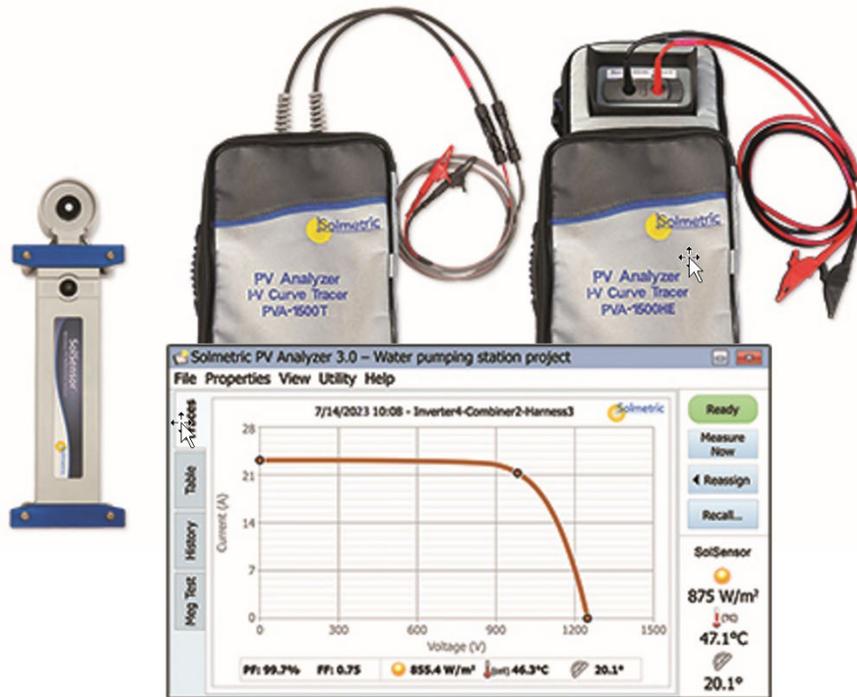# SOLMETRIC PV ANALYZER™ I-V CURVE TRACER

USER'S GUIDE

PVA-1500

Versions S, V2, V3, V4, T, and HE

with SolSensor™ 300/300V2

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1 Getting Started

Overview

This User Guide covers the PVA-1500 I-V Measurement Units, the SolSensors, and PVA application software. Throughout this user's guide when you see "PV Analyzer" or "PVA-1500" it is referring to all 1500 Volt versions, including the PVA-1500S, PVA-1500V2, PVA-1500V3, PVA-1500V4, PVA-1500T, and PVA-1500HE.

The Solmetric PV Analyzer is a portable electrical test instrument designed for commissioning and troubleshooting PV arrays. It measures the current-voltage (I-V) curves of PV modules and strings and immediately compares the results to the predictions of built-in PV models. Measurement results are easily saved for future reference and analysis. The I-V Measurement Unit and associated sensor unit are controlled wirelessly by your tablet or notebook PC. Wireless interfaces allow you to move around in the immediate work area without the trip hazards associated with hard-wired interconnections.

Irradiance, PV module temperature, and PV module tilt are measured by SolSensor, a wireless PV reference sensor that streams this data to your PC. Sensor measurements are also triggered simultaneously with the I-V curve measurement and saved with the I-V curve data.

The (I-V) curve of a PV module, string, harness, or array provides a detailed description of its energy conversion ability. The curve nominally ranges from the short circuit current (Isc) at zero volts, to the open circuit voltage (Voc) at zero current. At the 'knee' of a normal I-V curve are the maximum power current and voltage (Imp, Vmp), the point at which the array generates the maximum electrical power at the present irradiance and temperature. All of these important voltages and currents are captured when the I-V curve is measured. The detailed shape of the curve between these points gives additional information about the health of the PV module, string, or array under test.

The value of the measured I-V curve is greatly increased by comparing it with the predictions of a comprehensive PV model. The model takes into account the specifications of the PV modules, the number of modules in series and strings in parallel, and the losses in system wiring. Other data used by the model includes the irradiance in the plane of the array, the module temperature, and array orientation.

The PC software that controls the PV analyzer contains a powerful graphical Array Navigator tool with a graphical array tree that you touch to save and recall your measurement data. The New Project Wizard guides you in setting up the PV model and customizing the array tree to your project.

The PC software can also save insulation resistance data collected by a separate insulation resistance tester. This data is stored and managed using the same type of array tree touch interface as the I-V measurement results.

NOTE	On its website Solmetric posts notices of software updates. It's a good idea to check this from time to time by visiting Solmetric.com. Select Support, Downloads, *PV Analyzer software and documentation*. You will see a link to download the current software, and the current version number. Compare that version number with the version you are running, which is found by selecting Help, About. If you want to update, just download the newer version and run the installer. It is free and takes only a few minutes. Version 4.x PVA software supports all the curve tracers that use SolSensor.

Computer Minimum System Requirements

- Test and Supported Operating System: Windows® 11,10, 8, or 7 (32 and 64-bit versions)
- WiFi
- Display Resolution: 1024 X 600 (minimum)
- Processor Speed: >1 GHz, 1.5 GHz recommended. A Windows Experience Index (Processor component) of 2.3 or greater is recommended. This value is available on your PC's Control Panel under "Performance Information and Tools".
- RAM: 4 GB minimum, 8 GB recommended
- Available Disc Space: 100 Mbytes or more
- Systems that do not meet these requirements may not operate correctly.
- A Windows laptop or laptop will work well. Tablets tend to be more rugged than laptops in the field. When choosing a device, we recommend looking for:
- A device with a touchscreen for best productivity
- A tablet or a laptop that can be used as a tablet
- Good viewing contrast in bright sun
- Anti-glare screen surface
- Good viewing angle so multiple people can see the screen

Equipment

Curve Tracer Equipment

- I-V Measurement Unit
- Soft Case
- PVA Software Application (available at *http://www.solmetric.com/downloads-pva.html*)
- AC Wall Plug Charger
- MC-4 to MC-4 Connector-Saver Cable (2) (not used with PVA-1500HE)
- 1500V rated test leads for PVA-1500HE: banana jack to MC-4 and banana jack to dolphin clips. For other PVA models: MC-4 to dolphin clips
- MC-4 connector tool

- User's Guide — (available in the HELP menu of the PVA software and from *http://www.solmetric.com/downloads-pva.html*).
- Quick Reference Card
- Optional transit case and field charger kit

SolSensor Equipment

- SolSensor unit (The PVA-1500S operates with the SolSensor 300 and the PVA-1500/HE operates with the SolSensor 300V2).
- K-type thermocouple temperature sensors (2)
- Soft Case (unless PVA kit was purchased with the transit case option)
- Module Frame Clamp
- AC Wall Plug Charger
- Adhesive discs for thermocouple attachment (50)
- SolSensor tool lanyard
- Irradiance sensor cleaning supplies (micro-fiber cloth and distilled water spray)

Specifications

PVA-1500 I-V Measurement Unit Specifications

Safety Rating: Measuring Category CAT III 1500V (applies to the I-V Measurement Unit only. Refer to the PVA-1500 Test Lead and Clip Specifications section on page for their unique specifications).

Table 1. PVA-1500 electrical and mechanical specifications

Parameter		PVA-1500S/V2/V3/V4	PVA-1500T	PVA-1500HE
Voltage range (Voc)		20 – 1500 V DC		
Maximum current range (Isc)				
for module efficiency < 19% [1]		0 - 30 A DC		
for module efficiency ≥ 19% [1]		0 - 10A DC		0 - 30 A DC
Voltage accuracy (0 to 45° C)		±0.5% ±0.25 V		
Current accuracy (0 to 45° C)		±0.5% ±0.04 A		
Voltage resolution		25 mV		
Current resolution		2 mA		
Measurement Throughput [2]				
	Sweep-to-sweep delay (1@VOC < 1350 V)	<18 seconds	<9 seconds	
	Max # I-V sweeps per hour (1@VOC < 1350 V)	200 sweeps/hr	400 sweeps/hr	
	Max megawatts measured per hour	2.6 MW/hr	3.5 MW/hr	
Thermal Capacity [3]				
	# sweeps at 18s sweep-to-sweep delay	800 (77°F ambient) 225 (113°F ambient)	unlimited (77°F ambient) 550 (113°F ambient)	
	# sweeps at 9s sweep-to-sweep delay	N/A	unlimited (77°F ambient) 330 (113°F ambient)	

Parameter	PVA-1500S/V2/V3/V4	PVA-1500T	PVA-1500HE
I-V sweep duration [4]	0.05 - 2s. Typically 0.2s for PV strings.		
Number of I-V trace points	100 or 500 (user controlled)		
Wireless range (open line of sight)	100m		
Operating temperature range	32 to 113° F, 0 to +45º C		
Storage temperature range	-4 to 149° F, -20 to +65ºC		
Operating humidity	<90% RH, non-condensing. Avoid exposing a cold instrument to warm and humid air as condensation will result. Store the instrument in the same conditions in which it will be used.	<90% RH, non-condensing. Avoid exposing a cold instrument to warm and humid air as condensation will result. Store the instrument in the same conditions in which it will be used.	
Altitude	Up to 2000 m		
Battery charging time	6 hr.		
Battery run time	Approx. 8 hours[5]		Approx. 7 hours[5]
Warning features	Over-voltage, over-current, over-temperature, reverse polarity		
PV connector	Staubli MC4-EVO2		Banana Jacks
Charging/charged LED	No	Yes	
In-the-field firmware update-ready	No	Yes	
Interface to Table/Laptop[6]	Wireless USB dongle	Wireless interface between user's tablet or laptop, I-V unit, and SolSensor.	
Weight	6.6 kg[7]		7.3 kg[7]
Height	43.2 cm (including test lead and strain reliefs)		53.3 cm
Width	21.6 cm		
Depth	15.2 cm		

[1] High efficiency modules have high capacitance which can cause a large in-rush current when I-V curves are measured. This can trigger an over-current warning in the PVA that prevents the measurement from completing. The in-rush current is increased by higher efficiency, higher current

strings, higher voltage strings, higher bifaciality, and higher irradiance. For an explanation of flexibility in the 10A limit and how to handle high efficiency modules, see the section: Are you measuring high-efficiency modules?

[2] Time between pressing "Measure Now" and display of measurement result. The specifications shown are for 1000V < Voc ≤ 1350V. For other voltage ranges see Table 5. Max Megawatts per hour spec assumes reference PV system with Vmp = 1100V and Imp = 25A.

[3] Thermal capacity is the # of I-V sweeps before the PVA must cool down for an extended period. These specs assume a reference PV system with Voc = 1300V, Vmp = 1100 V, 16 strings per combiner, 5 min to move to next combiner with no measurements. No direct sunlight on I-V unit.

[4] Automatically selected. Measurement sweep time depends upon the characteristics of the test device (PV module, string, or array) electrical characteristics.

[5] Runtimes are at 25 °C internal temperature and is shorter at colder temperatures.

[6] The measurement is controlled via wireless link from the user's tablet or notebook PC.

[7] This measurement includes the soft case, test leads and charger.

PVA-1500 Test Lead and Clip Specifications

Table 2. Electrical and mechanical specifications for the test leads and clips provided with the PVA-1500.*

Parameter	Specification
Voltage range	0 – 1500 V DC
Current range	0 – 30 A DC
Temperature	0°C to 45°C
Humidity	Maximum relative humidity of 80 % for temperatures up to 31 °C decreasing linearly to 50 % relative humidity at 40 °C
Pollution degree	2
Altitude	Up to 2000 m
Lead length	152 cm
Lead colors	Positive = red, negative = black
Manufacturer (test leads and Dolphin clips)	Staubli

*Use only test leads and clips provided by Solmetric for the PVA-1500.

SolSensor Specifications

Table 3. SolSensor specifications

Parameter	SolSensor Specification
Irradiance	
Sensor type	Silicon photodiode with corrections for temperature, spectral, and angular effects
Measurement range	100 – 1,500 W/m^2
Accuracy	Typically, ±2% when used to predict the performance of well characterized poly- and monocrystalline PV modules with direct irradiance >600W/m^2. Contact Solmetric Application Engineering for more information on accurate irradiance measurements.
Resolution	1 W/m^2
Measurement interval	0.1 s (Measurement bandwidth approximately 10 Hz)
Temperature	
Sensor type	Type K thermocouple. Two inputs.
Measurement range	0 – 100ºC
Accuracy	Typically, less than 2C including inherent thermocouple limitations and assuming SmartTemp
Resolution	0.1ºC
Measurement interval	1 s
Tilt	
Sensor type	Electronic
Measurement range	0 – 90 deg from horizontal
Accuracy	±2 deg typical (0-45 deg)
General	
Measurement synchronization with I-V curve	Typically, less than 1s
Wireless range (open line of sight)	SolSensor 300/300V2: 100m
Operating temperature range	0 to 45ºC

Parameter	SolSensor Specification
Storage temperature range	-20 to 65ºC
Operating humidity	<90% RH, non-condensing. Avoid exposing a cold instrument to warm and humid air as condensation will result. Store the instrument in the same conditions in which it will be used.
Battery charging time	6 hr.
Battery run time	Greater than 16 hours typical use
Weight	0.9 kg (not including soft case and accessories)
Height	38.cm
Width	11 cm
Depth	7 cm
Ingress protection	IP65

Safety and Regulatory

PVA-1500 Safety and Regulatory

Warnings, Cautions, and Notes

Before operating the PVA-1500, familiarize yourself with the following notations.

WARNING	A *Warning* calls attention to a procedure, which, if not performed correctly, could result in personal injury or loss of life. Do not proceed beyond a warning note until the indicated conditions are fully understood and met.

CAUTION	A *Caution* calls attention to a procedure that, if not performed correctly, could result in damage to, or destruction of, the instrument. Do not proceed beyond a caution note until the indicated conditions are fully understood and met.

NOTE	A *Note* provides important or special information.

Declaration of Conformity

A declaration of conformity is available upon request.

Cleaning

To remove dirt or dust from the external case and/or hard enclosure of the PVA-1500, use a dry or slightly dampened cloth only.

WARNING	**To prevent electrical shock, disconnect the PVA-1500 from the PV system and/or battery charger before cleaning. Use only a dry cloth or cloth slightly dampened with water to clean the external case and hard enclosure parts. Do not attempt to clean internally.**

Instrument Markings

The PVA-1500 have the following markings on the front and/or rear panel. Familiarize yourself with these markings before operating the PVA-1500.

