs in Figs. 4-11 and 4-12 show an installation with the new short jack. The orange rubber trim along the edge upon which the module frame rests provides a cushion between the two metallic parts. Also note the tether that connects the short jack to the module. This tether is a stainless steel cable that is secured to a tab on the short jack at one end. The other end is secured to a clip

that fits around the mounting pin tether is to restrict the rotation of horizontal orientation. The new for the module to actuate.



Fig. 4-12. Module at full actuation and in normal position



Fig. 4-13

With the new short jack, the module is less constrained from motion in the horizontal direction than with the original short jack. Accordingly, to prevent the upper end of the module from escaping from the slot in the tall jack, a clip was designed (Fig. 4-13). The clip provides a barrier to prevent the module pin from finding its way out of the slot in the tall jack.

These innovations are now in use with the FS mounting systems.

In addition to the changes in the short jack and tall jack, a ballast piece was designed to add weight in key areas for preventing lifting or movement under extreme wind forces. The so-called “M” ballast, because of its shape, is made of a polymer concrete material and designed to sit on the baseplate and fit around the base of the tall jack.

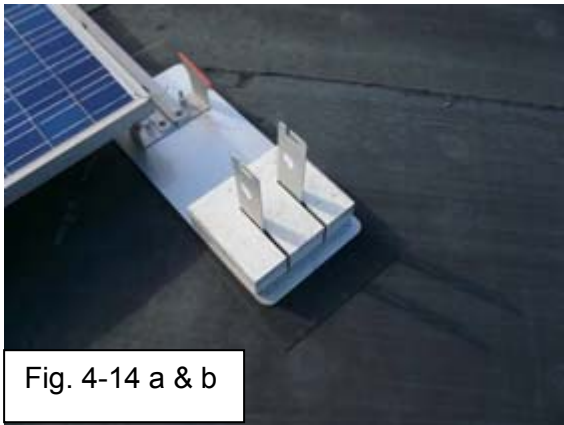


Fig. 4-14 a & b

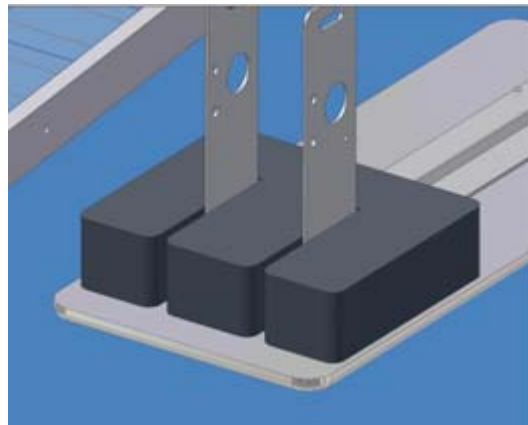


Fig. 4-14a & b show a photo and rendering of the M-ballast in place around the tall jack. This piece weighs approximately 20 lbs. Multiples can be placed on the baseplate if and as necessary (Fig. 4-15). The ballast is a component that is necessary in some circumstances. The new application guidelines define when and where and how many of these M-ballasts must be used in a given PV array.

Two other innovations were investigated but are not yet approved for use and are still in development: a modified tall jack with fewer components (Figs. 4-16 a & b), and a lower-cost polymer concrete baseplate to replace the current stainless steel version (Fig. 4-17).



Fig. 4-15. Multiple M-ballasts



Fig. 4-16a. Prototype tall jack with welded pipe



Fig. 4-16b. Original tall jack with PVC pipe nipple, bushings and lock rings

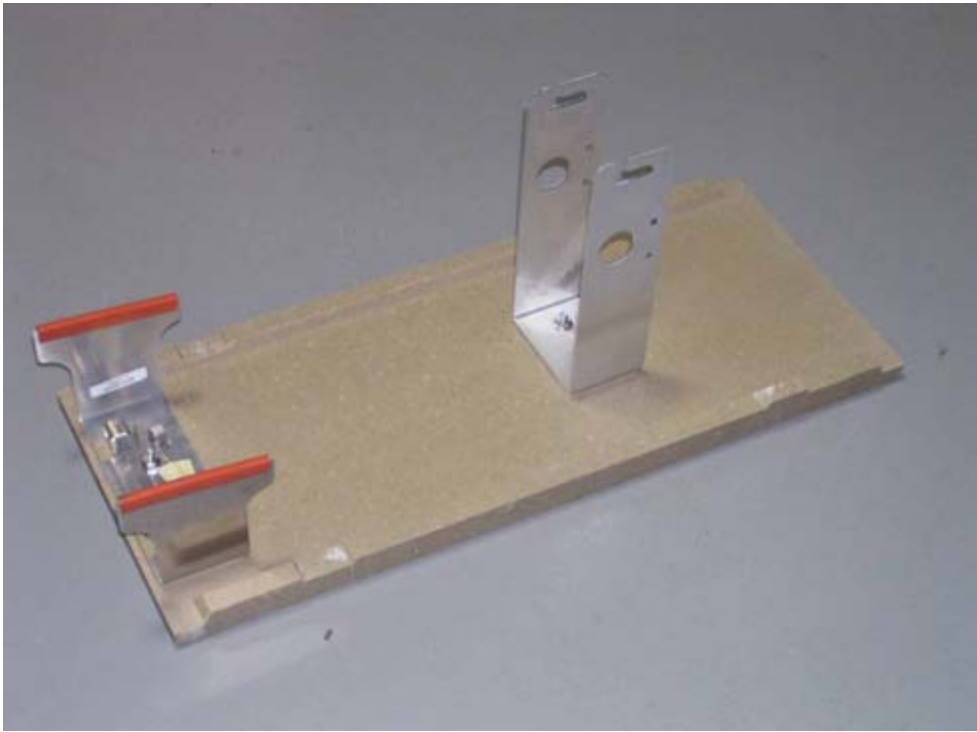


Fig.4-17. Polymer concrete baseplate prototype

4.5 Wind Tunnel Testing

An important element of the comprehensive engineering review of the FS mounting system was scale-model wind tunnel testing at Colorado State University. This facility operates commercially and is very experienced at modeling and testing for the solar industry. A six-module by six-row array of ASE-300 modules was constructed at a 1:40 scale for the testing (Fig. 4-18). The wind tunnel is about 40 feet long and designed to replicate exposure C (see the ANSI ASCE 7-02 standard, Wind Loads for Buildings and Other Structures). Over the course of three sessions and hundreds of separate runs, a large body of information was developed.



Fig. 4-18. Wind tunnel at Colorado State University

Tested configurations included:

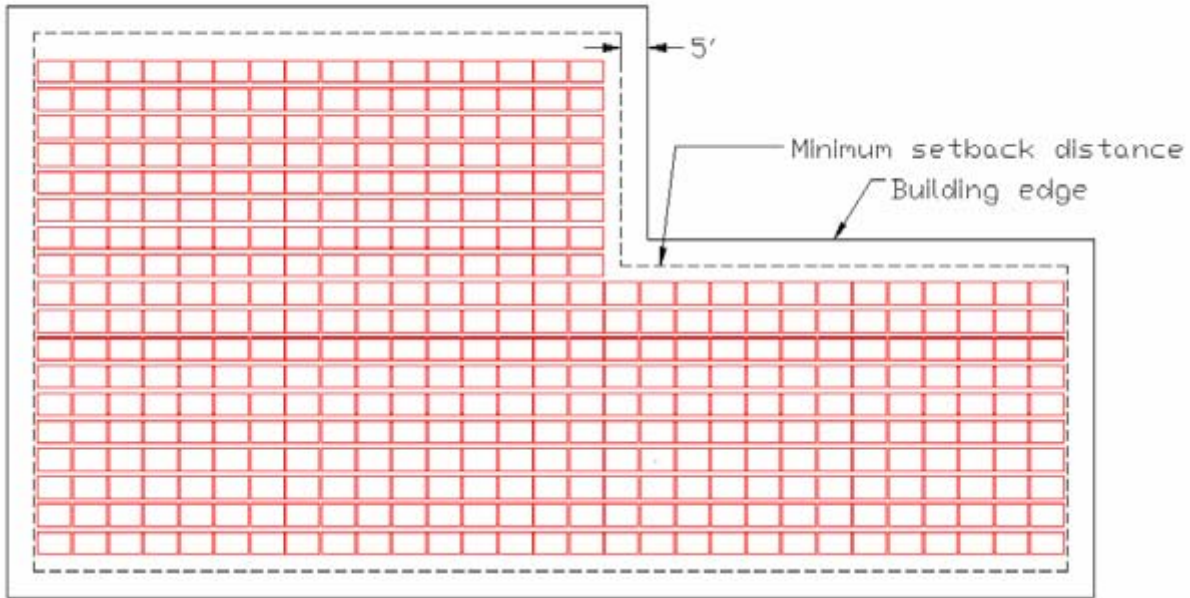
- wind direction from all compass points to array,
- array square to building and skewed 45-degrees
- building orientation to the wind: narrow, wide and 45-degrees off axis,
- varying array distance from roof edges
- presence or absence of a 3-foot parapet
- 6-row and 2-row array configurations

The procedure in the tunnel was to set the model and building in the desired orientation, and then gradually increase the wind speed until a failure was observed. The three defined failure modes were sliding, lifting (not actuating, but corner lifting) and excessive actuation events. The scale model included M-ballast pieces were deployed as desired to help prevent sliding or lifting type failures at high wind speeds. Over 200 separate runs were conducted. From this body of data, the new application guidelines were developed.

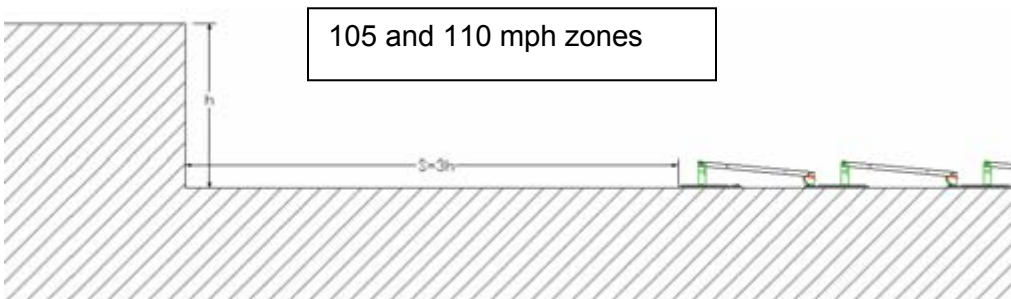
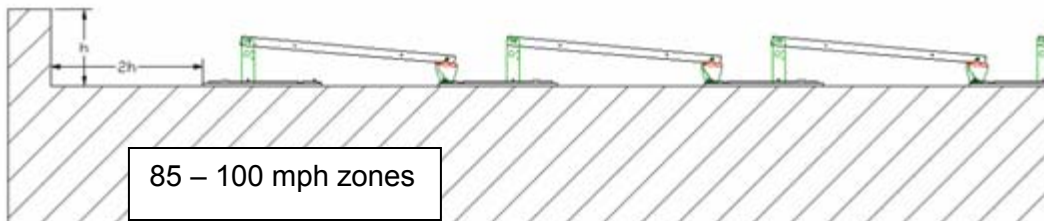
4.6 New Application Guidelines

The material in this section presents a portion of the new application guidelines, now in final preparation. The first step in the process of laying out an FS array on a building is to observe proper setbacks from building edges, parapets, walls and roof equipment on roofs.

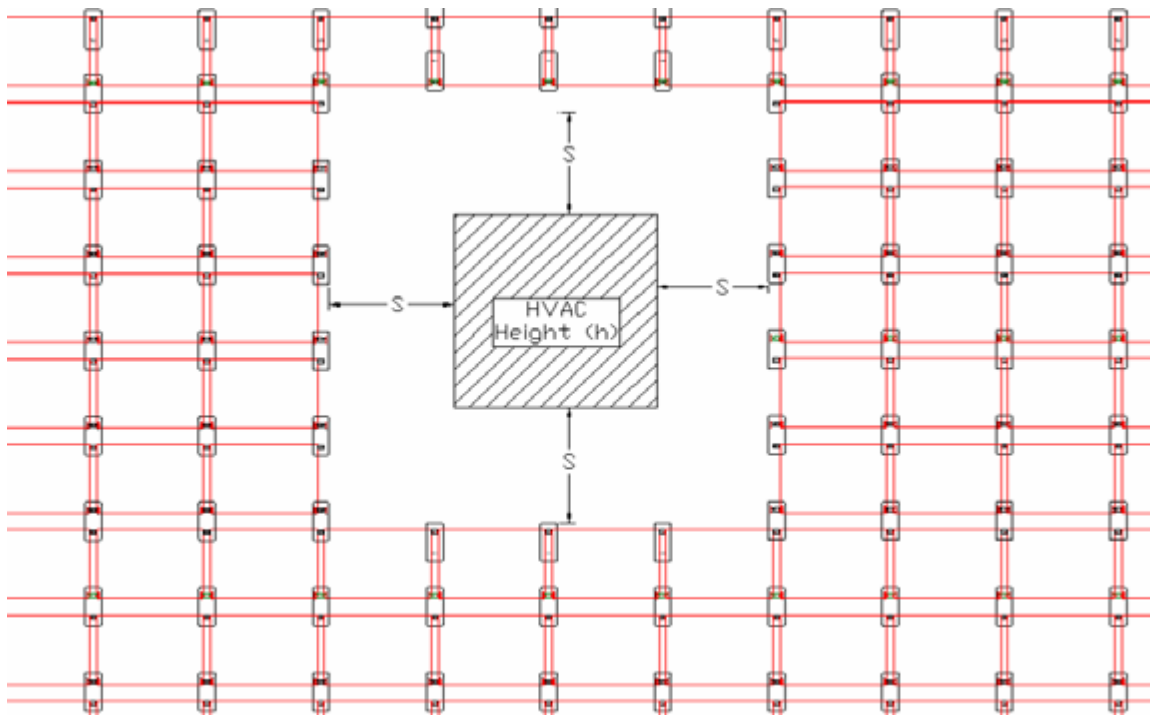
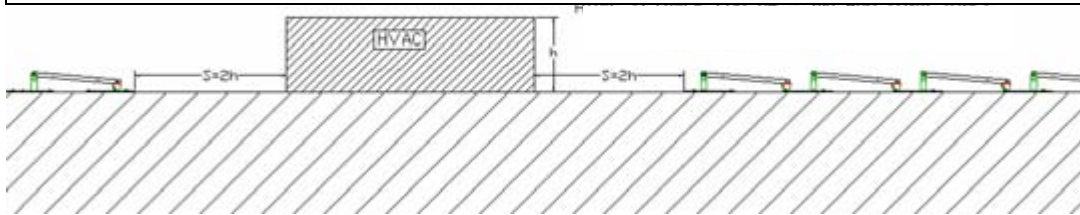
PV array must be set back at least 5-feet from building edges, all wind zones.



PV array must be set back at least 2 x parapet (or wall) height in 85 – 100 mph wind zones. Minimum setback is 3 x parapet (or wall) height in 105 – 110 mph zones.



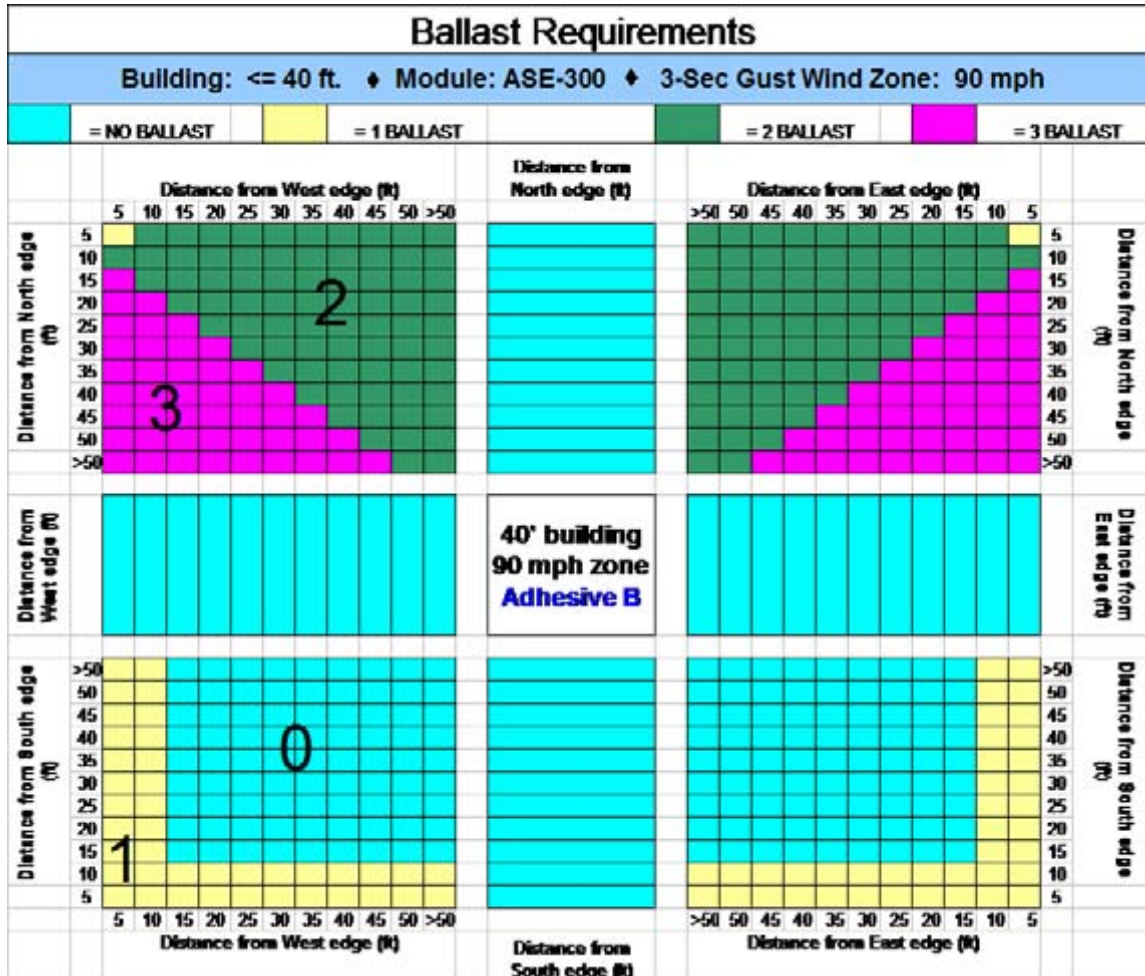
For equipment with any horizontal dimension of 6-ft or greater, PV array must be set back from all sides, at least 2 x equipment height in 85 – 100 mph wind zones. Minimum setback is 3 x equipment height in 105 – 110 mph zones.



The requirements for ballasting the array perimeter are also based upon the extensive wind tunnel testing of the FS system. A series of charts have been developed. Each chart is for a specific design wind speed and for buildings in one of two height categories: 40-ft or less, and 40+ to 60 ft. Charts exist for wind speeds of 85, 90, 95, 100, 105 and 110 mph. The FS system is restricted to buildings in zones at or below 110mph, which includes all but some extreme coastal regions of the US. It is also restricted to buildings no taller than 60 feet. The chart on the next page is an example ballast application chart. This chart is specific to the ASE300 PV module, on a building of height 40-ft or less, in a 90 mph wind zone of 90 mph (3-second gust specification), as identified in the top bar of the chart.

Note that the chart is divided into eight zones: four corners and four sides. These represent the different perimeter regions of an installed PV array. The corner charts present the color-coded requirements for ballast for the specific corner module. The color is decoded at the top of the chart, showing the number of 20-lb M ballast indicated for each color. For example, if a PV array has a NW corner that is 15 feet in from the west edge of the roof and 10 feet away from the north edge, that puts it in the green area, calling for 2 M-ballast to be used on that NE corner module's two baseplates only.

For all array corners, the user locates those corners on the appropriate section of the chart to determine the ballasting required. Similarly, the north, south, east and west edges of the array must also be located on the chart to determine the required ballast. On the chart below, the N, S, E and W edge regions are all blue, indicating no ballast is required for those perimeter modules on this building height and in this wind zone.



The chart for a higher wind speed region follows, to illustrate changes in these requirements as wind speed grows. Note in the 95 mph wind zone, the color patterns are different and indicate more ballast is required than in the 90 mph chart. Note also that there are regions of the NE and NW corner sections of the chart with no coloration; array corners are not allowed in these regions. That is, this does not preclude arrays from being located in these white regions, but it rather indicates that no NE or NW array corners can be located there.