The cTUVus mark signifies that the product has been thoroughly tested and specifically certified to comply with the electrical and fire safety regulations of Canada and the United States.

The instruction manual symbol. The product is marked with this symbol when it is necessary for you to refer to instructions in the manual.

This symbol indicates separate collection for electrical and electronic equipment, mandated under EU law as of August 13, 2005. All electrical and electronic equipment are required to be separated from normal waste for disposal. (Reference WEEE Directive, 2002/96/EC.)

The IEC HV symbol indicates the presence of hazardous voltages. Danger exists of electrical shock that can cause severe injury or death.

SolSensor Safety and Regulatory

Warnings, Cautions, and Notes

Before operating SolSensor, familiarize yourself with the following notations.

WARNING	**A *Warning* calls attention to a procedure, which, if not performed correctly, could result in personal injury or loss of life. Do not proceed beyond a warning note until the indicated conditions are fully understood and met.**

CAUTION	**A *Caution* calls attention to a procedure that, if not performed correctly, could result in damage to, or destruction of, the instrument. Do not proceed beyond a caution note until the indicated conditions are fully understood and met.**

NOTE	A *Note* provides important or special information.

Declaration of Conformity

A declaration of conformity is available upon request.

Cleaning

To remove dirt or dust from the SolSensor <u>enclosure</u>, use a dry or slightly dampened cloth only.

The irradiance sensor (white disc) is cleaned using a more carefully controlled process, to avoid damaging the irradiance sensor. See the SolSensor 300 Precautions/Cleaning section for details.

WARNING	**To prevent electrical shock, disconnect SolSensor from the battery charger before cleaning. Use only a dry cloth or cloth slightly dampened with water to clean the external enclosure parts. Do not attempt to clean internally.**
WARNING	**The irradiance sensor (white disc) is a precision instrument and is easily damaged if cleaned improperly. See the SolSensor 300 Precautions/Cleaning section for the proper cleaning process.**

Instrument Markings

The SolSensor 300 and SolSensor 300V2 have the following markings on the front and/or rear panel. Familiarize yourself with these markings before operating the SolSensor.

The cTUVus mark signifies that the product has been thoroughly tested and specifically certified to comply with the electrical and fire safety regulations of Canada and the United States.

The instruction manual symbol. The product is marked with this symbol when it is necessary for you to refer to instructions in the manual.

This symbol indicates separate collection for electrical and electronic equipment, mandated under EU law as of August 13, 2005. All electrical and electronic equipment are required to be separated from normal waste for disposal. (Reference WEEE Directive, 2002/96/EC.)

Precautions

PVA-1500 Precautions

Using Test Leads and Clips

Use only the test leads and clips specifically provided by Solmetric for use with the PVA-1500. These leads and clips are specially rated for use at voltages up to 1500V and 30A DC. The test leads are labeled as shown in the figure below.

Figure 1. PVA-1500S/V2/V3/V4/T MC-4 to alligator clip (left), and PVA-1500HE banana jack to alligator clip (middle) and banana jack to gold-plated MC-4 (right)

WARNING	**Operating temperature and humidity of the test leads and clips are more narrowly specified than the PVA-1500 I-V Measurement Units. For details see *PVA-1500 Test Lead and Clip Specifications* in this Guide.**

WARNING	**Do not use the PVA-1500 series test leads and clips to measure mains circuits (circuits energized by electricity from a utility or other type of power station).**

WARNING	**Working with PV circuits presents potentially fatal shock hazard. Read the entire *PVA-1500 Precautions* section of this Guide before using the test leads.**

WARNING	**The PVA-1500 is only for use with ungrounded PV circuits.**

Always inspect the test leads and clips prior to each use. If any damage or looseness of connectors is observed, do not use them - replace the test leads and clips. Contact *Support@Solmetric.com* for assistance.

Always de-energize the PV equipment contacts before attaching the test leads and clips. For example, when testing in a PV combiner box, open the disconnect switch and lift all the fuses before attaching the test leads and clips.

Always wear electrical PPE when connecting, disconnecting, or repositioning the test leads and clips.

For optimum safety, wherever possible do not handle the test leads and clips while they are energized by the PV source circuit.

Do not use the test leads and clips when it is raining or misting.

Clean the test leads and clips with a moist cloth only. Do not use solvents or soaps.

Using PV Connector Saver Jumpers

PV connectors, regardless of manufacturer, are not designed for large numbers of connection/disconnection cycles. For this reason, the PVA-1500 is shipped with connector-saver jumpers attached to its own PV connectors. The connector-saver jumpers are intended to take wear and tear, greatly extending the life of the PV connectors on the test leads and the PVA-1500 itself. Leave the connector-saver jumpers connected to the PVA-1500's primary PV leads at all times. Make all your PV circuit connections/disconnections to the connector-saver jumpers, not to the PVA-1500 connectors.

CAUTION	**When the lifetime of the connector-save jumpers has been reached (typically 100 connection/disconnection cycles), remove them, cut them in half to prevent further use, and recycle them. Replace them with fresh connector-saver jumpers, which can be ordered from Solmetric.** **Using the connector-saver jumpers as described here will extend the life of the PVA-1500 PV connectors by 100 times.**

PV/Electrical Safety Precautions

Installed PV systems are not consistent in design or construction. Therefore, the guidance provided in this section is general in nature, and it is critical that you apply techniques and precautions appropriate to the circumstances, following best PV/electrical safety precautions.

WARNING	**The information below is important but not necessarily complete; the operator must assess the potential dangers of each PV system, and take appropriate precautions.** **FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.**

- Never work alone.
- Do not use the PVA-1500 in wet environments.
- Do not operate or subject the PVA-1500 to temperatures beyond the published operating and storage temperature specifications.
- Wear electrical safety gloves.
- Wear eye protection.
- Wear fall protection where required.
- Assume that metal surfaces are energized unless proven otherwise.
- Isolate the PV source circuit under test from the inverter, and from other PV source circuits, before making any connections to the test device (PV module, string, or array).
- Always pause the measurement sequence using the LED-illuminated pushbutton switch on the I-V Unit before connecting or disconnecting the test leads of the PVA-1500.
- Do not use the PVA-1500 to test devices that produce more than the instrument's specified maximum current and voltage.
- Connect the test leads to the test device (PV module, string, or array) with the correct polarity.
- Protect the primary test lead connectors of the PVA-1500 by installing connector-saver jumpers. Replace the connector-saver jumpers when they have reached 100 connections.
- Special 1500v test leads and alligator clips are provided with the PVA-1500. Do not substitute other test leads. Also, do not use the test leads from a PVA-1000S, which are rated only to 1000v.

WARNING	**Do not remove instrument covers. There are no user serviceable parts within. Operation of the instrument in a manner not specified by Solmetric may result in personal injury or loss of life.**

- Do not use the I-V Unit if it is damaged. Always inspect for damage before using.
- Keep PV connectors away from soil and dirt. Always inspect PV connectors for damage and dirt before connecting. Do not use if damaged.
- Do not use the I-V Unit if it is performing abnormally. Contact Solmetric for guidance or return the I-V Unit to the factory for service.

Battery Precautions

CAUTION	**The PVA-1500 contains a small lithium battery and should not be disposed of with general refuse. Dispose of the battery in accordance with all local codes and regulations for products containing lithium batteries. Contact your local environmental control or disposal agency for further details.**

WARNING	**Only use the battery charger supplied by Solmetric.**

Measuring High-Efficiency PV Modules

High-efficiency PV modules have high capacitance and can produce a short but intense inrush current at the start of the I-V measurement. With the PVA-1500S/V2/V3/V4 this inrush current can trigger the I-V Measurement Unit's over-current protection circuit, causing the I-V Unit to internally disconnect from the PV source circuit and temporarily enter the over-current "Disabled" mode. See the section: Are you measuring high-efficiency modules?

SolSensor Precautions

Covering the Irradiance Sensor

When not in use, always keep the irradiance sensor (white acrylic disc) covered using the supplied black rubber cover. Remove the cover after mounting SolSensor in the plane of the array, and replace the cover again before moving SolSensor to another location.

WARNING	**The white acrylic 'eye' of the irradiance sensor is a precision optical element which must be kept in 'like new' condition to assure accurate measurements. It is easily damaged by impact or abrasion, and its accuracy is also compromised by soiling. Keep the cover on when not in use.**

Cleaning the Irradiance Sensor

The irradiance sensor (white acrylic disc) should be cleaned using only a soft cloth and distilled water. Tip the SolSensor unit on its side so that the irradiance sensor is facing horizontally. Spray the white acrylic disc with a fine mist of distilled water. Let the excess water runoff, carrying dust and dirt with it. Dry the white acrylic disc with a soft, clean, dry cloth. Never use soap or chemical solutions or abrasive cloths.

WARNING	**To clean the irradiance sensor, use only distilled water and a clean, soft, dry cloth. Soap or chemical cleaners, and coarse cloth, can cause permanent damage to the acrylic material and degrade irradiance measurement accuracy.**

Battery Precautions

CAUTION	**SolSensor contains a small lithium battery and should not be disposed of with general refuse. Dispose of the battery in accordance with all local codes and regulations for products containing lithium batteries. Contact your local environmental control or disposal agency for further details.**

WARNING	**Only use the battery charger supplied by Solmetric.**

Installation Procedure

This section describes the installation procedure for all versions of the I-V Measurement Unit.

I-V Measurement Unit Installation Procedure

Hardware Installation

The only hardware installation is to ensure that the battery is fully charged before operating. Refer to Charging the Battery.

Software Installation

Software may be shipped with the instrument on a USB flash drive.

1. Insert the PVA software USB flash drive into the slot on your Windows® computer.
2. If the welcome screen does not automatically open as shown in Figure 2, either double-click on the setup.exe file on the USB flash drive or run setup.exe from the Run dialog. Alternately, the installation file is available at *http://www.solmetric.com/downloads-pva.html*.

Figure 2. Welcome screen

3. Follow the instructions in the welcome screen to install the PVA software. The drivers for the wireless USB adapter will also be installed.
4. During installation, the following dialog may appear. Connect your computer to the Internet to allow downloading of the required prerequisites.
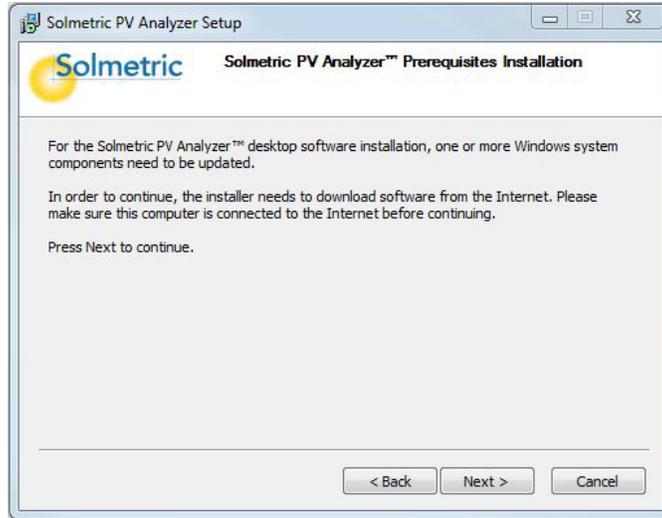
Figure 3. Prerequisites dialog

5.   After you start the installation, the following dialog appears for selecting the installation location. A default location is provided.
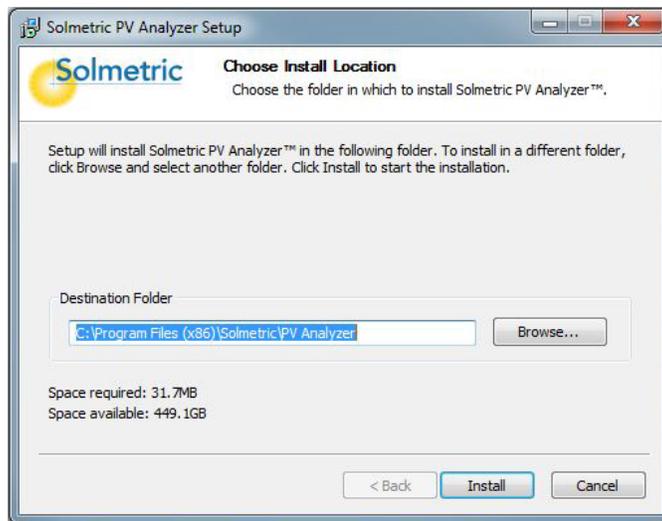
Figure 4. Installation default location dialog

When the installation process is finished, the following dialog appears.

Figure 5. Installation complete dialog

6. If the Run Solmetric PV analyzer box is selected, the PVA software will launch when you click Finish. Alternately, you can start the PVA software by double-clicking on the shortcut icon on your desktop.

7. When the initialization is complete, the screen shown in Figure 6 will appear.
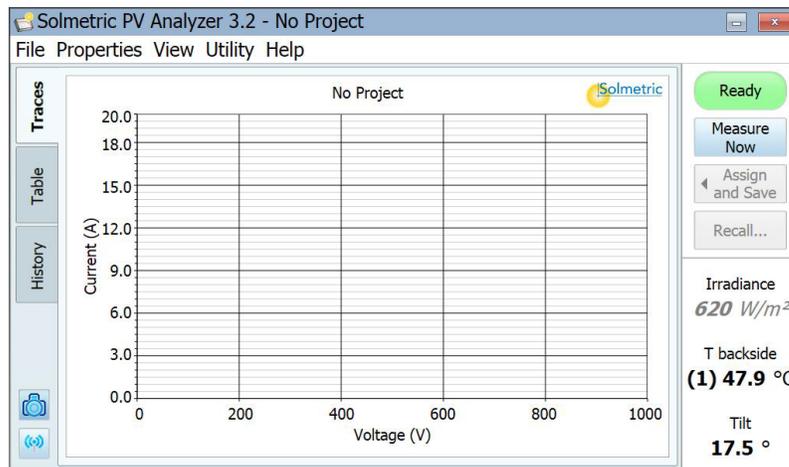
Figure 6. The software user interface

8. During installation, the directory structure shown below was created in your Documents directory. If you upgraded from v1.x software, you will see the Models and Traces folders in the list. If v1.x software was never installed on this computer, those two folders will not appear.
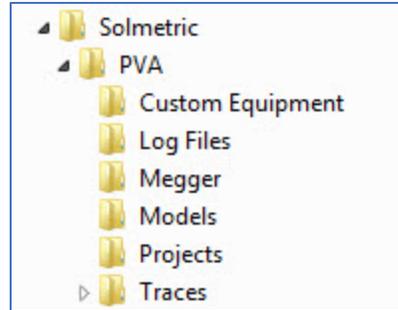
Figure 7. Directory structure of PVA software

Updating the PV Equipment Databases

If your PC is connected to the internet when you start the PVA software, the software will check whether updated PV module equipment databases are available to be downloaded from Solmetric. Downloading takes only a few moments, and you do not need to restart your computer.