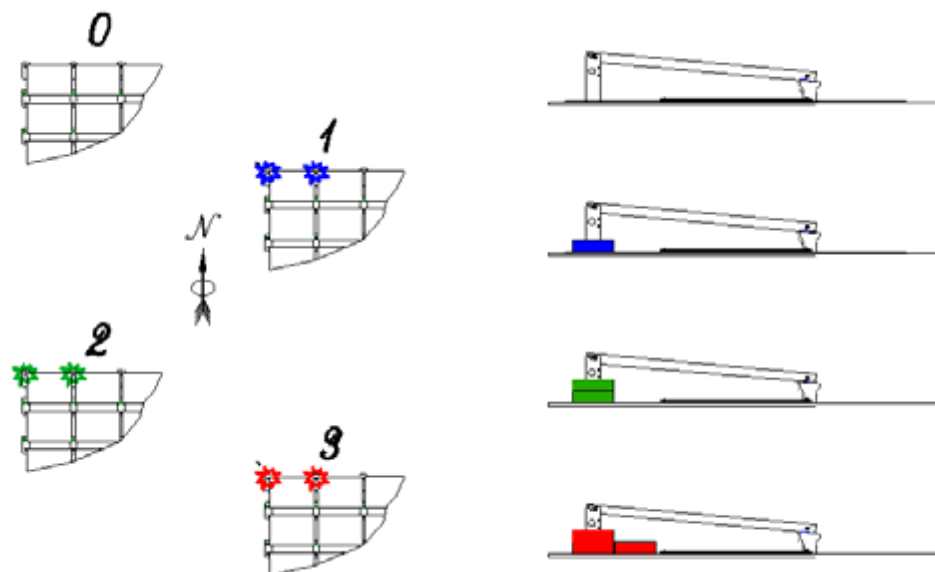
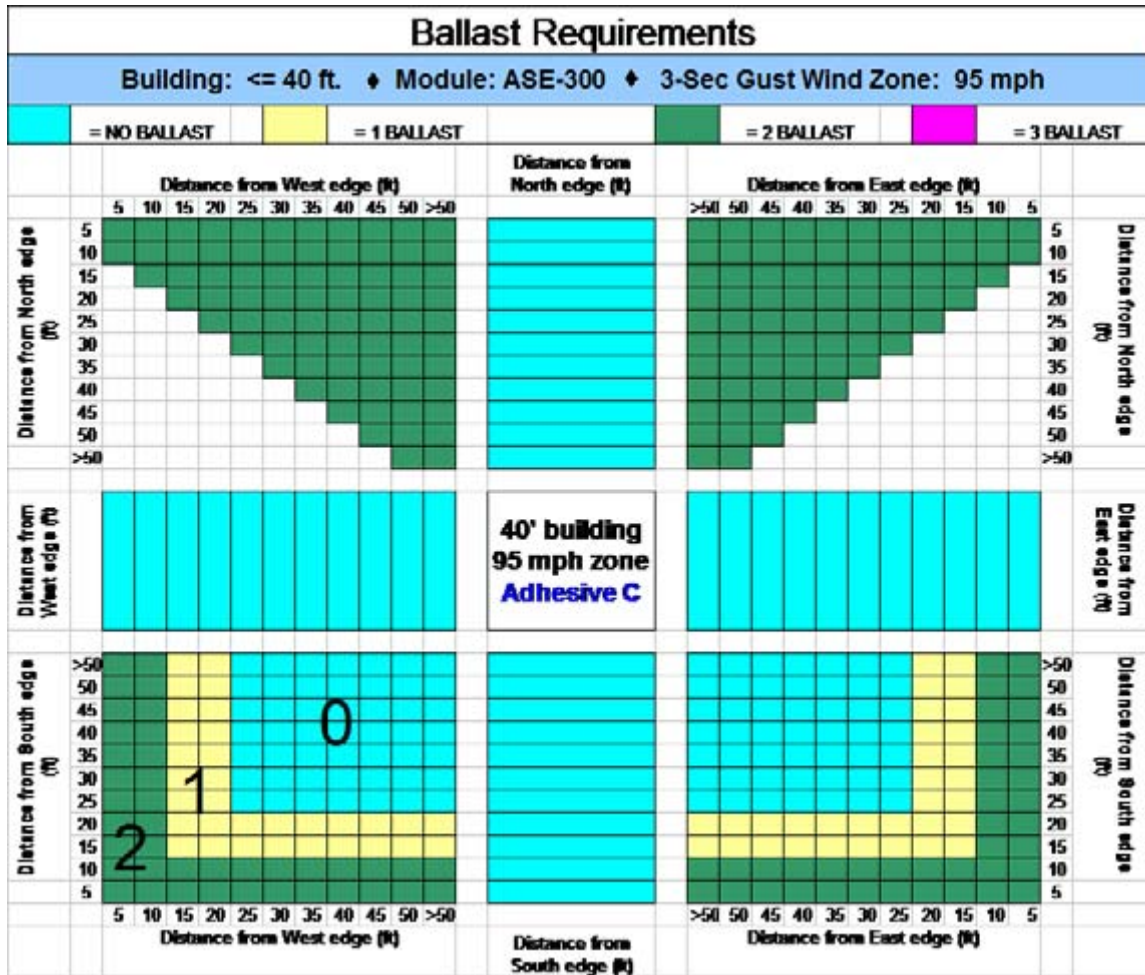


Figure shows examples of applying varying amounts of ballast to an array corner. Note that ballast in corners is only applied to the two baseplates associated with the corner module.

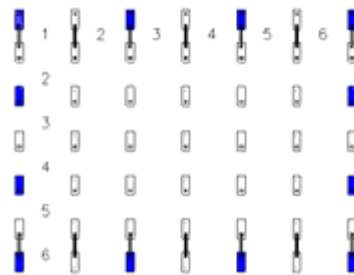
The final issue to address in the application of the FS system is the use of adhesive to bond some of the perimeter baseplates to the roof surface. Note that the use of adhesive has been an accepted practice for meeting seismic design requirements in certain seismic zones, mostly in California. It should also be noted that the adhesive is not being used in the FS system as a means to prevent sliding *up to and beyond the design wind speed*. The inherent features of the FS system and any additional ballast as defined in the colorful charts, were tested and proven in the wind tunnel to prevent failure, including sliding, up to the safety-margin wind speed. The safety margin built into the application guidelines for the FS array is approximately 20 mph greater than the site design wind speed. For example, if an FS array were installed in a 100 mph 3-second gust wind zone region, the treatment called for in the application guidelines in terms of ballasting will have demonstrated its ability to withstand 120 mph 3-second gusts. Adhesive is an added safety feature that would only be called on to resist horizontal movement in the safety margin region or higher -- well beyond the design wind speed.

The requirement for adhesive is indicated in the central block on the charts, and is identified as A, B or C. These treatments apply only to perimeter baseplates and are explained in the graphics below.

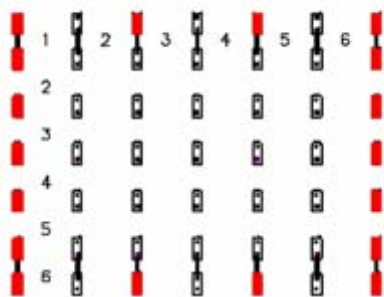
A -- No Adhesive Required



B -- Every Other Perimeter Baseplate



C -- Sides All, Every Other N & S



4.7 Conclusion

The FS mounting system is unique in that it relies on a dynamic feature to withstand extreme wind forces. This mechanism has been demonstrated in the wind tunnel and shown to work effectively. The evolution of the product has brought about an improved version that simplifies installation and assures the proper performance of the system. Additional wind tunnel testing complemented earlier work and has made possible the clear definition of the FS product's applicability. Comprehensive new application guidelines are being finalized and will be released early in 2007. Cost reduction of the components in the system remains an area of active investigation. Adaptation of the mounting system to a broader variety of modules is also under study.



Fig. 4-19. An example array using the new FS hardware and ASE-300 PV modules

5.0 Task 3.8d: Investigation of Dark I-V Measurements

A current-voltage, or I-V curve of a PV module is the standard measurement to determine its basic electrical characteristics. This measurement requires a solar simulator in the factory environment to provide a calibrated solar-intensity flash during the measurement of the PV module. An alternate approach is to force current through the module and simultaneously measure the current and developed voltage, in the absence of any solar-intensity flash. The resulting “dark” I-V curve is somewhat easier to obtain than an illuminated I-V curve and it can reveal very interesting details about the subject PV module. This section describes the design of equipment developed at Schott Solar to measure the dark I-V characteristics of its modules, and the initial results obtained in trial uses.

5.1 Proof-of-Concept

The intent of the effort at Schott Solar was to complete a proof-of-concept test station that could measure dark I-V curves on the ASE-300 module (as a whole and on the sub-strings).

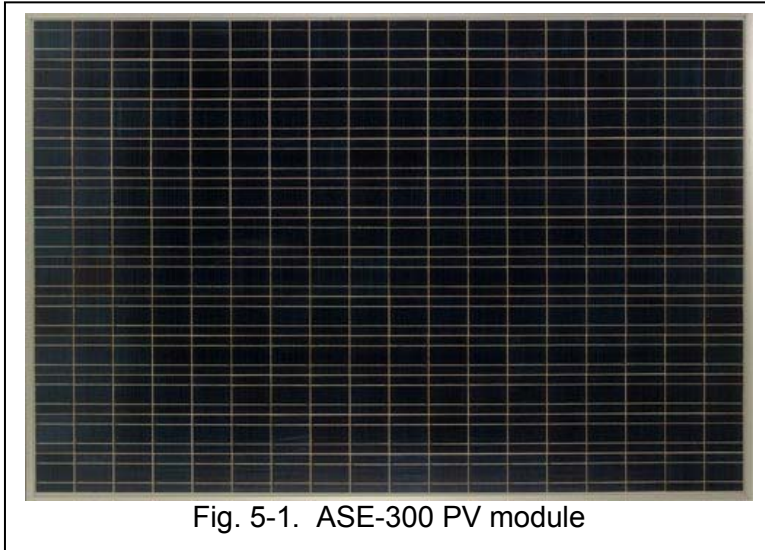


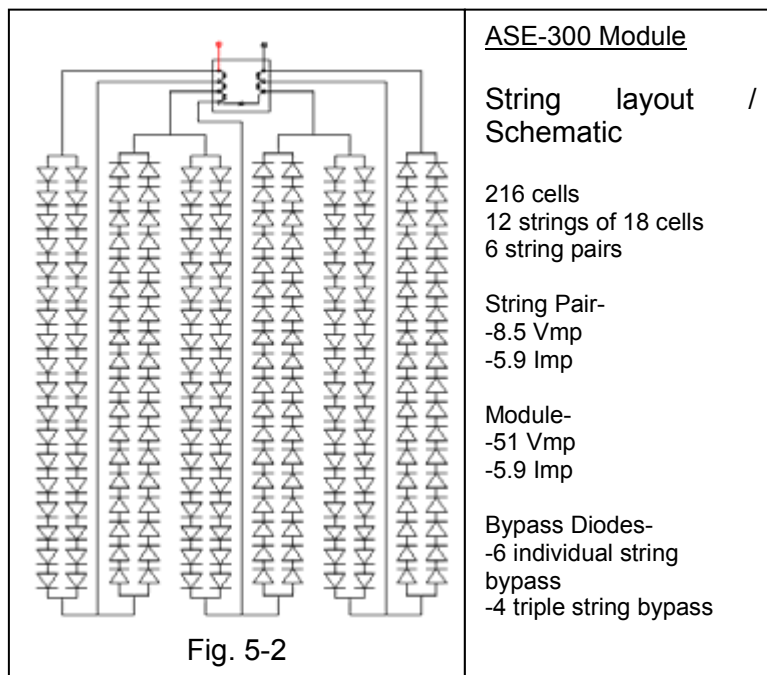
Fig. 5-1. ASE-300 PV module

In the Billerica, MA factory, Schott Solar primarily manufactures the ASE-300 module. This module incorporates 216 100mm square cells for a nominal power of 300 Watts. The 216 cells are made up as 6 string-pairs each containing 2 parallel strings of 18 cells in series. The process of taking individual solar cells, stringing them into 18-cell source circuits, and combining these circuits to create the ASE-300 includes many checks and screens along the way. Once the module leaves the final pre-lamination inspection, it is believed to be completely correct and healthy. Still there are PV modules that come out of the lamination step that prove to be faulty for one reason or another. Some of the module problems observed are introduced during lamination and cannot be seen prior to that step. However, other problem types that are not seen until after lamination have the potential to be found, not visually, but by careful measurement prior to lamination. Specifically, a dark I-V curve test could be performed on the individual strings in the module, before lamination, to ascertain that all cells and strings are behaving normally. Certain problems that heretofore could not be uncovered, would be apparent during this test, and could be fixed. With such a test station on the production floor, a significant number of modules could be repaired and processed that would have otherwise been scrap or downgraded, discount units. If the problem can be found, identified, and solved, before lamination – before it is too late – then a great deal of loss can be avoided by the company.

Our proof-of-concept goals were to develop a procedure to consistently uncover invisible problems with laminate string-pairs in our manufacturing process. We aimed to compare healthy modules to modules with known faults that were measurable by the Schott ASE300 flash tester (an illuminated I-V curve). Because of factory space and process constraints, this proof-of-concept effort tested PV modules after lamination. A final dark I-V test station would be placed before lamination and possibly after cell stringing.

5.2 The ASE-300 PV Module

The ASE-300 PV module incorporates 216 100mm square cells in a 12 cell by 18 cell physical configuration. Two strings of 18 cells are connected in parallel, resulting in 6 separate string pairs (see Figure 5-2).



The product to test, therefore, is a laminate with seven tabs passing through the back glass. Adjacent tabs electrically connect a pair of 18 cell strings amounting to 36 cells. The string pair has a nominal Vmp of 8.5 Volts and Imp of 5.9 amps. In order to properly isolate and test each string pair, there are no bypass diodes in the circuit under test.

5.3 Dark I-V Method

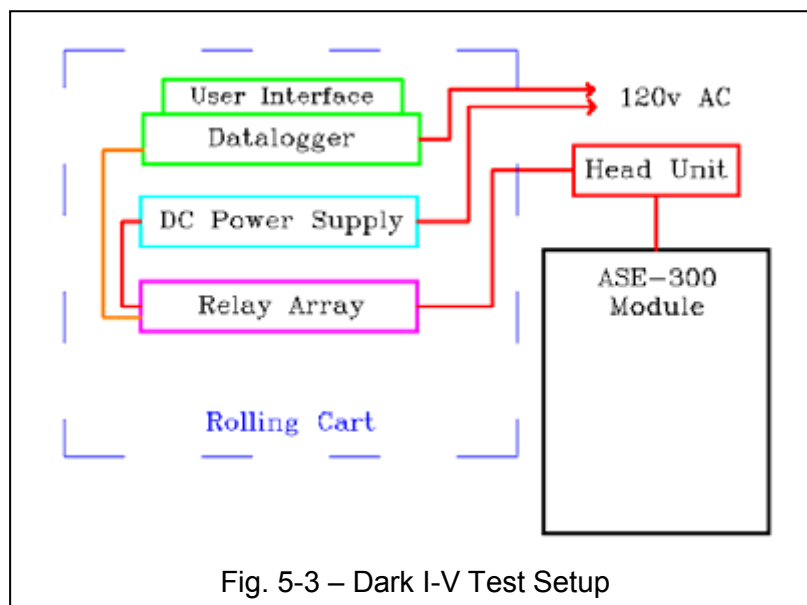
Dark current and voltage (I-V) testing has been applied to photovoltaic cells since the 1960s. More recently Sandia National Laboratories has refined the process for series/parallel combinations of cells ("Dark current-voltage measurements on photovoltaic modules as a diagnostic or manufacturing tool", King et al). King found that using non-linear regression procedures on the dark I-V data, he could estimate the series resistance, shunt resistance, diode factor, and saturation current on a module made up of cells in various series and parallel combinations.

Although this detailed analysis is interesting to Schott Solar in manufacturing, the goal of the first Dark I-V prototype, as previously stated, is to uncover gross errors on string and series

connections in a pre-laminated module. Instead of teasing out all parameters we were mostly concerned with series resistance as a marker for a healthy module. In our Dark IV procedure we screen the module from room light and, for each of the six string pairs, apply a current source across the ribbon leads. Specifically, a power supply forces current through the string pair from the positive contact to the negative. The resulting current and voltage are measured at pre-determined points until we reach our maximum current limit. The current flow through the string pair is opposite the current flow when the module is in light. However, each cell's p-n junction reacts in a "forward-biased" nature (as if functioning correctly). The resultant I-V curve reveals predictable electrical characteristics of the string pair. Tests in the King paper indicate that applying current equivalent to that which the PV module would generate under 1.5 suns is appropriate to discern series resistance variations in the PV module. For the ASE300 we chose 10 amps as our maximum current, since the short-circuit current is approximately 6.4 amps.

5.4 Dark I-V Equipment

For our Dark I-V tester we developed a programmable, Campbell Scientific- based, datalogging system to control a cascading relay box and also measure current and voltage sensors. The relay scheme allowed the datalogger system to test all string combinations automatically. The operator, however, needs to change the current levels on the power supply manually. Based on a brief search on the market, we determined that there are controllable power supplies available that allow for automated current adjustment.



We set up the dark I-V datalogging equipment on a rolling cart with the main components on three shelves (Figure 5-3). The first component is a NEMA 3R enclosure housing the Campbell datalogger. On the enclosure we have an on/off switch for the data acquisition system, a reset button to start the test program, and three indicator LEDs to lead the user through the program. The second component is an 80 Volt, 10 Amp power supply. The third main component is a controllable relay board inside another NEMA 3R enclosure. From the relay board we routed seven wires to a harness. The harness attached to a specially designed ribbon clip apparatus, or a specially design junction box cover depending on the type of laminate we attached to.