SolSensor Installation Procedure

No installation steps are required for the SolSensor.

Charging the Battery

Charging the Battery on the PVA-1500 I-V Measurement units

The battery in the I-V Unit is not removable. It may be recharged by attaching the battery charger to the connector on the I-V Unit shown in Figure 8 and plugging the charger into an AC outlet. The pushbutton LED will blink slowly to indicate that the I-V Unit battery is being charged, and the LED will glow solid when the battery is fully charged. Note: if the I-V unit is plugged in and connected to the PC App, the LED will indicate the connected state (solid LED), not the charging/charged state.
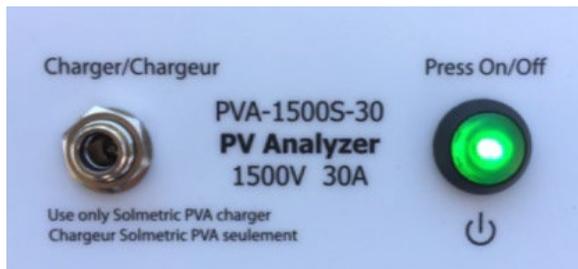
Figure 8. Battery charger connector on the I-V Measurement Unit

Charging the battery can take up to 6 hours. Charge the battery every night before use in the field.

The PVA software interface will warn you when the battery level is low or close to shutting down the I-V Measurement Unit. Also, you can check the battery voltage level by clicking on the Ready button or by selecting Battery Level in the Utility menu. When checking the battery level, make sure the I-V Unit has been turned on for at least 30 seconds.

The software user interface displays the Disabled alert (below the Measure Now button) when the battery is nearing the end of its charge. In this state, no measurements can be taken.

Charging the SolSensor

The SolSensor battery is not removable. It may be recharged by attaching the battery charger to the charging connector on SolSensor shown in Figure 9 and plugging the charger into an AC outlet.

Figure 9. Charger connected

Charging the battery can take up to 6 hours. Charge the battery every night before use in the field.

When the SolSensor 300V2 is charging, the pushbutton LED blinks slowly. When charging is complete, the LED glows steadily. Note: if the SolSensor is plugged in and connected to the PC App, the LED will indicate the connected state (solid LED), not the charging/charged state.

You can check the battery voltage level by clicking on the Ready button in the PVA software following an I-V measurement, or by selecting Battery Level in the Utility menu.

There is no charging indicator on SolSensor 300 or earlier.

Your Wireless Network

Your PVA-1500/SolSensor Wireless Network

Communication between your PC and the PVA-1500 I-V Measurement Unit is by conventional WiFi. The I-V Unit creates a hotspot when you turn it on. Just find that hotspot in your PC's network list and connect to it. The SSID (hotspot name) has the format "pva1500_yyyyyy" where yyyyyy is the unique identifier of the I-V Unit.

The SolSensor automatically links to the I-V Unit when both instruments are turned on. All communications between your PC and the SolSensor are relayed through the I-V Unit.

To see a diagram of your wireless network, select the network icon at the lower left corner of any screen in the PVA software.
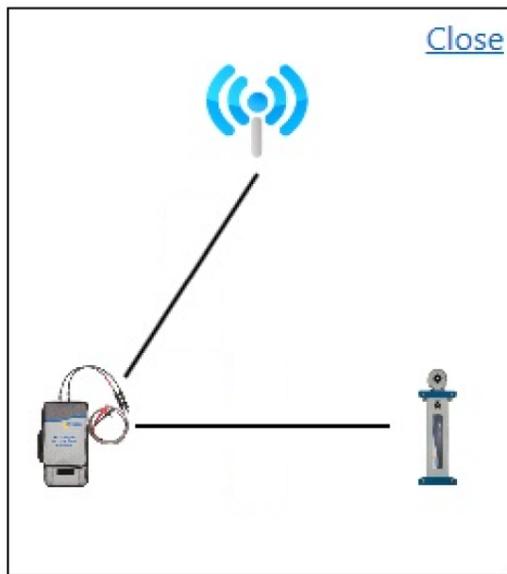
Figure 10. The WiFi network of the PVA-1500, SolSensor, and your PC.

Your I-V Unit and SolSensor come from the factory paired to one another. A SolSensor can only be paired to one unique I-V Unit at a time. A SolSensor can be paired to a different I-V Unit by following the pairing process described in *Operational States of the PVA-1500 I-V Measurement Units*. When a SolSensor is paired to an I-V Unit it forgets any previous pairing. If multiple SolSensor units are paired to a given I-V Unit, be sure only one of the SolSensor units is powered ON at any given time.

Because the PC connects with the PVA-1500 I-V Measurement Unit via Wi-Fi, the built-in Wi-Fi interface is not available to simultaneously connect to other networks or devices. To avoid this limitation, you can add a USB Wi-Fi adapter as the second network interface.

When you are using the PVA-1500 and the WiFi link to the I-V Unit hotspot temporarily drops, there is some chance that the PC will attempt to automatically connect to another network in your list that is set to "connect automatically". To avoid this, pull up the network list on your PC, check the "connect automatically" box for the I-V Unit hotspot, and uncheck the same box for the unwanted network.

2 Setting Up and Using the I-V Measurement Unit and SolSensor

System Controls and Settings

The LED pushbutton switch on the I-V Unit, shown in Figure 11, is used to enable, pause, and reset the I-V unit. The LED indicates these various operational states, also the status of the wireless network. When the PVA-1500 is turned on, it creates a Wi-Fi hotspot to which you will connect via your PC's network list.
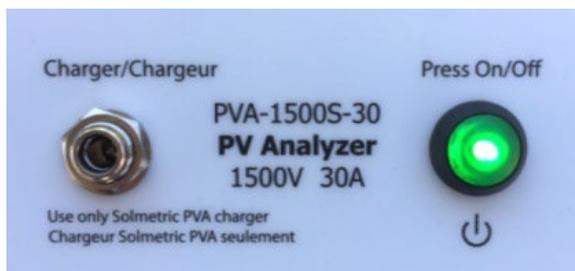
Figure 11. LED-illuminated button switch

The I-V Measurement Unit can be in the following operational states:

- Power off
- Network search
- Sweep enabled
- Sweeping
- Sweep disabled
- Reset

Operational States of the PVA-1500 I-V Unit and Solsensor

The table below describes the operational states of these instruments.

Table 4. Pushbutton LED table for the PVA-1500 I-V unit and SolSensor

LED Behavior	Device State	Pushbutton Behavior
Off	Off	Press once to turn on
Very slow flashing (I-V Unit only))	Paused. I-V Unit turns off automatically in 15 minutes to conserve battery	Press once to enable measurements or 3x to turn off I-V Unit
Flashing	No Wifi or Connection to App	Press 3x to turn off
Rapid flashing	Booting or Error (if continuous)	
Steady On	Connected to PC App, sweep enabled	Press once to pause (I-V unit only), or 3x to turn off
	Any state	Press 3x to turn off
Five flashes, pause, repeat	Attempting to pair I-V unit and SolSensor	Press 5x in rapid succession to initiate pairing
Plugged in, no connection to PC App, and Slow flashing or steady On	Flashing means Battery being charged. Steady On means fully charged.	

When you turn the PVA-1500 I-V Measurement Unit on by pressing the pushbutton once, the LED flashes rapidly while booting, then flashes more slowly until it connects with your PC wifi and PC App. Once it connects to the App, the LED stays steadily lighted.

Before connecting the I-V Unit's test leads to the PV circuit, press the pushbutton once to pause the I-V Unit. This prevents accidentally triggering a measurement while you are making connections. During the paused state, the LED will flash with long pauses to show that the I-V Unit is still available. If the I-V Unit is left in the paused state for longer than 15 minutes, it will turn itself off to conserve battery power. When this happens, just turn it back on with a single button push.

Press the button once to enable the I-V Unit to make measurements under control of the PVA software. The LED stays steadily lighted, indicating the I-V Unit is ready to take measurements.

If the network connection is lost, the LED blinks rapidly to indicate it's lost the connection to the PC App. Note when using the PVA-1500 and SolSensor 300V2: if the I-V Unit or SolSensor charger is plugged-in and connected to the PC App and the PC App connection is subsequently lost, the LED will

indicate the charge state (either flashing because its charging or solid because its fully charged) as opposed to the flashing state to indicate that it is disconnected from the PC App.

If you are using the PVA-1500 and SolSensor 300V2 and pairing between them is lost, you can initiate re-pairing by pressing the I-V Unit's LED button five times in rapid succession. Wait until the I-V Unit's LED begins to flash in groups of five, then press SolSensor's LED pushbutton five times in rapid succession. Both LED's will flash in groups of five until pairing is achieved.

If it is necessary to reset either the PVA-1500 I-V Unit or the SolSensor 300xx, just hold the LED pushbutton down for at least 12 seconds and release.

Setting Up the I-V Measurement Unit

1. Place the I-V Measurement Unit near the PV circuits to be measured.

2. Ensure that the connector-saver jumpers are installed on the primary test leads. The connector-saver jumpers protect the PVA's main lead connectors from the wear and tear of repeated interconnections. They should not be removed except for replacement.

3. If necessary, connect alligator clip leads or extension cables to the connector-saver jumpers. Use only clip leads or cables that are rated for at least the maximum current and voltage of the I-V Measurement Unit. The Solmetric PVA test leads are recommended for this application. These heavy-duty armored test leads have MC-4 connectors at one end and 4-mm sheathed banana plugs with jumbo alligator clips at the other end. PVA-1500 test leads are specially designed for 1500v use. Do not re-use PVA-1000S test leads or test leads from other instruments with the PVA-1500.

4. When extension cables that are longer than 10 feet (one-way) are added in between the circuit being tested and the I-V unit, the cables should be routed parallel next to each other to minimize the inductance they add to the circuit.

5. If you will be using the Solmetric SolSensor, refer to the section Setting Up SolSensor for setup information.

Setting Up SolSensor

Below Figure 12 shows the SolSensor Wireless PV Reference sensor mounted on the frame of a PV module.

Figure 12. SolSensor mounted on the frame of a PV module

CAUTION:	**SolSensor contains a sensitive irradiance measurement device that can be damaged by impact or abrasion. The irradiance sensor's accuracy can also be compromised by soiling. Cover the irradiance sensor with the protective cap whenever it is not actually mounted and in use.**

CAUTION:	**To clean the irradiance sensor, use only distilled water and a soft cloth. A soft microfiber cloth and a spray bottle of distilled water are supplied as standard accessories to SolSensor. Spray the white sensor element and gently wipe it with the microfiber cloth. Do not use cleaning fluids or solvents to clean the sensor, as these can cause micro-cracks in the material, reducing the accuracy of the irradiance measurement.**

Mounting SolSensor to a PV module frame

Below, Figure 13 shows SolSensor attached to a PV module with the Module Frame Clamp and secured with the Tool Lanyard.

NOTE	Mounting SolSensor along the upper horizontal edge of the module allows you to achieve better irradiance accuracy earlier and later in the day.

Figure 13. SolSensor tool lanyard secured to a racking member.

To mount SolSensor, follow these steps:

1. Remove SolSensor, the Module Frame Clamp, and the tool lanyard from the soft case.
2. Attach the tool lanyard to an eyelet on SolSensor. Then loop the lanyard around a racking member and clip it back on itself, as shown in Figure 13.
3. Place SolSensor against the top horizontal leg of the module frame, with its metal posts and ears seated against the frame surfaces, as shown in Figure 14.

Figure 14. SolSensor correctly seated along the upper horizontal leg of the module frame.

4. Holding SolSensor in that position, slip the tip of the Module Frame Clamp inside the frame of the module. Seat the tip of the clamp on the flat inner surface of the frame as shown in Figure 15 and not on a shelf or ridge from which it could slip, allowing SolSensor to come loose.
5. Squeeze the clamp mechanism until SolSensor is firmly held against the side of the module frame.

Figure 15. Tip of frame clamp properly seated on inside surface of module frame

6. Inspect the mounting and assure that the posts and blue ears are in contact with the upper edge of the module frame. If there is space under one or both of the blue ears, the irradiance sensor will not be in the plane of the array as desired; loosen the clamp slightly, reposition SolSensor, and re-tighten the clamp.
7. Connect the thermocouple to SolSensor, inserting the yellow plug of the thermocouple wire into the upper left yellow receptacle labeled TC1 (see Figure 16).

Figure 16. Thermocouple plugged into the TC1 connector.

8. Tape the tip of the thermocouple into firm contact with the module backside, far enough under the module to avoid the cooler outer edges. When testing single, free-standing modules, attach the thermocouple tip as shown in Figure 17. For most accurate temperature measurements, use a wide piece of high temperature polyester tape. Other types of tape will sag at high temperature, allowing the tip of the thermocouple to pull away from the backsheet of the module. Use firm pressure to roll the tape over the thermocouple tip, forcing the tip into intimate contact with the module backside.
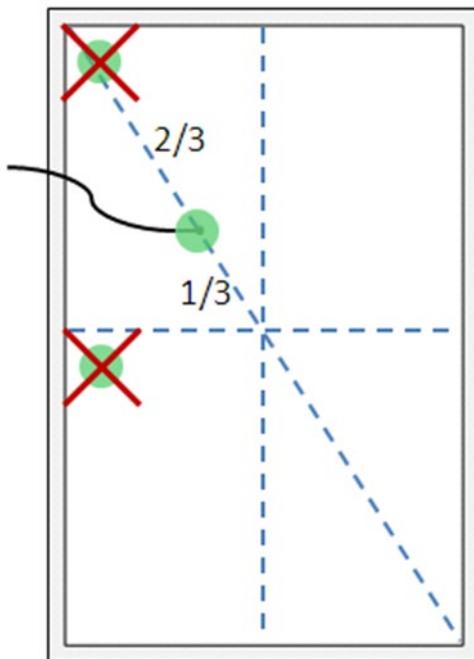
Figure 17. Locating the thermocouple tip on a single free-standing module.