Fig. 5-4 – Dark I-V tester

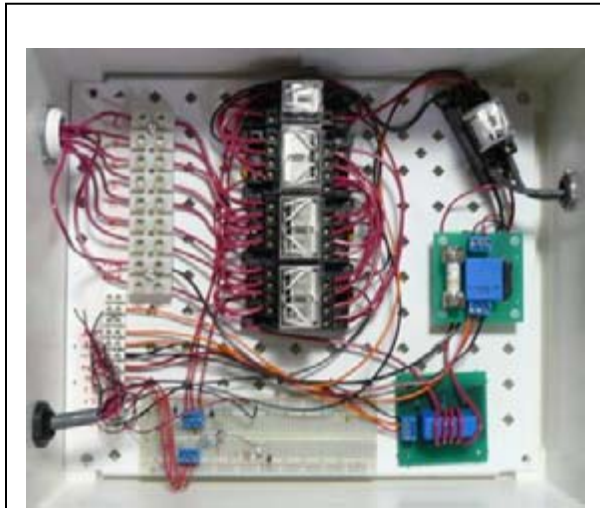


Fig. 5-5 – Relay board

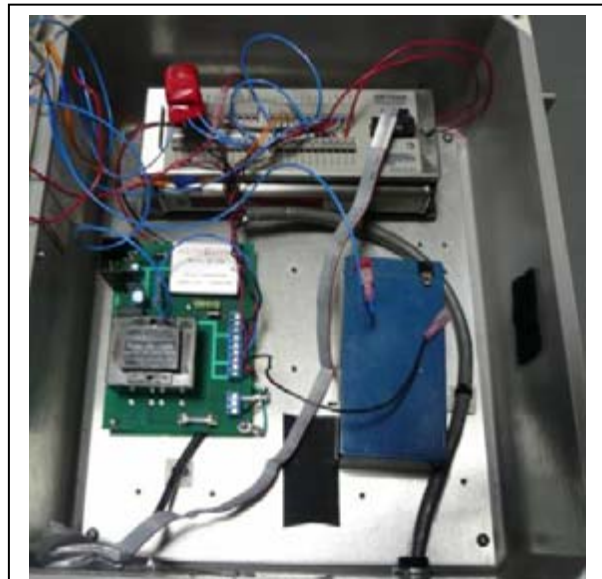


Fig. 5-6 – Datalogger

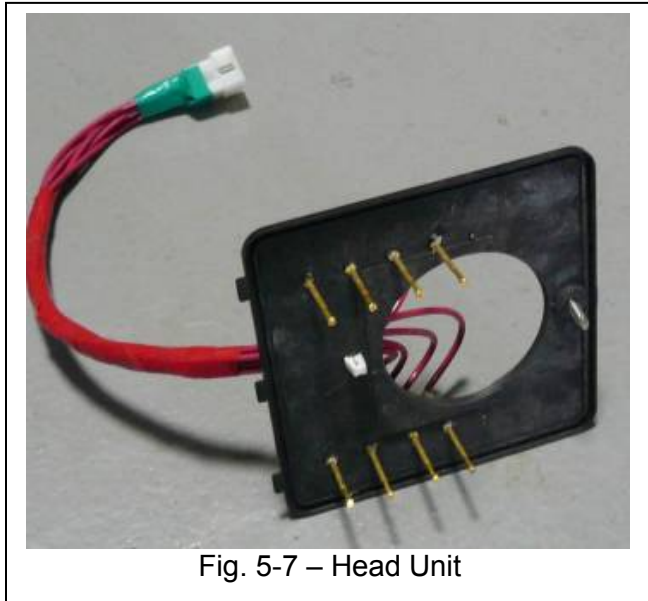


Fig. 5-7 – Head Unit



Fig. 5-8 – Power Supply

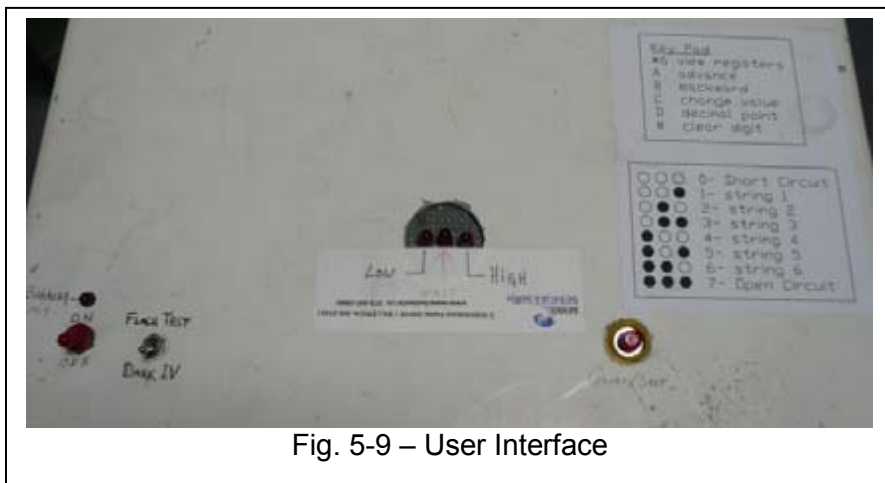


Fig. 5-9 – User Interface

The general procedure for measuring the dark I-V data for a PV module was to use a Hall-effect current sensor, measured by the datalogger, to adjust the power supply to a pre-determined current. When the datalogger senses that the current is within range, it then: 1) controls the relay board to select a string pair, 2) applies current, and 3) measures the resulting voltage. For each current set-point, the datalogger automatically measures all six string pairs in the ASE-300 PV module.

Since the basic operation of the prototype is to drive current and then measure voltage, the voltage drop in the sensing wires affects the overall voltage measurement. We therefore used a dummy calibration card to simulate a PV module with all strings shorted to gather calibration data at different current values (Figure 5-10).

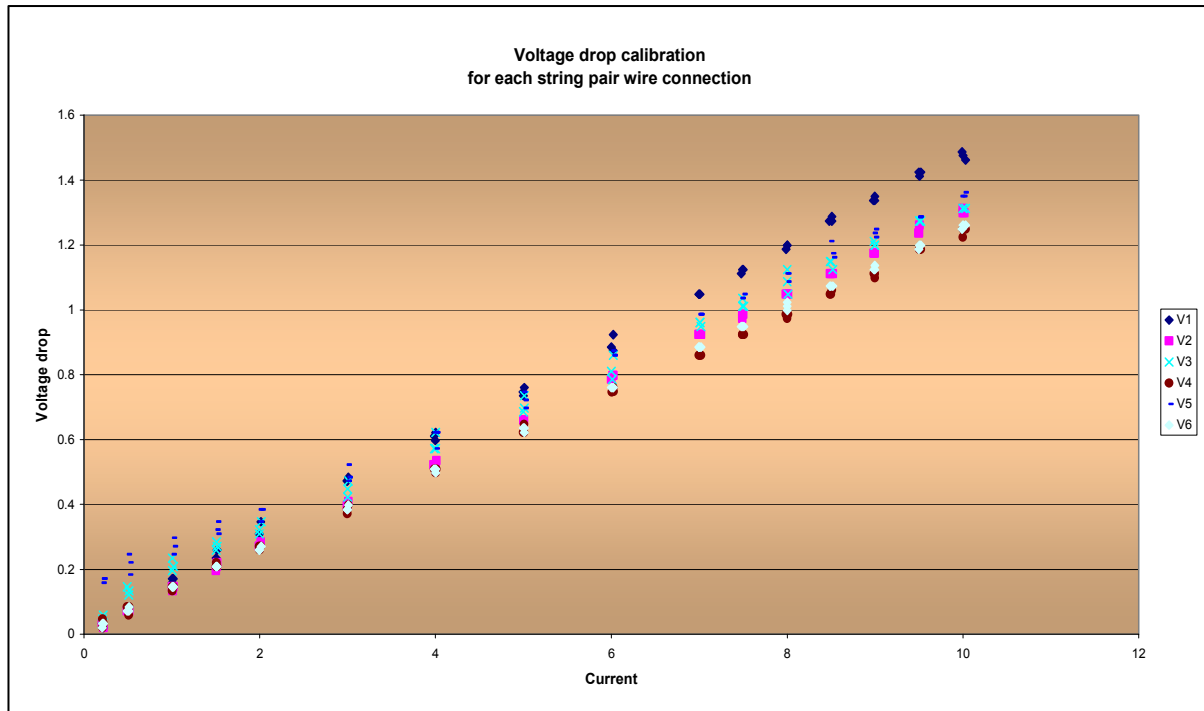


Fig. 5-10 – Calibration check

5.5 Hardware Setup

The hardware and setup to prepare for taking a dark I-V curve is as follows:

1. Datalogger (Campbell CR10x) 12 channel

2. Current Measurement

- **Hardware: LEM LA-55 current transducer**
- Set up: 50-ohm sensing resistor and 5 loop winding through transducer, resulting in a 10A max current measurement

3. Voltage Measurement

- **Hardware: LEM LV-25P voltage transducer**
- Set up: 4.5-ohm control resistor for a max voltage measurement of 40V

4. Relay system

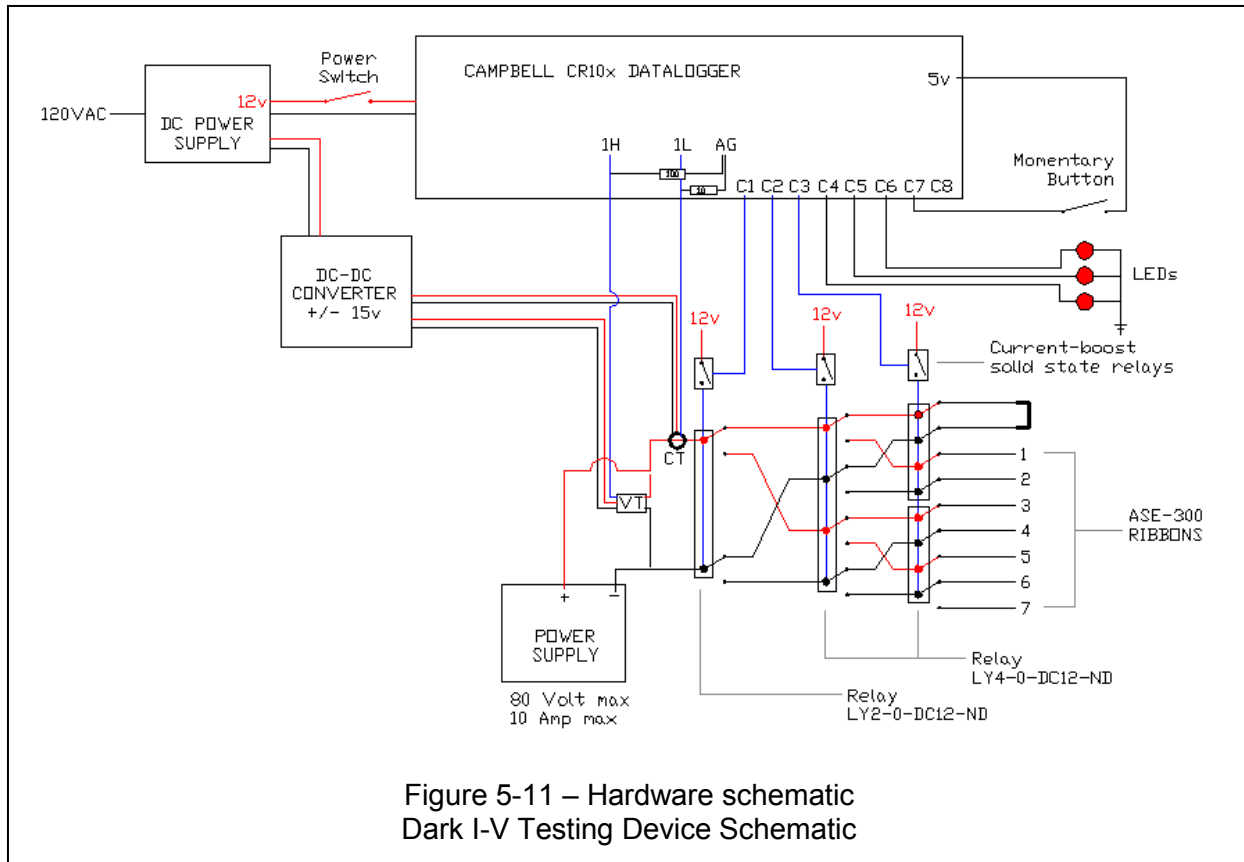
- **Hardware:**
 - **4PDT relay (Digikey LY4-0-DC12-ND) x3**
 - **2PDT relay (Digikey LY2-0-DC12-ND) x1**
 - **Solid state relays x3 (circuit in figure 14.10-2 in CR10x manual)**
- Set up: Relays are configured in the array shown in Figure 5-5. The three solid-state relays are used to boost the Datalogger control signal (current not sufficient to actuate LY2/4). The normal position of all relays results in a short-circuit at the power supply connection. The Datalogger can control the relay array to connect the power supply to any of the six string pairs (in proper polarity) or to an open-circuit for Voc measurement.

5. Module Connection Head-Units

- Ribbon connection: This unit is used for connecting the dark I-V tester to a laminate with only ribbon cables available for electrical connection. The ribbon head-unit consists of 7 clamps mounted on a Plexiglas plate, the 7 clamps compress the module ribbon against a metallic surface that is wired to a connection harness
- Diode-card connection: This unit is used for connecting the dark I-V tester to a module with the diode box already mounted. The diode-card head-unit is a modified diode-box lid with 7 spring pins wired to a connection harness. A dummy diode card is installed, the module ribbons are laid on top of their proper solder tabs and the head-unit is installed.

6. User Interface

- Hardware
 - 2 position switch (Datalogger power)
 - Momentary button (Program start)
 - LED x3 (Power Supply current; low, high, correct)



5.6 Dark I-V Run Procedure

1. Attach dark I-V head-unit to PV module
2. Turn power supply current knob down to zero (counter-clockwise)
3. Turn on power supply
4. Using LED indicator, raise the current on the power supply until the center LED illuminates. After several seconds the LED will flash to indicate that the current has stabilized in the correct range
5. The voltage test will then automatically proceed for each string pair at that current level.
6. At the end of a current level tests, the LED indicators will show that the current is too low, adjust the current upwards (procedure 4)
7. At the end of the test, the LED indicators will all be off
8. Turn off power supply
9. Disconnect head-unit from module

5.7 Results

Figures 5-12 and 5-13 show typical results from a dark I-V test on all string pairs in a healthy PV module and also in a low power module. Note, as expected, the healthy module has six similar I-V curves. The six string pairs in an ASE-300 provide a reasonable statistical sample to compare dark I-V runs. It turns out to be very beneficial to have six strings that are from a similar batch of cells that passed through the manufacturing process at a similar time. Each resulting I-V curve provides a baseline within the module to compare against outliers. Figure 5-13 shows the six I-V curves for a low power module and demonstrates this. The likelihood is that the majority of I-V curves will be clustered together to create a baseline within each module. Therefore an operator can easily discover an outlier based on the consistency of the manufacturing process for the current batch of cells/strings.

The outlier in Figure 5-13 is a string with several shorted cells, resulting in lower series resistance for that string. If the string had higher series resistance than normal, then the curve would lie to the right of the group of healthy strings.

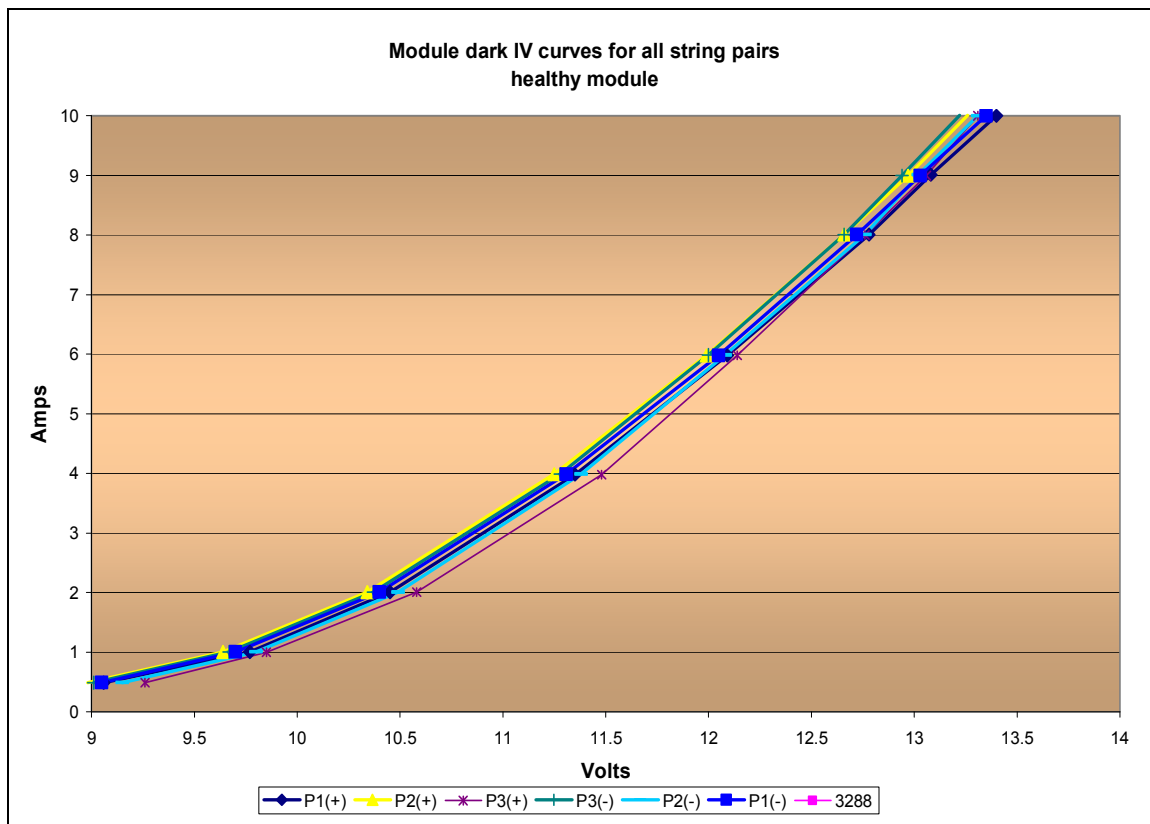


Fig. 5-12. Healthy PV Module

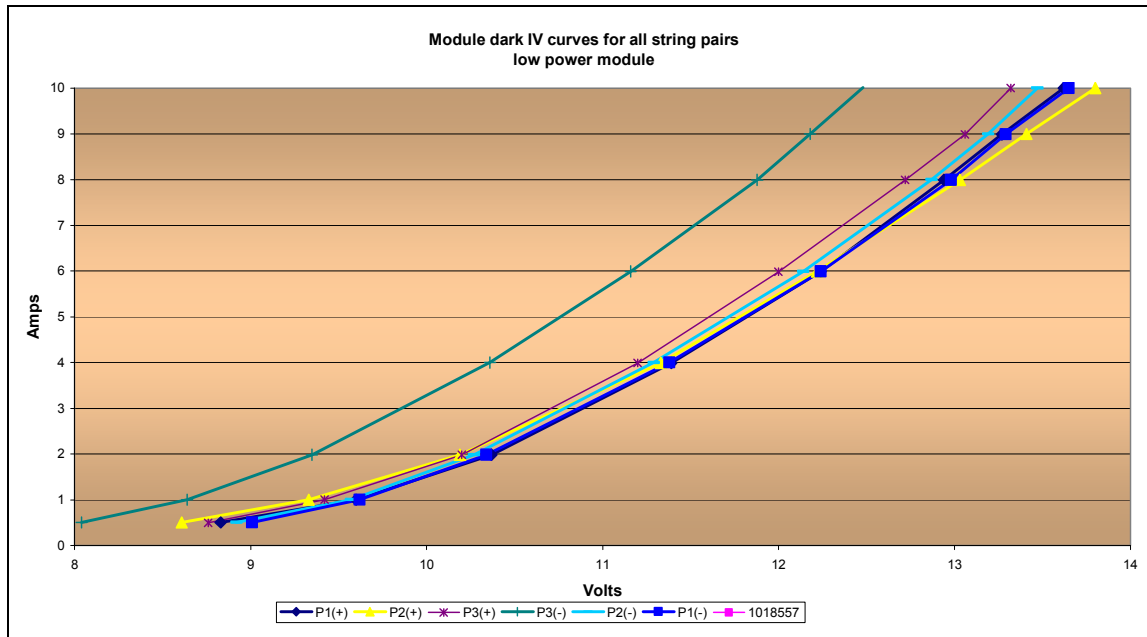


Fig. 5-13. Low Power Module

5.8 Discussion and Next Steps

Having demonstrated the dark I-V tool and seen the test's ability to distinguish an outlier from a group of 6 PV module substrings, the next step was to measure a set of approximately 20 normal PV modules. These modules were tested in an effort to begin the process of establishing baseline parameters and variance for normal substrings. In the course of measuring these modules, certain deficiencies in the tool became apparent. In order to establish repeatable, accurate statistics for normal module variability in the dark I-V curve, resistance in the measurement leads and contacts had to be accounted for. This led to a refinement of the process and a calibration step that measures these resistance values and accounts for them in the interpretation of measured dark I-V data and results.

The intent of Schott's investigation was to gain initial experience and evaluate the efficacy of the dark I-V measurement for identifying correctable circuit and cell problems in a PV module before its lamination. The equipment achieved "proof of concept", as the initial dark I-V measurements of a module with known problems showed a clear difference between the offending substring and the other normal substrings. At its current stage, the dark I-V tool can be used on finished, laminated PV modules to help isolate cell and circuit problems that were either created during lamination or were not found prior to lamination. In such cases, there is still value in the aberrant PV module; the problem substring can be electrically (not physically) removed from the circuit and the module sold as an off-spec product.

The dark I-V test equipment will continue to be developed for expanded use at the company. Before it can serve as a production tool, used to measure every module prior to its lamination, further refinement is necessary. For example, the method of attaching power leads to the flat-wire "ribbon" conductors emerging from the PV laminate in a quick but reliable and low-resistance manner must be further developed. The existing equipment set could also be simplified with a programmable power supply. In addition, numerous measurements of the standard, healthy module substrings must be completed to create baseline characteristics and determine the normal variability in dark I-V curves for healthy substrings made with any of the standard cell types.

As a final next step, discussions with plant floor managers need to address a workable dark I-V station that can integrate smoothly into the module assembly work flow and address safety issues during the measurement of a pre-laminated laminate. The successful starting point for dark I-V measurements has been achieved.

6.0 Task 3.8f: Development and Listing of the ASE-300/34

The company's flagship PV module is the ASE-300/50, with roughly a 50-Volt maximum power voltage and an open-circuit voltage of ~62 Volts. A second module version that is based on the same physical platform is the ASE-300/17, with an open-circuit voltage of ~20 Volts. The company successfully completed the development of a third version, the ASE-300/34, with an open-circuit voltage of ~40 Volts. The intent of this development is to replace the ASE-300/17, which is relatively high in cost to manufacture and has limited application in the market. The primary difference is the cell string wiring configuration. In the 34-Volt module, the overall wiring is 72 cells in series by 3 in parallel.

The challenge of this module design was to engineer a bypass diode circuit that was low in cost and met all the performance requirements. Numerous variations on the diode circuit board were designed and tested, before finalizing this key element in the ASE-300/34.

The attached correspondence from Underwriter's Laboratories shows that the ASE300/34 is now listed. Three versions of this module were listed: framed, unframed and a laminate (with no wiring junction box). The ASE300/34 has a nominal operating voltage of 34 Volts, compared to the standard version that has an operating voltage of ~50 Volts.

NOTICE OF AUTHORIZATION TO APPLY THE UL MARK

April 3, 2006

Mr. James Barker
Rwe Schott Solar Inc
4 Suburban Park Dr
Billerica, MA 01821
United States

E-mail: jim.barker@rweschottsolar.us

Reference: File E101694 Project 06NK08789 P.O. Number 86483

Product: USR - MODELS ASE-300DGU/34 & ASE-300DGL/34

Dear Mr. Barker,

UL's investigation of your product has been completed under the above project number and the subject product was determined to comply with the applicable requirements.