9. Remove the protective cover from SolSensor irradiance sensor.

10. Press the button to turn SolSensor on, as shown in Figure 18. The LED will blink on and off as it attempts a wireless connection, and will glow steadily when the connection is made. The SolSensor 300xx links to the PVA-1500 I-V Unit, which relays its communications with the PC. Make sure the I-V Unit is turned on. The original SolSensor links to the wireless USB adapter plugged into your PC.

Figure 18. SolSensor pushbutton with LED lit. LED blinks until wireless network is established, after which it remains on.

Optimizing wireless transmission range

Follow these practices to achieve best SolSensor transmission range.

When using the PVA-1500:

- Locate SolSensor for best line-of-sight to the I-V Measurement Unit, which acts as a relay station between SolSensor and your PC.
- Avoid locations where the signal must transmit through buildings or trucks, or through many rows of PV modules and racking.
- Avoid placing SolSensor directly on a metal surface such as a metal roof or HVAC box, as this reduces range. If mounting SolSensor on a torque tube of a single-axis tracker, it may help your range if you first mount SolSensor to a short bar, and then mount the bar to the torque tube.

Transmission range can also sometimes be increased by locating SolSensor on the top frame edge of a top-row module, or near the end of an array where there is better line of sight to where the I-V Measurement Unit is set up.

If it is not possible to achieve the necessary transmission range with the above methods, SolSensor can be mounted on a tripod and oriented to the correct azimuth and tilt. Choose a location that has sky exposure similar to the array itself.

Mounting SolSensor on a tripod

Tripod mounting allows more flexibility in locating SolSensor for best wireless range. Tripod mounting is also useful when it is not feasible to access the array. In this case you can set the PV Analyzer software to derive the module cell temperature from the measured I-V curve. To deploy SolSensor on a tripod, you will need the following equipment (contact *support@solmetric.com* for specific equipment recommendations):

1. Sturdy tripod

2. Tripod level indicator
   This is typically a disc with a bubble level that mounts between the tripod and the rest of the fittings described here. Some tripods have a built-in level indicator. Note: level indicators vary widely in their sensitivity and accuracy.

3. Tripod leveling head
   This device enables you to quickly and conveniently create a level mounting surface, without needing to adjust the legs of the tripod.

4. Panning unit
   This device rotates about the vertical axis, allowing you to adjust the azimuth of SolSensor independent of the tilt.

5. Tilt unit
   This device rotates about a horizontal axis, allowing you to set the tilt independent of the azimuth. Typically, you will mount the tilt unit on the panning unit, which is in turn mounted on the leveling indicator and the leveling unit and the tripod itself.

6. Adapter plate
   Firmly attach this plate to the bottom of SolSensor and to the top of the tilt unit.

To properly deploy SolSensor on a tripod setup, follow these steps. The instructions assume that you are using a tripod leveling unit. If you are not, level the tripod mounting surface by adjusting the tripod legs.

1. Assemble SolSensor and the tripod-related hardware as shown in <u>Figure 19</u>.

Figure 19. Tripod mounting setup

2. Chose a location to set up the tripod. Consider the following factors:

    - Location should have an open view of the sky, similar to the array itself. Avoid locations where trees or built structures obscure parts of the sky, especially on cloudy days where diffuse light makes up a significant part of total irradiance. Also avoid locations that have substantial albedo effects (reflections).
    - Location should have good line of sight to the combiner boxes or other locations where you will be using your PC.
    - If you plan to use thermocouples to measure module backside temperature, locate the tripod close enough to a sub-array that you can attach the tip of the thermocouple well under the modules, away from the cooler outer edges of the array. A thermocouple extension cable may be useful; contact *support@solmetric.com* for recommendations.

3. Fully spread the legs of the tripod and seat them firmly.

4. Connect the thermocouple wire to SolSensor and attach the thermocouple tip to the backside of a PV module. Avoid attaching it near the edges of the module, which run cooler than normal.

5. If you will be averaging the readings of two thermocouples, also deploy the second thermocouple.

6. Adjust the leveling unit to center the bubble, and then lock the leveling unit.

7. Rotate the panning unit to orient SolSensor to the desired true azimuth, then lock panning unit. Be sure your compass has been adjusted for the local magnetic declination. A magnetic declination calculator is available at *http://www.ngdc.noaa.gov/geomag-web/?id=declinationFormId*

To avoid distortion of the earth's magnetic field by components in SolSensor or the tripod mounting hardware, separate the compass horizontally from SolSensor by inserting a non-ferrous rectangular spacer.

8. Rotate the tilt unit until the tilt angle indicated in the PV Analyzer software matches the actual tilt of the PV array, and then lock the tilt unit.

CAUTION:	**Your irradiance measurement accuracy depends upon correct orientation of SolSensor. It is important that the above steps be carried out in the order listed, to keep the tilt and azimuth adjustments independent of one another.**

Connecting to the Solar PV Equipment

Installed PV systems vary in design and construction. Therefore, the guidance provided in this section is general in nature, and it is critical that you apply techniques and precautions appropriate to the circumstances, following best PV/electrical safety precautions.

WARNING	**The procedure described below is important but does not cover all situations; the operator must assess the potential dangers of each PV system, and take appropriate precautions.** **FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.**

1. Isolate the PV module string to be tested (test string) from the inverter and from other strings in the array. If the measurement is being made at a fused DC combiner box, isolate the combiner box by means of a DC disconnect switch, and isolate the PV strings from one another by pulling their fuses.

    If the measurement is being made at a string inverter and the strings run directly to the inverter, isolate the strings from one another by pulling their series fuses.

2. Press the button on the I-V Measurement Unit to disable the I-V sweep.

WARNING	**PV circuits continue to present danger of electrical shock while the system is paused. FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.**

3. Following safe operating procedures, connect the PV leads of the I-V Measurement Unit to the PV source to be measured. The connection can be made at the PV module itself, or at the ends of home run cables, or at a combiner box. If your strings run directly to the inverter, isolate them from one another and from the inverter by pulling their fuses. Connect the

Solmetric PVA test leads to the string to be measured. In some cases, you can attach an alligator clip to the fuse clip, using it as a test point.
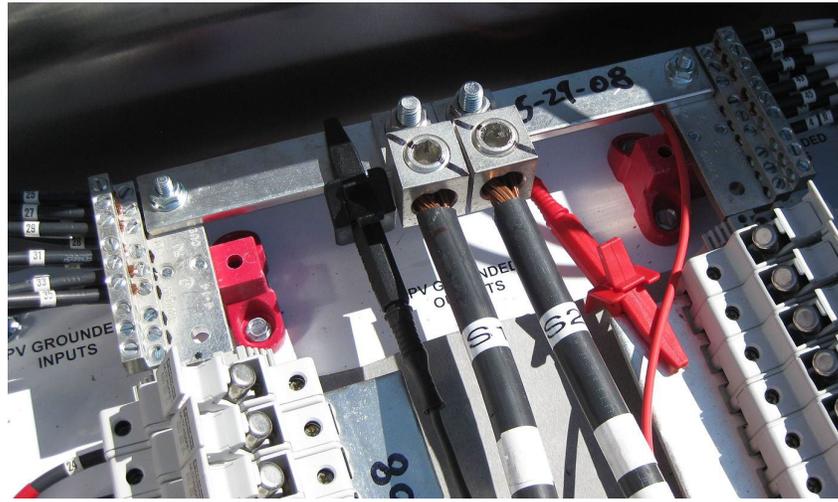
Figure 20. Example of I-V Measurement Unit test leads clipped to the buss bars of a PV combiner box

4. If the distance between the circuit being tested and the I-V Measurement Unit requires the use of extension cables, use a PV cable that is properly rated for the maximum system voltage, with correctly installed connectors. Select a wire gauge that will result in a suitably small voltage drop.

5. When extension cables that are longer than 10 feet (one-way) are added in between the circuit being tested and the I-V unit, the cables should be widely spaced to minimize the inductance they add to the circuit.

6. If connecting at a fused combiner box, insert only one fuse at a time, to select the string you wish to measure.

Powering-Up the I-V Measurement Unit

Press the power button once on the I-V Measurement Unit. Refer to figure below.
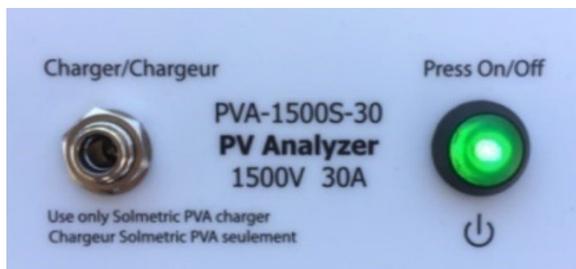
Figure 21. Powering-up the I-V Measurement Unit

The PVA-1500 LED will flash rapidly indicating it is booting, then more slowly indicating that it is waiting to connect to your PC WiFi and the PVA App. Once connected to the App, the LED will be steady ON. If a network is not established within 15 minutes, the I-V Measurement Unit will turn off to conserve the battery. In normal use, the I-V Measurement Unit will not go into sleep mode if the LED is steady ON. However, the I-V Measurement Unit does enter sleep mode 15 minutes after it has been placed in Pause mode by pressing the On/Off button (in Pause mode the LED is flashed briefly every 3 seconds).

I-V Measurements

The I-V Measurement Unit will measure an I-V curve each time you click on the **Measure Now** button. I-V data is transmitted to the PC shortly after each I-V sweep is taken. Data is not stored in the I-V Measurement Unit after it is transmitted. The Voc measurement is performed the instant before the actual I-V sweep begins.

Sweep Disabled

PV current is stopped automatically at the end of each I-V measurement. However, before connecting or disconnecting test leads or cables, press the LED pushbutton on the front of the I-V Measurement Unit to pause the measurement sequence. Manually disabling the I-V Measurement Unit in this way will assure that an I-V measurement is not accidentally taken when it is not expected. When you're ready to take another measurement, just press the LED pushbutton again.

WARNING	**If the LED on the PVA is illuminated (either solid on or flashing), do not connect or disconnect the PV leads.**

Over-Temperature Protection

Built-in safeguards prevent the I-V Measurement Unit from operating at potentially damaging internal temperatures.

The I-V Measurement Unit absorbs energy with each measurement, and across a series of measurements the instrument's internal temperature gradually increases. Some of this accumulated heat is shed during the time between measurements and while the equipment is being moved around the site between measurement sessions. If, on average, the heat gain exceeds the heat loss and the internal

temperature continues to rise, the internal temperature sensor is triggered. When that happens, the I-V Measurement Unit shuts down to allow the instrument to cool down, and the PVA software posts the Disabled message in the Status indicator, directly above the Measure Now button.

CAUTION	Place the **I-V Measurement Unit** in the shade to reduce the likelihood of thermal shutdown. Never place the I-V Measurement Unit on an asphalt driveway, on a solar panel, or roof in direct sunlight.

Sweep-to-Sweep Delay and Thermal Capacity of the PVA-1500

In order to manage the internal temperature of the I-V unit there is a sweep-to-sweep delay that limits how quickly a subsequent I-V sweep can be made. The delay is different depending on the Voc measured as shown in Table 5.

Table 5. Sweep-to-Sweep delay

Voc	PVA-1500S/V2/V3/V4	PVA-1500T/HE
≤200V	6 seconds	6 seconds
201-1000V	10 seconds	6 seconds
1001-1350V	17 seconds	8 seconds
>1350V	22 seconds	11 seconds

The thermal capacity of the PVA-1500 is the number of I-V measurements that can be made before the maximum allowable internal temperature is reached and an extended cool off period is required. Thermal capacity decreases with higher Voc, higher outdoor ambient temperatures, and shorter wait time between measurements. For a reference PV system with 16 strings per combiner box and string Voc of 1300V, if the 16 strings are measured one after another followed by 5 minutes of no measurements (e.g. while moving to the next combiner box), then the thermal capacity is as shown in Table 6.

Table 6. Thermal Capacity (# I-V measurements before extended cool-down)

Sweep-to-sweep delay	PVA-1500S/V2/V3/V4	PVA-1500T/HE
18 seconds	800 (77°F ambient) 225 (113°F ambient)	unlimited (77°F ambient) 550 (113°F ambient)
9 seconds	N/A	unlimited (77°F ambient) 330 (113°F ambient)

After reaching the thermal capacity a message will appear and further measurements will not be allowed. Every minute of cooling (for example: no measurements) increases the number of subsequent measurements that will be allowed before thermal capacity will be reached again. Keeping the I-V unit out of the sun and/or moving it to an air conditioned environment will help increase the rate of recovery.

CAUTION	**The rigid grey enclosure of the I-V Measurement Unit (inside the soft case) gets very hot. Do not touch.**

Operating Under High-Temperature Conditions

The most demanding thermal conditions for the measurement unit are:

- Hot day
- No wind
- No shade
- High open circuit voltage
- I-V sweeps taken in rapid sequence

If you expect these conditions, plan ahead to minimize temperature rise in the I-V Measurement Unit. Shade the measurement unit from direct sunlight, elevate it above hot surfaces, and allow more time between I-V sweeps.

Over-Voltage Warnings

PVA-1500 Over-voltage Condition

If the open-circuit voltage of the PV source under test exceeds the specified maximum DC input voltage of the I-V Measurement Unit, the instrument may be damaged and require factory repairs. Over-voltage can occur if the PV system's DC voltage is higher than expected or two strings are accidentally wired in series.

If a PV voltage greater than 1,525V is detected, an over-voltage warning will appear in the PVA software. Reduce the PV voltage before continuing to make measurements. If a PV voltage in excess of 1,550V is detected, the I-V Unit internally disables itself to prevent further measurements and a warning is posted, advising the user to return the unit to Solmetric for inspection and repair of possible internal damage.

WARNING	**Severe over-voltage conditions can damage the I-V Measurement Unit input protection circuitry.**

Over-Current Warnings

If the I-V Unit is exposed to current in excess of its specified DC input current, damage may occur to the I-V Unit requiring a return to the factory for repair. A warning message will appear when excess current has been applied to the unit.

Over-current can occur when:

- Measuring too many strings in parallel
- Measuring strings that are still electrically connected to the rest of the array or the inverter (for example, when the combiner box DC disconnect is not opened), and
- When using a PVA-1500S/V2/V3/V4/T and when measuring a string of high efficiency ($\geq$ 19%) PV modules with a current over 10 Amps.

High-efficiency modules produce a short but intense pulse of current at the start of every I-V curve measurement. The I-V Unit is designed to tolerate that intense pulse from a single high-efficiency module or string, but measuring two or more in parallel with current over 10 Amps will trigger the over current warning. See the section: Are you measuring high-efficiency modules?