This letter temporarily supplements the UL Follow-Up Services Procedure and serves as authorization to apply the UL Recognized Marking and/or Recognized Component Mark only at the factory under UL's Follow-Up Service Program to the subject product, which is constructed as described below:

Similar to the subject model, which was submitted to UL for this investigation. The UL Records covering the product will be in the Follow-Up Services Procedure, File E101694, Volume 2.

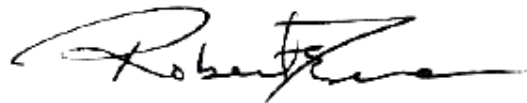
To provide the manufacturer with the intended authorization to use the UL Mark, the addressee must send a copy of this Notice and all attached material to each manufacturing location as currently authorized in File E101694, Volume 2.

This authorization is effective from the date of this Notice and only for products at the indicated manufacturing locations. Records in the Follow-Up Services Procedure covering the product are now being prepared and will be sent to the indicated manufacturing locations in the near future. Please note that Follow-Up Services Procedures are sent to the manufacturers only unless the Applicant specifically requests this document.

Products that bear the UL Mark shall be identical to those that were evaluated by UL and found to comply with UL's requirements. If changes in construction are discovered, appropriate action will be taken for products not in conformance with UL's requirements and continued use of the UL Mark may be withdrawn.

Sincerely,

Reviewed by:



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Staff Engineer
Department: 3014CNBK
Tel: 847-664-2229
Fax: 847-509-6298
E-mail: steve.jochums@us.ul.com

Robert E. Pence
Senior Staff Engineer
Department: 3014CNBK

NOTICE OF AUTHORIZATION TO APPLY THE UL MARK

April 3, 2006

Mr. James Barker
Rwe Schott Solar Inc
4 Suburban Park Dr
Billerica, MA 01821
United States

E-mail: jim.barker@rwechottsolar.us

Reference: File E101694 Project 06NK08789 P.O. Number 86483

Product: USL - MODEL ASE-300DGF/34

Dear Mr. Barker,

UL's investigation of your product has been completed under the above project number and the subject product was determined to comply with the applicable requirements.

This letter temporarily supplements the UL Follow-Up Services Procedure and serves as authorization to apply the UL Listing Mark only at the factory under UL's Follow-Up Service Program to the subject product, which is constructed as described below:

Similar to the subject model, which was submitted to UL for this investigation. The UL Records covering the product will be in the Follow-Up Services Procedure, File E101694, Volume 1.

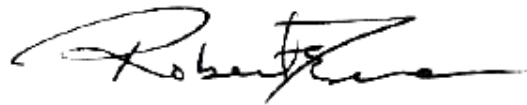
To provide the manufacturer with the intended authorization to use the UL Mark, the addressee must send a copy of this Notice and all attached material to each manufacturing location as currently authorized in File E101694, Volume 1.

This authorization is effective from the date of this Notice and only for products at the indicated manufacturing locations. Records in the Follow-Up Services Procedure covering the product are now being prepared and will be sent to the indicated manufacturing locations in the near future. Please note that Follow-Up Services Procedures are sent to the manufacturers only unless the Applicant specifically requests this document.

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Sincerely,

Reviewed by:



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Robert E. Pence
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7.0 Task 3.9: Photovoltaic Source Circuit Protectors

Wiring photovoltaic arrays begins with plugging together the quick-connectors supplied on the PV modules to wire them in series, forming electrical source circuits. For the ASE-300/50, a typical source circuit is 8 modules wired in series. Combining multiple 8-module source circuits in parallel is necessary in large arrays and requires some form of wiring junction boxes where the quick-connector cables on the PV modules can terminate. At that termination, over-current protection is required to protect the PV modules in a source circuit, in accordance with the ratings stated on the PV module's label. For the ASE-300/50 the required over-current protection is a 12 amp fuse.

In such a junction box, the wiring from multiple PV source circuits is also bussed in parallel to form a single output circuit. Further parallel-wiring can be done by allowing the output of one such junction box to be parallel-connected to the output of another. In this way PV source circuits are protected, combined safely in full compliance with the National Electrical Code, and form higher-current subarray circuits.

RWE Schott Solar developed and UL-listed a PV Source Circuit Protector (PVSCP™) in the early 1990s, to provide the required functionality for PV array wiring and so enable fully code-compliant PV systems to be installed for the first time. The company's PVSCPs have been in use for more than a decade, and recently it was recognized that these units needed to be updated.

Three models of the company's PVSCPs were newly defined and new components were selected to increase the robustness and durability of the product. The models are described in the following section.

7.1 PVSCP Ratings

| Model: PVSCP-2F/65 | Maximum Rating | |
|--------------------------------------|-----------------------|--------|
| PV Source Circuit (input) – Fused | 30 Amps, 600 V | DC, AC |
| PV Output Circuit (output) | 65 Amps, 600 V | DC, AC |

| Model: PVSCP-2F/150 | Maximum Rating | |
|---|-----------------------|--------|
| PV Source Circuit (input) – Fused | 30 Amps, 600 V | DC, AC |
| PV Output Circuit (output) with single conductor per lug | 150 Amps, 600 V | DC, AC |
| with two conductors per lug (for paralleling), 4AWG limit | 95 Amps, 600 V | DC, AC |

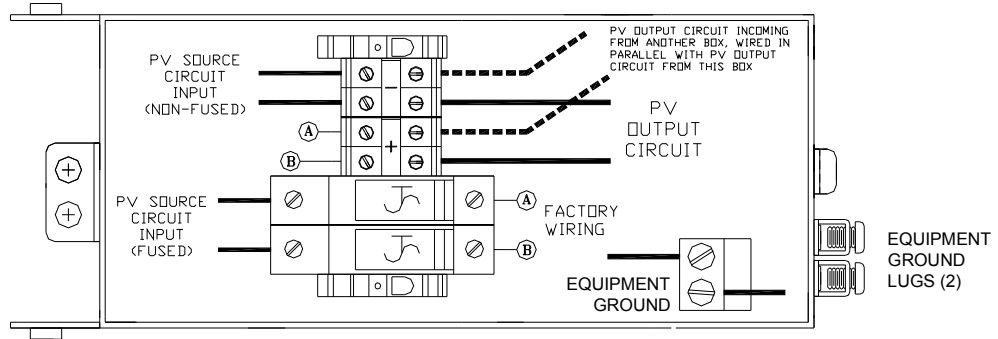
| Model: PVSCP-N/150 | Maximum Rating | |
|---------------------------|-----------------------|--------|
| Input and Output | 150 Amps, 600 V | DC, AC |

Conductor Size, Combinations and Termination Tightening Torque

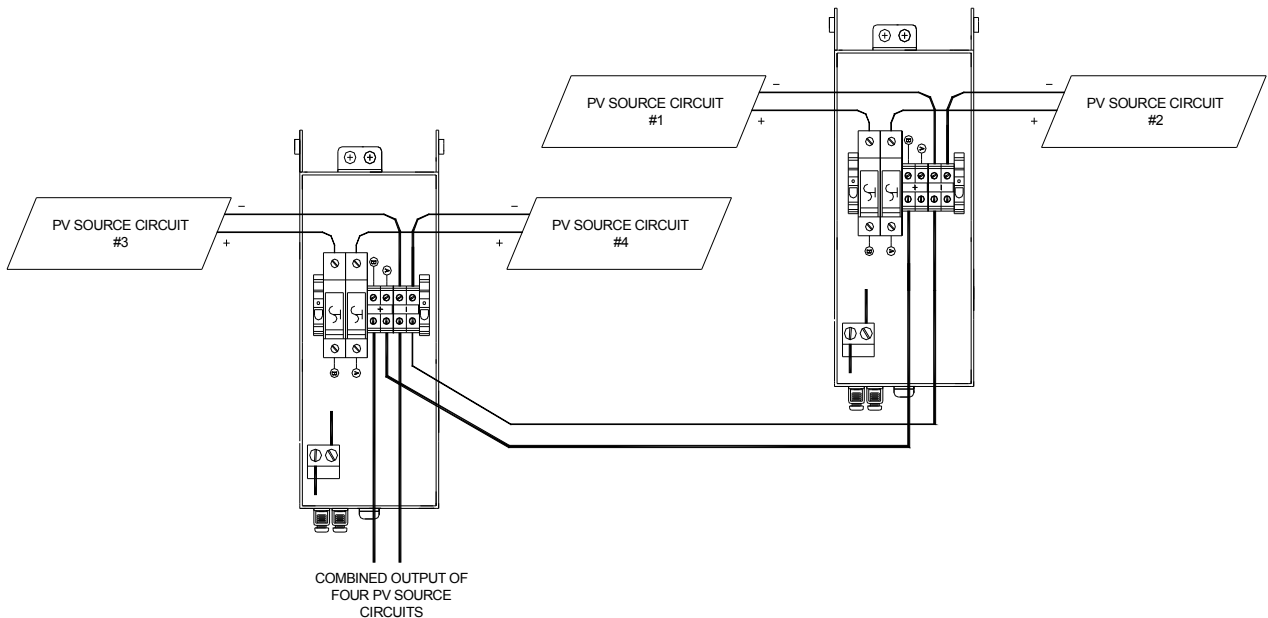
| | Non-fused Terminations | Fused Terminations |
|----------------------------|---|---|
| Model: PVSCP-2F/65 | 1 per position #22 - #6 AWG 10.6 – 12.3 in-lb | 1 per position** #16 - #6 AWG 14.75 in-lb |
| Model: PVSCP-2F/150 | 1 or 2 per position* #10 - #4 AWG 25 in-lb | |
| Model: PVSCP-N/150 | 1 or 2 per position* #10 - #4 AWG 25 in-lb | NA |

7.2 Wiring Drawings

PVSCP-2F/65

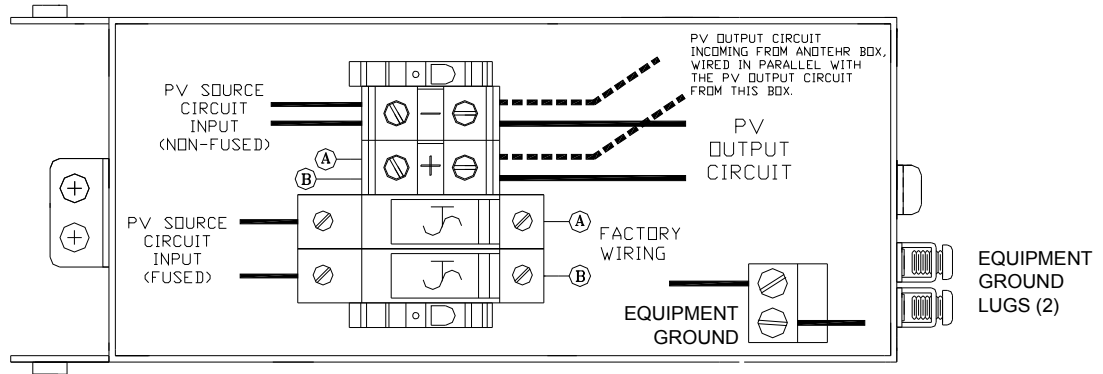


Usage Note: A PV output circuit from another identical box can be wired in parallel with the PV Output Circuit of this box (see diagram below) using the spare terminals provided for this purpose. When PV Output Circuits are wired in parallel as shown, the current rating of the terminals must be considered. The current rating of the terminals must be compared with the sum of the fuse ratings of all the PV Source Circuit Inputs from all boxes wired in parallel.

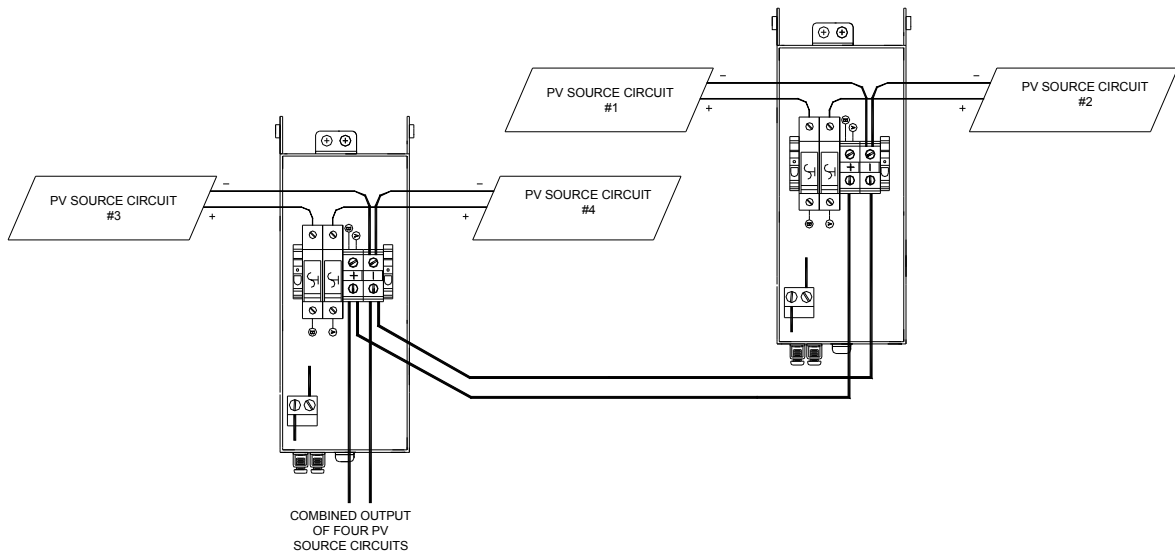


(Note: for simplicity, drawing does not depict the required ground wiring.)

PVSCP-2F/150

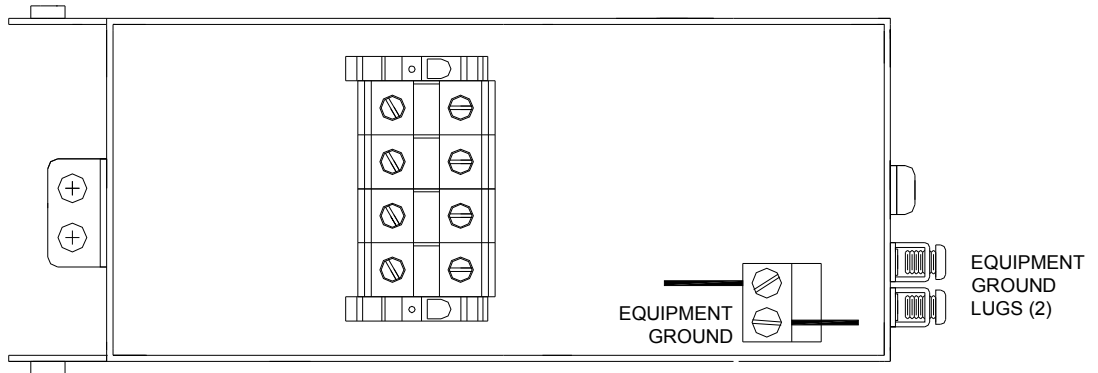


Usage Note: A PV output circuit from another identical box can be wired in parallel with the PV Output Circuit of this box (see diagram below). These terminals allow up to 2 conductors per lug, as shown. When PV Output Circuits are wired in parallel as shown, the current limit of the terminals must be considered. The current rating of the terminals must be compared with the sum of the fuse ratings of all the PV Source Circuit Inputs from all boxes wired in parallel.



(Note: for simplicity, drawing does not depict the required ground wiring.)

PVSCP-N/150



Usage Note: This general-purpose terminal box may be used within its ratings for any purpose, such as forming series strings of modules from partial source circuit groups.

7.3 Photographs of the UL Listed PVSCPs



Fig. 7-1a,b,c. The PVSCP is a white painted custom aluminum enclosure and lid. The box dimensions are specifically designed to coordinate with the company's PV array mounting hardware. Note identical labels on box side and lid to warn of hazardous voltages inside.





Fig. 7-2. External ground lugs are provided to terminate module frame ground conductors. These lugs are tin-plated copper.

Fig. 7-3. Box lid secures to box base with two captive fasteners on tab. Mounting flanges contain pressed-in 1/4-20 nuts for simplified attachment to the company's PV array mounting hardware.



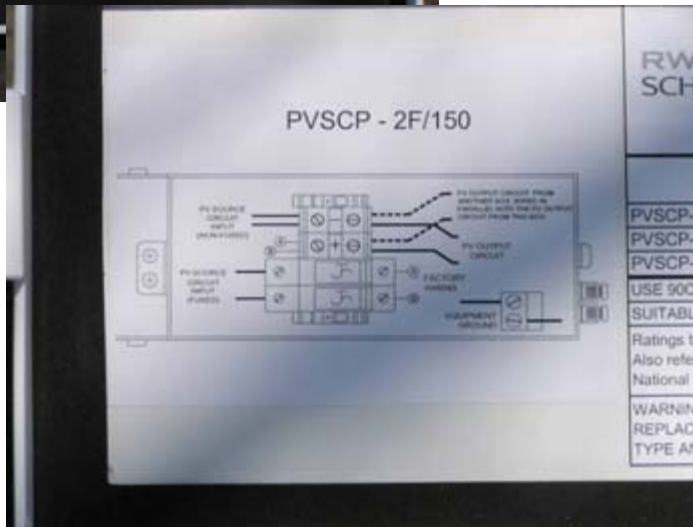


Fig. 7-4. Lid has a gasket and two labels inside.



Fig. 7-5a,b. Main label has all required ratings and warnings. The label was designed to allow the assembler to check boxes to indicate the model and the date of manufacture.

Left side label (below) is a wiring diagram for the specific model.



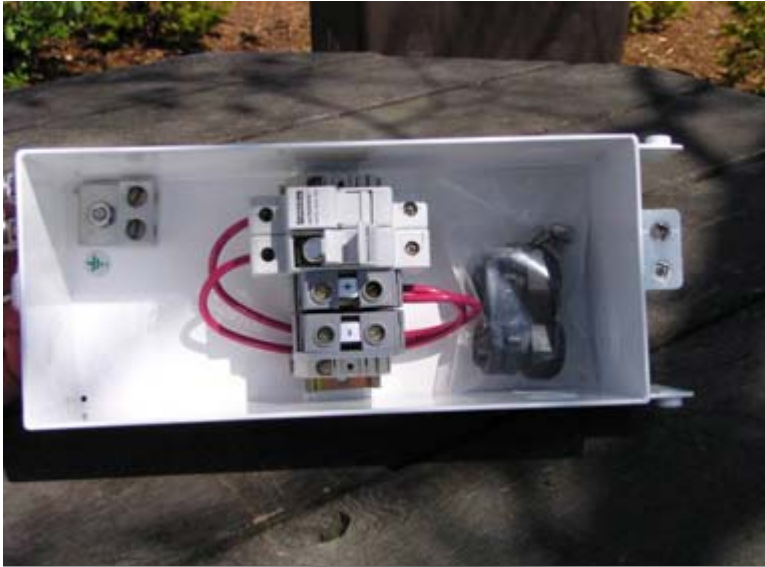


Fig. 7-6. Interior of box includes the lugs with pre-wired jumpers, a ground lug and a bag with strain reliefs and fasteners to secure the box to the company's mounting brackets.



Fig. 7-7. Terminal blocks for the PVSCP 2F/150. Terminals are mounted on a rail secured to the bottom of the enclosure. Fused blocks accommodate up to 30amp fuses. When popped open (as shown in lower fuse block) the fuse is isolated from live circuits and safe to remove.



Fig. 7-8a,b. Terminal blocks for the PVSCP 2F/65 (top photo) and PVSCP N/150 (lower photo) are shown.



8.0 Conclusions

Schott Solar focused extensively on the FS mounting system during Phase 2 of this contract because of its great importance to the company. The progress made in both the design of the mounting system for improved performance, and the further understanding of its applicability through additional wind-tunnel testing, has helped the company maintain its strong position in the marketplace with this valued product.

Market conditions and company shifts during the conduct of this multi-year project made it necessary to adjust the scope and schedule on several occasions. Schott Solar is grateful to NREL for its continued support through these varied changes.

REPORT DOCUMENTATION PAGE

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| 14. ABSTRACT (Maximum 200 Words) This report summarizes the progress by Schott Solar, Inc., under NREL's Photovoltaics (PV) Manufacturing R&D Project. The second, expanded phase of this work is reported here and details progress on the following: a meter-interconnect device (MID); a free-standing (FS) mounting system; investigations of dark current-voltage (I-V) curves as a way to unearth problems with PV module strings; a new 34-volt version of the company's flagship ASE-300 PV module; and updated source-circuit protectors. | | | | | | |
| 15. SUBJECT TERMS PV; building-integrated PV; module; source-circuit protector; meter-interconnect device; SunTrack data collector; reference cell device; dark I-V tool; mounting system | | | | | | |
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