CAUTION	**Do not measure high-efficiency PV modules (or strings) in parallel or over 10 Amps.**

Reverse Polarity or Zero Volts Detection

If the I-V Measurement Unit detects a voltage less than -0.5V, the software posts the warning "Negative Voltage Detected," an internal protection circuit prevents internal damage, and an I-V measurement does not take place. It is likely that the I-V Unit is connected with the wrong polarity across a circuit.

If the I-V Measurement Unit measures a voltage between -0.5V and 0.5V the software posts the warning "0 volts detected" and an I-V measurement does not take place. It is likely that the I-V Unit is not connected to the circuit, the circuit has an open, or for some other reason the circuit has close to 0V.

3 Software Overview

Using Projects

The PV Analyzer stores all of your setup information and measurement results in a specialized Windows file type file type called a Project file. The PV Analyzer software guides you through the steps of creating a Project for a particular array.

All PV modules within a Project must be of the same type and must be mounted at the same azimuth. Often a site will have multiple PV arrays with a mix of different modules and azimuths. To accommodate these differences, create a separate Project for each case. To save time, you can copy and paste your first Project file, re-name it, and edit just those features that are different.

The PVA's have a special feature for measuring the performance of strings in horizontal single-axis tracking systems. The software is able to automatically 'flip', at solar noon, from a morning azimuth to an afternoon azimuth. SolSensor reports the tilt with each measurement.

NOTE	To preserve software responsiveness for large PV sites, consider creating multiple projects. For example, in a 50 MW project, create a separate Project for each pad or each inverter. This will also improve the speed of the Data Analysis Tool that you will use to analyze your data.
NOTE	Be sure that your PC is set to the correct date and time, and that the time zone and daylight savings setting are correct. These parameters are used to calculate the position of the sun at the exact moment of the I-V curve measurement. This allows the software to calculate the angle of incidence of the direct sunlight and use that information to optimize the accuracy of irradiance sensor and the PV model. **Errors in these settings will introduce errors in the effective irradiance measurement and in the predicted performance of the PV modules under test, and as a result will also cause errors in the Performance Factor** (measured maximum power / predicted maximum power). It is especially important to be aware of this requirement if you are traveling between time zones with your equipment. I-V measurements are automatically "stamped" with the date and time at the instant the measurement is performed. If your computer is connected to the internet, each time you open the New Project Wizard, the PVA PC software checks a web time server for the correct Universal Time and adjusts your computer's clock as needed. Choose the time zone and daylight savings setting. All dates and times associated with the saved measurement data are preserved even if the Project is subsequently opened in another time zone.

Using the System Tree

The PV Analyzer provides a very efficient means of saving your data. After each fresh I-V curve measurement is displayed the software also displays a 'tree' representation of your PV system, which you touch or click to tell the software where you took your measurement in the array. This allows the PV model to retrieve wiring characteristics and other details that are unique to that location, and also tells the software where to save the measurement result. The predictive model points (Isc, max power point, and Voc) are displayed on the I-V curve graph only after you have identified the location of the measurement.

Main Screen Overview

The PVA software runs on a PC that is your interface for making measurements and storing, viewing, and exporting data. The software is fully touch-enabled, so using a tablet PC is most efficient. The main screen is shown below, with the Traces tab selected.
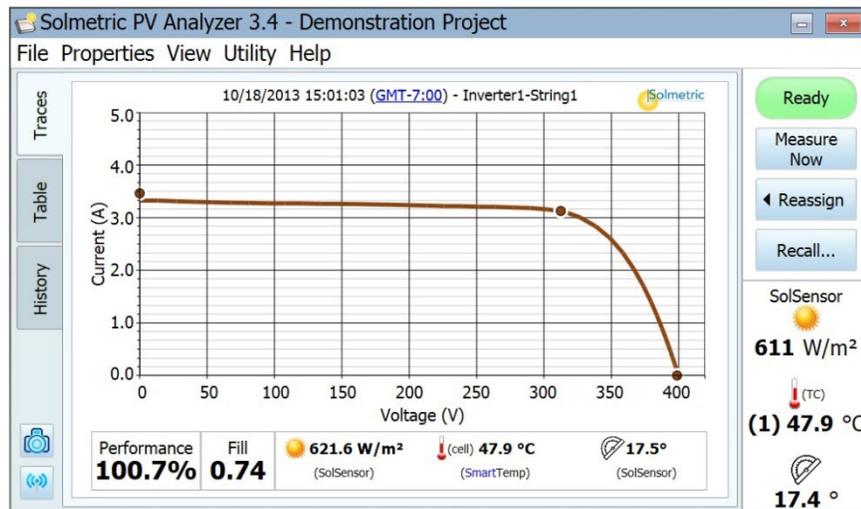
Figure 22. PVA software main screen

The Title Bar at the top of the screen displays the name of the Project that is currently loaded.

The Menu Bar provides access to additional controls and options.

The Tabs along the left side of the screen provide different ways of viewing your data.

Menu Bar

File Menu

The File Menu, shown in Figure 23, is used to create a new project, browse and load existing projects, load recent projects, and export measurement data.
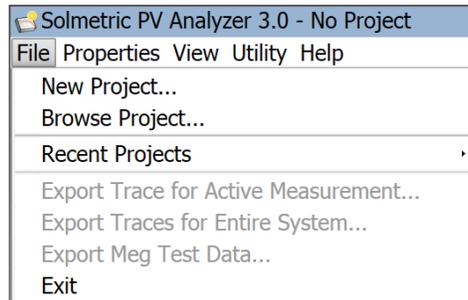
Figure 23. File Menu

Browse Project

Used to access previously saved Projects for retrieval.

Recent Projects

Provides convenient access to recent Projects.

Export Trace for Active Measurement

Exports the measurement results for the measurement currently displayed in the Traces screen, as a csv file.

Export Traces for Entire System

Exports the measurement results for the currently loaded Project, as a Windows folder tree. It is organized hierarchically as System\Inverter\Combiner\String IV Data (csv files). Only the last measurement result for each location in the array is exported.

Data in this hierarchical format can be analyzed automatically by the Solmetric Data Analysis Tool.

Export Meg Test Data

Exports the Meg test data as a .csv file, for the currently loaded project.

New Project

Clicking **New Project…** brings up the Site Info screen, shown in the figure below. This is the first of three screens of the New Project Wizard.
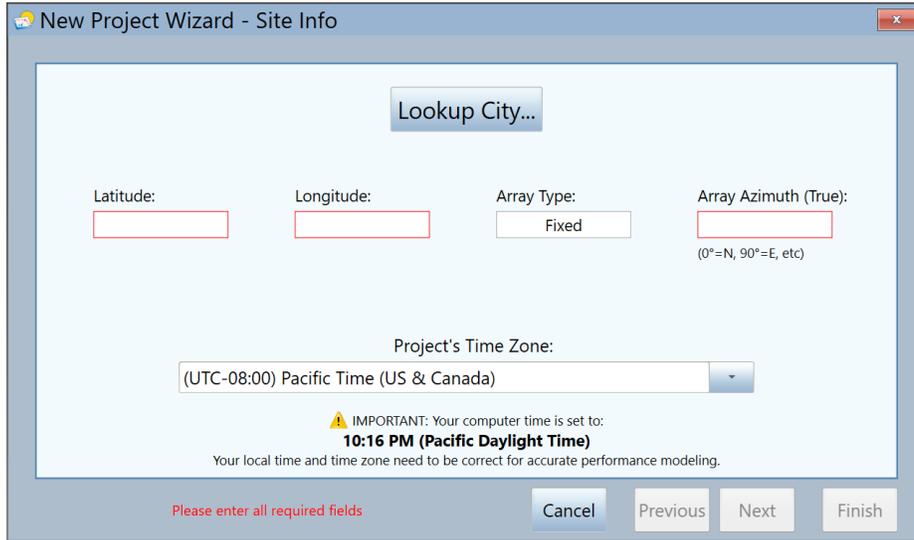
Figure 24. The Site Info screen of the New Project Wizard

Enter the latitude and longitude of the PV installation in the boxes provided, or use the Lookup City button to substitute the latitude and longitude of a city near your PV installation.

The Site Info screen has a special feature for horizontal single-axis tracking systems, which allows the I-V curves to be taken while the tracker is working. This has the advantage of taking all of your measurements at the greatest possible irradiance level. The user enters the morning azimuth of the array, and at solar noon the software adds 180 degrees for the afternoon azimuth.

Figure 25 shows example settings for a fixed (non-tracking) array.
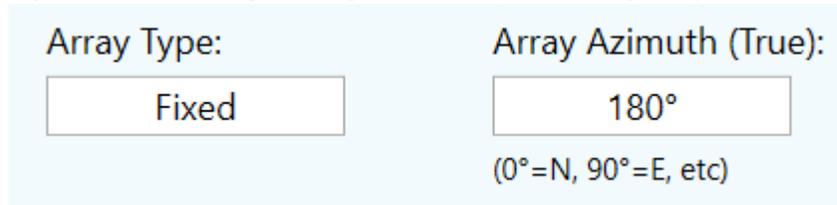
Figure 25. Controls in the Site Info screen, set for a fixed array with 180-degree azimuth.

Figure 26 shows the array type and azimuth settings for a horizontal single-axis tracker. In this example, the PV modules are facing East in the morning hours (before solar noon). At solar noon, the PVA software will add 180-degrees to the morning azimuth.

To clarify what we mean by azimuth in a tracker, imagine that the tracker is stopped at a fixed setting and we want to determine the azimuth at which the modules are oriented. Imagine placing a marble on

the module's glass surface, near the upper frame element, and releasing the marble to roll downhill. It will roll down in a straight line, like an arrow, and the projection of that arrow on a horizontal surface (typically the ground, if it's level) is in the direction of the azimuth of your module.
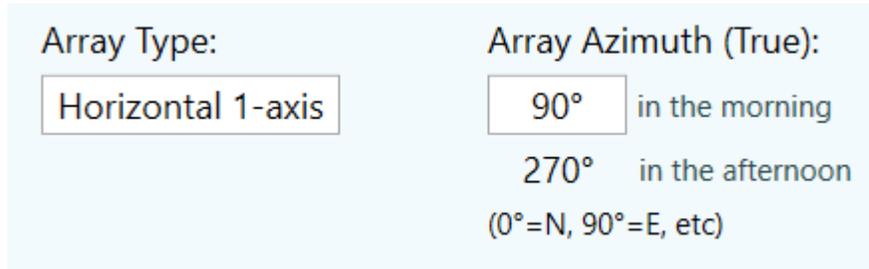
Figure 26. Most common settings for a horizontal single-axis tracking system.

The final step in the Site Info screen is to make sure that your PC clock is set correctly. These parameters include the time, date, and time zone.

CAUTION	**Each measurement you make is stamped with the technician's PC's values of time, date, and time zone. These values must be correct for the irradiance sensor to correctly interpret the irradiance, and for the PVA software to correctly calculate the Performance Factor. The time, date, and time zone cannot be corrected after the measurements have been taken.**
	This caution applies to the PC that is controlling the I-V curve measurement process, not the PC on which the PVA project file was originally created. At the start of a measurement session, always be sure the PC's time, date, and time zone are correct.
	When the operator launches the software at the PV system site for a day of measurements, the first thing to do is to check the PC's clock to make sure that the date, time, and time zone are correct.

In the drop list control, select the time zone of the PV project installation site, as shown in the example in Figure 27. [filename Computer Clock]

Figure 27. The time zone control in the Site Info screen.

When the latitude, longitude, azimuth, date, time, and time zone are entered correctly, click **Next** to advance to the PV Module screen, shown in the figure below.

Figure 28. The PV Module screen of the New Project Wizard.

Selecting your PV Module

Selecting your PV module (Figure 28) makes the module's performance parameters available to the Project so that the software can calculate the expected I-V curve and the Performance Factor.

Start by typing the name of the manufacturer. When your manufacturer appears in the short list, click on it to select it. Then repeat that process for the model number of the PV module. If the manufacturer or model # you are looking for is not in the list, you can click "New Custom…" and enter the manufacturer, model #, and specifications and then save it as a custom module. This custom module will be stored as part of the project file so that if the project file is shared with another computer, the custom module will appear on the second computer as well.

If you wish to add that module to your Favorites list, click the star icon.

After you have selected the model number, the performance parameters for that module appear in the scrolling table, as shown in Figure 29.
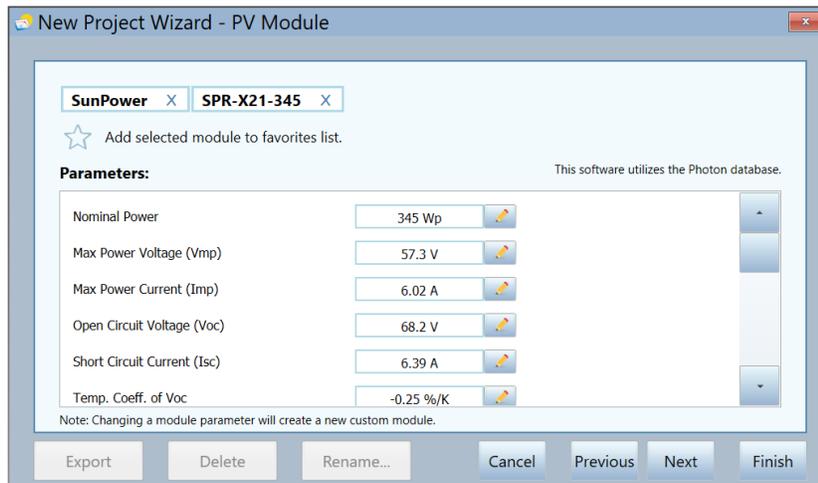
Figure 29. Selection of the PV module's manufacturer and model number, and corresponding list of module performance parameters.

Review the 17 parameter values. If edits are needed, use the pencil icon buttons to enter the correct information. After editing, you have the option of renaming that module and saving it in the custom equipment folder.

Creating the System Tree

When you have finished selecting or editing your PV module, click Next to advance to the final step in the New Project Wizard, shown in Figure 30.
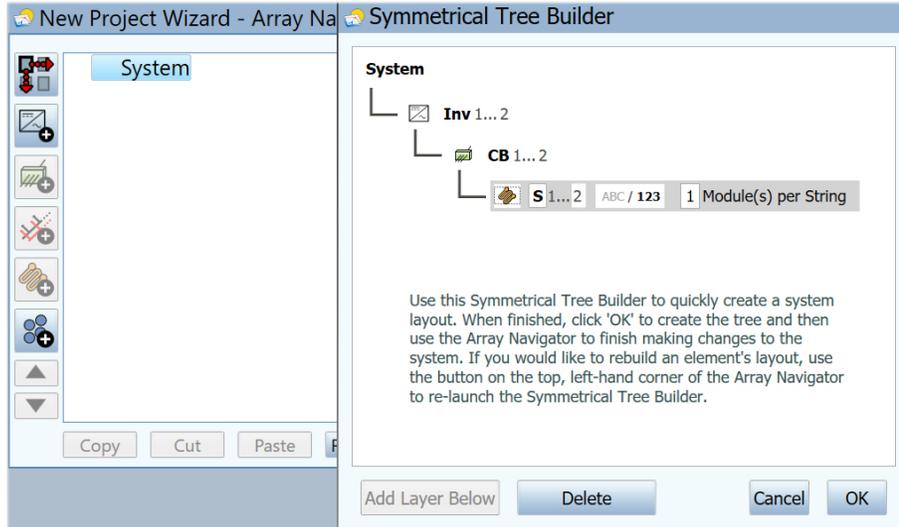
Figure 30. Array Navigator with Symmetrical Tree Builder. This is the final step in creating a Project.

This screen is used to describe your PV system hardware. The information you enter here is used for two purposes:

1. Clean a visual 'tree' representation of your array that you can 'touch' to save and recall your measurement data.

2. Create the PV model that the software uses to predict expected performance.

An example of a finished array tree is shown in Figure 31. For clarity, the names of the 'layers' of the tree have been completely spelled out. In practice you should abbreviate the names so that the so that the 'path names' for your measurements will fit in the software's tree displays and headers and in reasonable-sized spreadsheet cells.
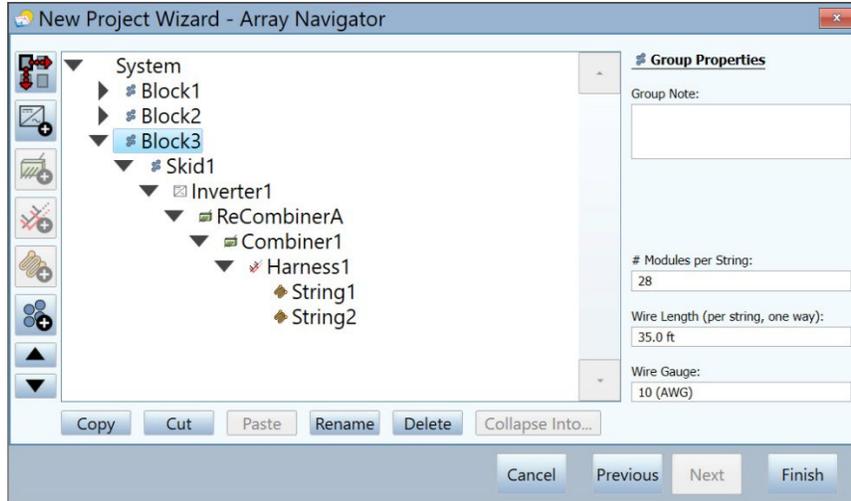
Figure 31. Finished array tree for a utility PV field.

The process of creating your tree has two parts. First, use the Symmetrical Tree Builder screen (shown in Figure 32) to create the basic structure of the tree. If it is a large utility-scale project, the design is likely to be modular, and in this first screen you will describe that modular, 'symmetric' structure that repeats again and again across the field. The second part of the process is to use the Array Navigator screen, which appears when you click **OK** on the Tree Builder, to customizations your tree.

Using the Symmetrical Tree Builder

The Symmetrical Tree Builder opens with a default system tree, shown in Figure 32.
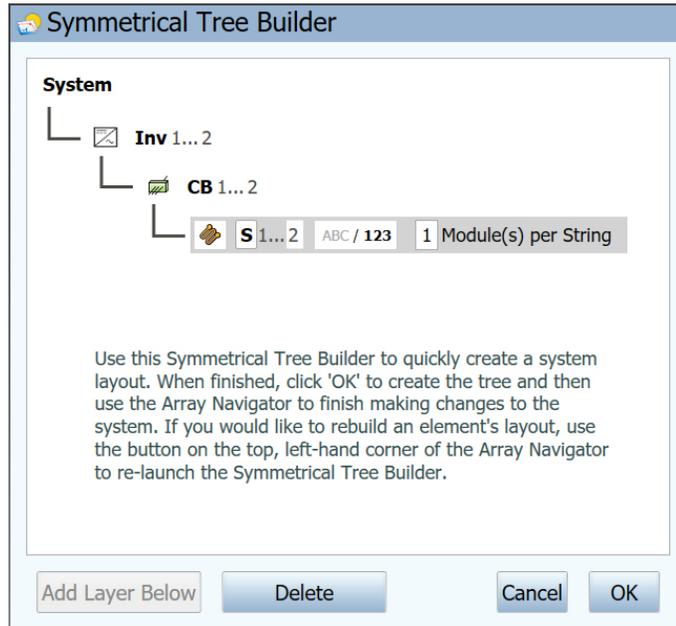
Figure 32. The default system tree in the Symmetrical Tree Builder.

Edit the tree so that it matches the design of your PV field. You can change any of the following:

- Number of layers in the tree.
- Names of the layers
- The quantity in each layer
- Represent items by number or alphabetically
- Number of modules in each string.

To add a layer to the tree, highlight the next highest layer and select **Add Layer Below**. To delete a layer, just highlight the layer and select **Delete**. A layer can be an inverter, a group, a combiner, or a string. Add a 'combiner' layer to represent anything that combines electrical circuits. Add a 'harness' when strings are wired in parallel out in the array. Use 'group' layers to represent other organizational levels: blocks, parking lots, skids, pads, tracking motor groups, and so on.

There are some limitations on which tree elements can be nested under one another. The rules are based mainly on the requirement that the PV source under test must ultimately nest (directly or indirectly) under an inverter. This list spells out that flexibility:

Which elements can nest under the **System**?

- Groups
- Inverters
- Not electrical devices like PV modules, strings, or combiners

Which elements can nest under a **Group**?

- Other groups
- Inverters
- Combiners (only if the group is under an inverter)
- Harnesses (only if the group is under an inverter)
- Strings (only if the group is under an inverter)
- PV modules (only if the group is under an inverter)

Which elements can nest under an **Inverter**?

- Groups
- Combiners
- Harnesses
- Strings
- PV modules

Which elements can nest under a **Combiner**?

- Groups
- Combiners
- Harnesses
- Strings
- PV modules

Which elements can nest under a **String**?

- PV modules

TIP:	Rename the layers to agree with the naming conventions used in your engineering drawings, so that there will be no confusion about where measurements were made.
	Try not to use more 'non-electrical' layers than necessary ('block', 'field', 'parking lot', etc.). Also, abbreviate the names of the layers to keep them as short as possible. It is important to allow each measurement's complete 'path name' to appear in the software display and in your data analysis and final report.

In each layer there are editable fields, which appear with white background when you highlight a layer. Use these fields to customize the name of the layer, to change the quantity, to use numbers or letters, and in the case of strings, to indicate the number of modules in the string.

When you think your tree is complete, double-check it against your engineering drawings to be sure it's correct, because it is not convenient to change the structure of this basic tree after exiting the Symmetrical Tree Builder.

After closing the Symmetrical Tree Builder, use the editing features of the Array Navigator to add or delete items, adjust quantities, copy and paste, move up and down, and so on. Often a PV installation includes a smaller PV system to take advantage of remaining space; and you can add that system at this time.

When you have finished editing the structure of your tree, you can edit the array's string wiring properties. The controls are shown in Figure 33.
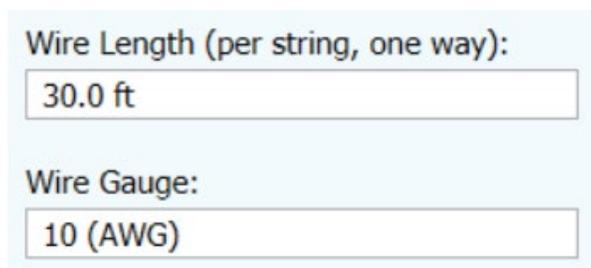
Figure 33. Controls for editing the string wiring properties of your array tree.

The wiring properties are used by the PV model to calculate the expected I-V curve, but have no impact on the actual I-V curve trace measurement. Some energy is always lost in the wiring, and the purpose of this feature is to enable the software to calculate those losses (of voltage and power) so that they do not make the PV modules look like they are underperforming.

To use the wiring properties controls, first select a level of the tree to which you want the changes to apply. **The changes you make will be applied to all strings at or below the level of the tree that you edit.**

TIP:	Systems are usually designed to minimize wiring losses, so it's not necessary to be exact about entering wiring characteristics. For example, if the strings in a combiner box have one-way wiring lengths ranging from 50 to 100 feet, you may just want to assign 75 feet to them all. And if the entire project has string wiring with that range of length, you can highlight the top level of the tree (System) to make your edit, and the wiring properties will be pushed down to all strings in the project.

You can also highlight a level of the tree and change the number of modules per string for all strings at that level and below.

When you are finished creating your system tree, click **Finish** and save your Project.

Cloning, Modifying, and Reusing a Previous Project

If you need to create a new Project that will be very similar to one you have done before, you can save time by recycling the earlier project and adjusting it as needed. Follow these instructions.

1. If you are not sure where to find the Projects folder, launch the PVA software, open the File menu, click on Browse Project..., and you will see the path to the Projects folder.

2. Navigate to your Projects folder, as shown in .
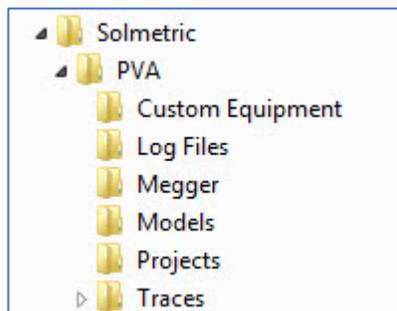
Figure 34. Directory structure used by the PVA software

3. Highlight the Project file you want to recycle, and copy and paste it.

4. Rename the copy with the name of your new project.

5. From the PVA software File menu, select Browse Project..., and navigate to the new Project file.

6. Use the screens in the Properties menu to edit the Project as needed. You will need to delete all of the data to avoid confusion with the new data. The easiest way to do this is to delete the inverters and build a new tree.

Properties Menu

The Properties menu, shown in Figure 35, enables you to view and edit the settings of the currently loaded Project. The items in this menu access the same screens that appeared in the New Project Wizard. See the File Menu/New Project… section for details on the use of these screens. [filename is Properties Menu].
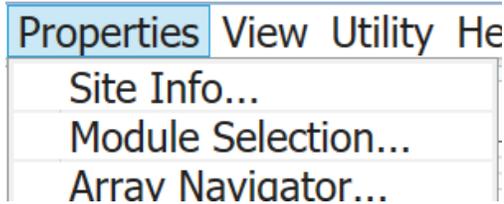
Figure 35. Properties Menu

View Menu

Trace view options...

These controls select which features are displayed in the Traces screen. Options include:

I-V	Measured current vs. voltage curve
I-V (STC)	Measured current vs. voltage curve translated to STC
P-V	Power vs. voltage curve calculated from measured I-V curve.

To show this legend at the bottom of the Traces screen, check "Show legend under chart".

Show Meg Test Tab

Click the check box to display the Meg Test tab at the left side of the measurement screen.

Utility Menu

The Utility Menu provides access to housekeeping functions and miscellaneous tools. The Utility Menu is shown in Figure 36 and described in Table 7.
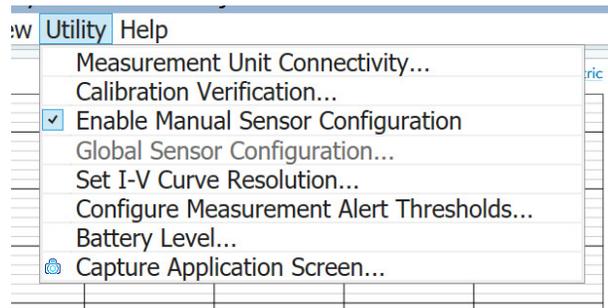
Figure 36. Utility Menu, used to control housekeeping functions.

Table 7. Utility menu description

Name	Description
Measurement Unit Connectivity	This dialog is used to switch between connecting to a PVA-1500 via WiFi and a PVA-1000 via wireless USB.
Calibration Verification	See *Calibration Verification* for a description of this dialog.
Enable manual sensor configuration	Check this menu item to display, as shown here the controls for selecting your irradiance, temperature, and tilt sensing options. See Chapter 6 Measuring Irradiance, Temperature, and Tilt for guidance on sensor choices.
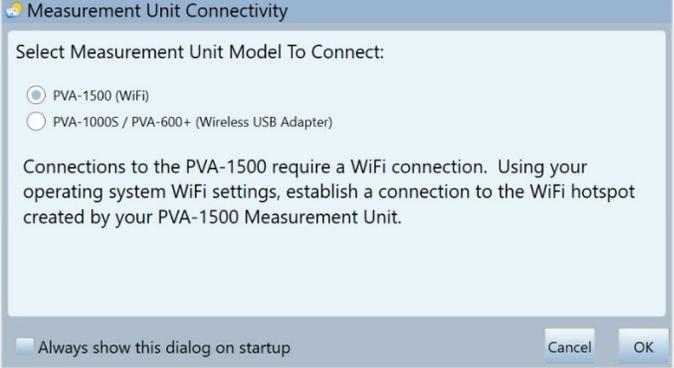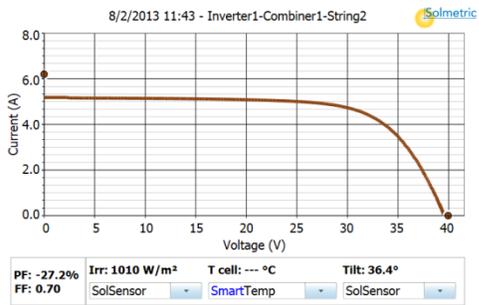
Name	Description
Global Sensor Configuration...	The controls shown in the figure below allow you to change the sensor choices for all of the measurements currently saved in the project. Select the desired sensors from the dropdown lists. **CAUTION: This action cannot be undone. Create a backup file before taking this action.** See Chapter 6 Measuring Irradiance, Temperature, and Tilt for information on your sensor choices.
Set I-V Curve Resolution...	Displays controls for selecting the number of measurement points in your I-V curve. Select 100 points for commissioning and most troubleshooting. Select 500 points for some research and more detailed troubleshooting applications. The resolution can be changed at any time, and will remain in effect for subsequent measurements, until you change it again. The software responds much more quickly when using 100 points.
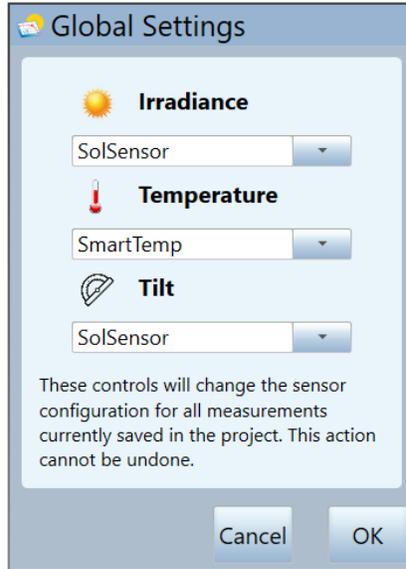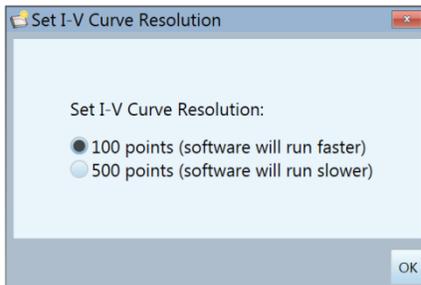
Name	Description
Configure Measurement Alert thresholds…	Set thresholds that the software will automatically check after each measurement is "Assigned and Saved" (but not if the measurement is only "Assigned"). These alerts are useful for catching problems before the user moves on to other circuits or leaves the site.
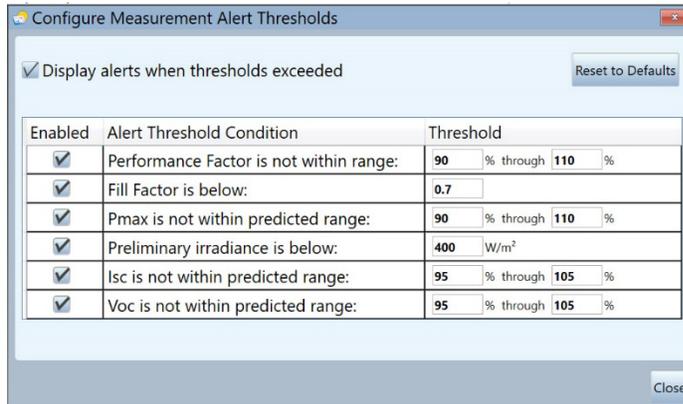
Name	Description
Battery Level…	To check the battery voltage, select **Battery Level…** in the Utility menu, or just click on the Status indicator any time the indicator is displaying **Ready**. Battery voltages are also listed in many of the popup messages that accompany status and disable messages. The battery voltage at which the unit will shut down is also reported. Wait 30 seconds to check the battery voltage if you just removed the I-V unit from the charger or just turned on the I-V Unit. This allows internal functions to complete, for a more accurate battery reading.

In the PVA-1500 software, the battery levels of both the I-V Measurement Unit and SolSensor are reported.

The instruments shut down when the battery voltage has dropped to a preset lower limit. A warning appears in the software approximately one hour before the shutdown.

The shutdown voltage levels are:

 PVA-1500 I-V Measurement Unit and SolSensor 300:   3.05V

The type of Lithium ion battery used in these instruments has a very square discharge curve, so there is relatively slight variation in battery voltage from the fully charged state to the shutdown level. |
| Capture Application Screen | Captures and saves the currently displayed screen. |

Help Menu
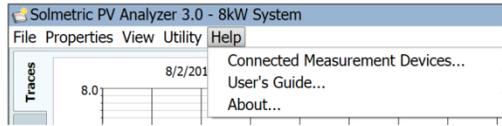
Figure 37. Help Menu

Table 8. Help menu description

Name	Description
Connected Measurement Devices...	The figure below shows the network diagram, which represents your PC, I-V Measurement Unit, SolSensor, and the wireless signal levels between them. When using the PVA-1500 and SolSensor 300, the I-V Unit relays all communications between the PC and SolSensor. Refer to this screen to find out what firmware version is running in the I-V Unit and SolSensor.
User's Guide	Accesses the PVA User's Guide. The guide can be downloaded and printed if desired; a hard copy of the guide is not provided with the products. In addition, the User Guide is available in the Support page of the Solmetric website, under **Downloads**.
About	Accesses the software version number and software build date. Please have this information ready if you call Solmetric about your PVA.
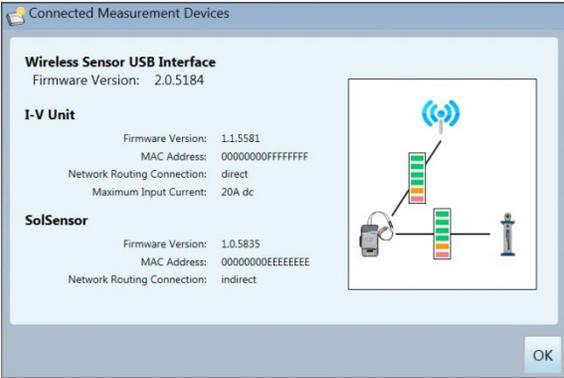
Using the Tab Screens

The tabs along the left edge of the screen display measurement data in various ways. The paragraphs below explain how the features of each tab are used.

Certain elements are common to more than one tab. These include the **Status** indicator, the **Measure Now** button, the **Assign** and **Save...** button, the **Reassign...** button, the wireless sensor displays, and the **Environmental Inputs** slide-up panel.

Traces Tab

Displays the most recent measurement results along with the predicted shape of the I-V curve (if a PV model is selected). Figure 38 is an example of the Traces tab screen.
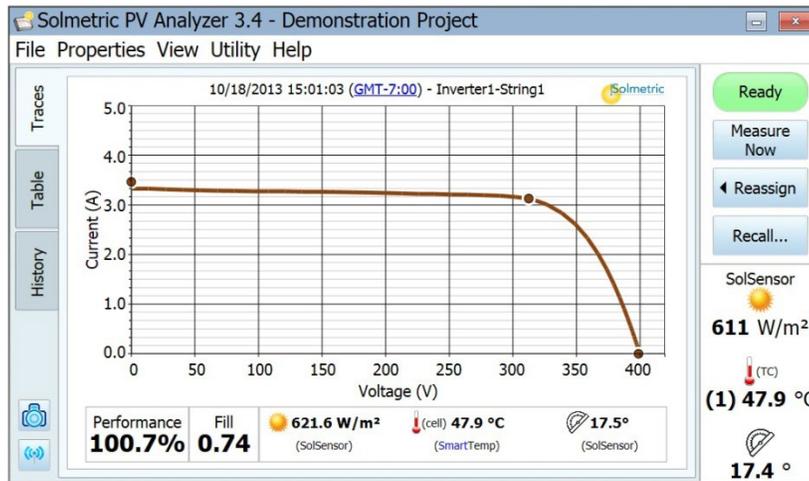
Figure 38. Traces tab, showing the measured I-V curve and the expected locations of Isc, maximum power point, and Voc.

The graph area can display four types of information. Select View, then trace View Options to choose the desired view as described below:

- I-V curve. This solid red curve displays the measured I-V points transmitted from the I-V Measurement Unit. Points below 0 V are not displayed.
- I-V curve prediction markers. The three red dots are the predicted I-V points for the short circuit current Isc (Isc, 0), the maximum power point (Imp, Vmp), and the open circuit voltage Voc (0, Voc).
- P-V curve. This solid blue curve displays the power available from the test device (module or string), calculated from the I-V curve by multiplying I x V for each I-V point. The blue point marks the maximum value on the P-V curve. This value is calculated by fitting a mathematical curve to the top of the P-V curve and then calculating the maximum value of the fitted curve. This reduces the impact of electrical noise on measurement accuracy. The location of the blue marker is not derived from the PV model.

- I-V curve translated to STC.

Table 9. Traces tab description

Name	Description
Measurement ID	The label just above the graph identifies the displayed I-V trace. If you have not yet assigned or saved the trace, the ID will show only the date and time at which the measurement was taken.
	If you have assigned the trace to a location in the system tree but not yet saved it, the ID will show the date, time, and the location in the system tree and indicate that the data has not been saved.
	If you have assigned and saved the trace, the ID will show the date, time, and location in the system tree.
	Also shown in the measurement ID is a link showing the time offset from GMT. Click on the link to check the time zone.
Current (A)	Displays the current scale along the vertical axis on the left side of the graph.
Voltage (V)	Displays the voltage scale along the horizontal axis of the graph.
Power (W)	Displays the power scale along the vertical axis on the right side of the graph when the P-V curve is selected in the View menu. The current and power axes auto-scale independently. As a result, the relative heights of the I-V and P-V curves change when auto-scaling occurs.
Ready (in Status indicator)	At the upper right corner of the measurement screens is an indicator that shows the readiness of the PV analyzer system to take a fresh I-V measurement. If the system is able to take a fresh measurement, the indicator displays "Ready". If it is not ready, a diagnostic message will appear, accompanied by a question mark icon. Click on the question mark or the status indicator for details.
Measure Now	Highlighted in green when the system is ready to start a new I-V measurement. Click this button to take a fresh measurement.
Measuring (in Status indicator)	During a measurement, the **Measuring** label blinks.

Name	Description
Assign and Save Reassign	Before the PV model points for a new measurement can be displayed on the I-V graph, the measurement must be assigned or saved to a location in the System Tree in the Array Navigator. This allows the model to 'read' information it requires from the Tree, such as the number of PV modules in a string, and the wiring characteristics. Follow these steps. 1. After a fresh measurement is taken, the I-V curve is displayed, and the System Tree is temporarily displayed alongside it. 2. Click the location in the System Tree at which the measurement was taken. Then use the Assign and Save button to save your data to that location. If you want the model points to appear but don't want to save the trace, just click the **Assign** button. After a measurement has been saved, the **Assign and Save** button becomes the **Reassign** button. Click the **Reassign** button if you accidentally saved a measurement to the wrong location in the system tree. When the tree appears, just click on the correct location and then click **Assign and Save** again. The location will change and the Measurement ID above the I-V curve will show the new location.
Recall Measurement…	Recalls measurement data from the system tree. When the tree appears, click on the location of interest. If more than one measurement is stored at that location, click on the Date/Time of the measurement of interest and then click **Recall Measurement**.
Paused (in Status indicator)	Displayed when the I-V measurement process is Paused. In this state, PV source connections may be changed without interrupting a measurement. **ꓲ - PV circuits continue to present danger of electrical shock while system is paused. FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.**
Disabled (in Status indicator)	Displayed when a problem exists other than communication between the PC and I-V Measurement Unit. Problems could be related to low battery, over current, over voltage, over temperature, reversed polarity, and so on. No measurements can be taken while in this state.

Name	Description
	When "Disabled" is displayed, click on the status indicator or the question mark icon for information to aid in troubleshooting the problem.
Searching for I-V Unit (in Status indicator) PVA-1500	When this is displayed, click on the question mark icon for tips on establishing your connection. This status should change to Ready within seconds of connecting your PC to the I-V Unit's WiFi hot spot. If there is a problem it is typically because they are out of wireless range of one another, or you connected with a different I-V Unit that was in the same vicinity (uncommon).
SolSensor Displays	If SolSensor is turned on and within wireless range, its sensor values are displayed in the lower right corner of this screen.
	If the SolSensor 300 is turned off or out of wireless range of the I-V Unit, Searching for SolSensor is displayed in this area.
	If two thermocouples are connected to SolSensor, both temperatures will be displayed as shown below. However, it is most common to use only a single thermocouple.
	If two thermocouples are connected to SolSensor, both temperatures will be displayed as shown below.
	If a PV model and a Project have not yet been created, the irradiance value is a preliminary value and the value is displayed in gray, italic font as discussed in the section *Preliminary vs Effective Irradiance* and shown here:

Irradiance
1030 W/m²

T backside
(1) 55.8 °C
(2) 54.1 °C

Tilt
36.4 °

Once a Project is created and loaded, irradiance is displayed in black, regular font, as shown here:

Irradiance
1031 W/m²

T backside
(1) 55.8 °C
(2) 54.1 °C

Tilt
36.4 °

Name	Description
Searching for SolSensor (in SolSensor display area) PVA-1500	Displayed if the SolSensor 300 is turned off or out of wireless range of the I-V Unit, or the PC has not yet connected to the I-V Unit hotspot.
Summary Bar	Located directly below the displayed I-V curve, the Summary Bar displays the results of the currently displayed measurement.

The Performance Factor represents the measured maximum power value as a percentage of the value predicted by the PV model.

The Fill Factor (FF) is an indication of the squareness of the I-V curve (a more square 'knee' of the curve indicates greater efficiency of conversion from sunlight to electric power). It is defined as (I_{mp} x V_{mp}) / (I_{sc} x V_{oc}) and is discussed in detail in Chapter 7 Interpreting Measured I-V Curves.

Irradiance, temperature, and tilt are also displayed.

Table Tab

The Table Tab presents summaries of the predicted and measured I-V data and a translation of the measurement results to Standard Test Conditions. Figure 39 is an example of the Table Tab screen. This section describes the table itself. See the Traces Tab section for explanations of other controls and displays on this screen.
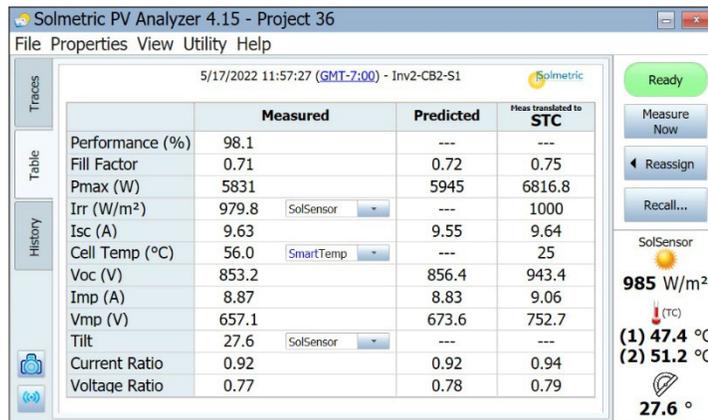
Figure 39. Table tab

Table 10. Table tab description

Name	Description
Measured	Displays actual measured values most recently measured.
Predicted	Displays the predicted values from the selected performance model.
Meas Translated to STC	Displays a translation of the measured parameters to Standard Test Conditions, 1000W/m2 and 25 C.
Performance (%)	Performance Factor.
Fill Factor	The Fill Factor (FF) is an indication of the squareness of the I-V curve (a more square 'knee' of the curve indicates greater efficiency of conversion from sunlight to electric power). It is defined as $(I_{mp} \times V_{mp}) / (I_{sc} \times V_{oc})$ and is discussed in detail in Chapter 7, Interpreting Measured I-V Curves..
P_{max} (W)	Measured maximum power values in Watts.
Irr (W/m^2)	Irradiance. This is the modeled effective irradiance.
I_{sc} (A)	Short circuit current. The first point of the I-V sweep is slightly to the right of the vertical axis of the I-V curve graph. The PVA software draws a horizontal line from this point back to the vertical axis.
Cell Temp (ºC)	Cell Temperature. This will differ from the backside thermocouple measurement by a model of the temperature drop from cell to backside which depends on irradiance.
V_{oc} (V)	Open circuit voltage. The Voc measurement is performed by a high impedance voltmeter circuit immediately before the actual I-V sweep. This Voc value is accurate even if the measured I-V curve does not extend all the way down to the horizontal axis.
I_{mp} (A)	Current at the maximum power point.
V_{mp} (V)	Voltage at the maximum power point.
Tilt	Tilt of array.
Current Ratio	The current ratio is a relative indication of the slope of the horizontal leg of the I-V curve. It is defined as I_{mp}/Isc. For more detail see Chapter 7, Interpreting Measured I-V Curves.
Voltage Ratio	The voltage ratio is a relative indication of the slope of the vertical leg of the I-V curve. It is defined as V_{mp}/V_{oc}. For more detail see Chapter 7, Interpreting Measured I-V Curves.

History Tab

Automatically displays the tabular results of your most recent measurements. New results appear in the left-hand column. Previous results are shifted to the right. The table holds up to 32 results. Once that limit is reached, the oldest measurement result is dropped from the table each time a new measurement is taken. The parameters displayed in the History tab are identical to the results shown in the Table tab. Additional parameters are displayed when the **Show Advanced Parameters** box is checked. The Advanced Parameters are shown in Table 11.
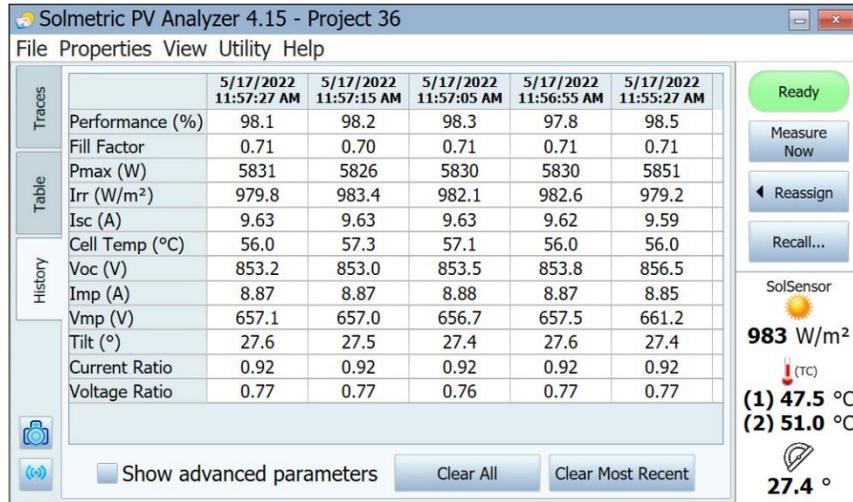
Figure 40. History tab

Table 11. History Tab Advanced Parameters

Name	Description
Prelim Irrad (W/m^2)	Preliminary Irradiance. This is the raw irradiance measured from the SolSensor. It includes calibration and temperature corrections, but does not include the model correction for effective irradiance. It can be useful to compare Preliminary Irradiance to the Modeled Effective Irradiance when there appears to be a problem with the Irradiance reading. See section Preliminary vs Effective Irradiance.
Irr Sensor	Irradiance Sensor input configuration. For example, this could be SolSensor, From I-V, or Manual. Enable Manual Sensor Configuration in the Utility Menu. See the section Utility Menu.
TC1 (ºC)	Thermocouple 1 temperature reading. Its useful to look at this when there is a problem with the Cell Temperature.
TC2 (ºC)	Thermocouple 2 temperature reading. Its useful to look at this when there is a problem with the Cell Temperature.
Temp Sensor	Temperature Sensor input configuration. For example, this could be SolSensor, TC1, TC1, Avg(TC1, TC2), From I-V, or Manual. Enable Manual Sensor Configuration in the Utility Menu. See the section Utility Menu.

The History tab is especially useful for inspecting the agreement between measurements taken at a combiner box during commissioning tests, and also for displaying sequential steps in a troubleshooting sequence. For example, when using the Selective Shading Method to find the failing module in a string of N (quantity) modules, you can use the History Tab to display and compare the N measurement results. The column with the odd result corresponds with shading the bad module.

The current contents of the History table are saved in your Project file, so the most recent contents will still be there when you close and re-open the PVA software. However, the contents are not saved to the System Tree like your I-V curves, and when you recall an I-V curve from the System Tree, the History table is not updated to match that recalled measurement. Also, the History table contents are not exported when you export your I-V curve data.

Meg Test Tab

This tab is used to record resistance measurement results obtained from a separate instrument such as the Megger® MIT430 Insulation Resistance Tester. Data is entered manually. The Meg Test tab is hidden by default. To enable this tab, use the control in the View menu.
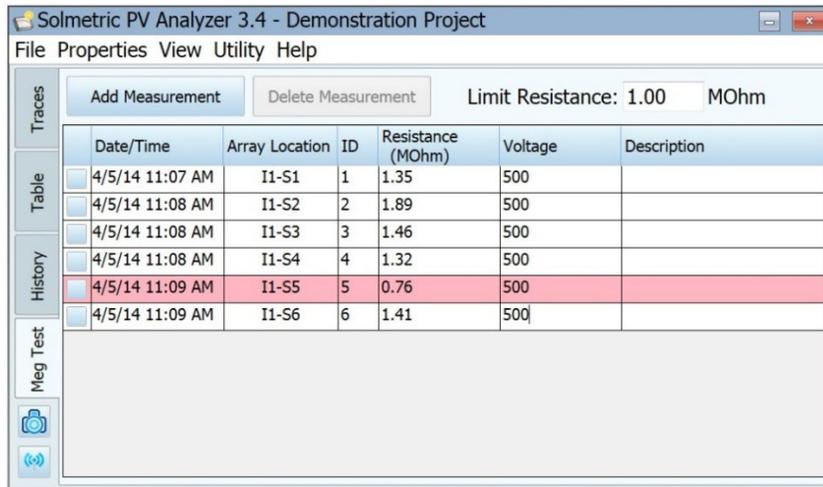
Figure 41. Meg Test tab

Table 12. Meg Test tab description

Name	Description
Add Measurement	Adds a new line to the table. The current date and time is listed, and the line is assigned an ID number.
Delete Measurement	Deletes the currently selected measurement from the list.
Limit Resistance	Enter the minimum acceptable value of insulation resistance. Any measured values that are below this limit will be highlighted in red in the table.
Selection box	Selects or clears the measurement of interest.
Date/Time	Displays the date and time each measurement was added to the table.
Array Location	Accesses the system tree for selecting the location at which the measurement was made.
ID	Automatically assigned identification number. The ID number increments by one count each time a measurement is added.
Resistance	The measured value of insulation resistance in megohms. Click in this field to enter the value manually.
Voltage	The voltage at which the insulation resistance was measured. Click in this field to enter the value manually.
Description	Optional description of the device under test.

Description of the Exported I-V Data File

This section describes the organization of the .csv (comma separated value) file that is created in your hard drive when you export measurements from the PVA software.

PV Analyzer users typically analyze their measurement results using the Solmetric I-V Data Analysis Tool (DAT), which automates the analysis and reporting process. You can download a free copy of the DAT by visiting *www.solmetric.com/pva-analysis-macro.html*. To use the DAT, you will first export your Project data from the PV Analyzer, and then import it into the DAT.

When you export Project data, the PVA software creates a Windows folder tree on your hard drive that has the same hierarchy as your Network Navigator system tree. Your I-V trace data is exported to this

folder structure in the form of comma separated value (.csv) files. If you measured strings of PV modules but did not save measurements of the individual modules in the strings, the lower-level directories in your folder structure will contain the string I-V trace .csv files.

When you use the Data Analysis Tool, you can import some or all of this data into the DAT for automated analysis and reporting by simply browsing to the desired level of the folder hierarchy.

It is also possible to view the individual I-V trace data files using a program that can read .csv files, such as Microsoft Excel (tm). This section describes the organization and contents of the .csv file.

Figure 42 shows the header information section of the csv file, and the following table describes its contents.

SOLMETRIC PVA IV DATA	2
Report Date	9/18/2013
Report Time	11:46:31 AM
PC Software Revision	1.1.6798
Project File	County Fairgrounds building A
Array Location	Inverter1-Combiner2-String5
PVA Measurement Uit MAC Address	00158D0000227CE7
SolSensor Uit MAC Address	00158D00001C6707

Figure 42. Header Information section of the exported csv file

Table 13. Description of the Header Information section of the exported csv file

Item	Description
Report Date and Time	When your measurement was made, as recorded from your computer's clock.
PC Software Revision	The version of PV Analyzer software that took this measurement.
Project File	The name of your project file at the time this measurement was taken.
Array Location	The location in the system tree at which the measurement was saved. Normally this maps directly into the hierarchy of the actual array.
PVA Measurement Unit MAC Address	The unique network address of the I-V Measurement Unit
SolSensor MAC Address	The unique network address of SolSensor

Figure 43 shows the cardinal values of the measured and predicted I-V curves. The abbreviations represent maximum power, maximum power voltage and current, open circuit voltage, and short circuit current.

In the PVA's PC software, the value of Pmax is obtained by fitting a third-order polynomial curve to the P-V (Power vs Voltage) curve, and then calculating Vmp (max power voltage) from the peak of the fitted curve. This value of Vmp is then used to interpolate Imp (max power current) from the I-V curve. This method reduces the amount of uncertainty contributed by electrical noise in the current and voltage measurements. The Data Analysis Tool (DAT) re-calculates Pmax for its purposes of charting and reporting data. It optionally fits a fourth-order polynomial, which can result in a very slight difference in Vmp, Imp, and Pmax between the PVA PC software and the DAT.

	MEASUREMENTS	MODEL PREDICTIONS
Pmax	1639.091342	1303.786362
Vmpp	407.1462651	391.6482064
Impp	4.025804685	3.328973146
Voc	514.4149505	517.2308276
Isc	4.695322551	3.879695677

Figure 43. The Measurement vs. Model section of the exported csv file

Figure 44 shows the SolSensor Measurements section of the exported csv file, and the table that follows describes the contents. All of the values were recorded at the time the I-V measurement was made.

SolSensor Measurements	
Irradiance (W/m^2)	607.3874995
Temperature Thermocouple 1 (Deg C)	50.24752808
Temperature Thermocouple 2 (Deg C)	#N/A
Pitch (Deg)	15.03951045
Roll (Deg)	-0.124151007
Tilt (from pitch and roll above) (Deg C)	15.04001105

Figure 44. The SolSensor Measurements section of the exported csv file

Table 14. Description of the SolSensor Measurements section of the exported csv file

Item	Description
Irradiance	Value of irradiance measured by SolSensor integrated Silicon photodiode sensor.
Temperature Thermocouple 1	The temperature reading from the thermocouple plugged into SolSensor TC1 socket.
Temperature Thermocouple 2	The temperature reading from the thermocouple plugged into SolSensor TC2 socket.
Pitch	The angle of SolSensor long axis relative to horizontal.
Roll	The angle of rotation of SolSensor about its long axis.
Tilt	SolSensor tilt, calculated from the pitch and roll

Below Figure 45 shows the Model Details section of the exported csv file, and Table 17 that follows explains the contents.

MODEL DETAILS		
Irradiance used in model (W/m^2)	607.3874995	Method: Measured
Cell Temperature used in model (Deg C)	56.04130905	Method: SmartTemp
Tilt use in model (Deg)	15.04001105	Method: Measured
Array Azimuth (Deg)	232	
User Series R (Ohms)	0.059934	
Performance Factor (%)	125.7	
Latitude	39	
Longitude	-122.92	
Time Zone	-8	
Module Mfr	Schott Solar	
Module Model	ASE-300-DGF/42-240	
# of Modules in String	11	
# of Strings in Parallel	1	
Inverter Mfr	Undefined Inverter	
Inverter Model	#N/A	
Wire AWG	10	
Wire Length (ft; one way)	30	

Figure 45. Model Details section of the exported csv file

Table 15. Description of the Model Details section of the exported csv file

Item	Description
Irradiance used in model	The value of irradiance used in the predictive model.
Cell temperature used in model	The value of PV cell temperature used in the predictive model.
Tilt used in model	The value of array tilt used in the predictive model.
Array azimuth	The compass direction the array is facing. 0=N, 90=E, 180=S, 270=W.
User Series R	The resistance of the conductors between the point of measurement and the PV source (typically the home run conductors), calculated from the wiring details entered by the user when the Project was created.
Performance Factor	The ratio of measured to predicted maximum power, expressed in %
Latitude and Longitude	The location on Earth where the measurement was made.
Time zone	The time zone in which the measurement was made.
Model Mfr	Manufacturer of the PV module
Module Model	Model number of the PV module
# of Modules in String	Number of modules connected measured in series.
# of Strings in Parallel	Number of strings measured in parallel.
Wire AWG	Wire gauge of the conductors between the point of measurement and the PV source.
Wire Length	Length (one-way, in ft) of the conductors between the point of measurement and the PV source.

Figure 46 shows the voltage, current, and power data saved from the measurement. The number of entries depends on the I-V curve resolution selected by the user for this particular measurement (default 100 points, user settable to 500 points).

The saved data array does not include the final values of Isc or Voc. The PV model calculates Isc by projecting the first current point onto the vertical (current) axis of the I-V graph. The uncertainty introduced by this step is minimal. The final value of Voc is measured a split second before the start of the I-V curve sweep, using a separate, internal high-impedance voltmeter. This assures that the PV source circuit is truly unloaded when Voc is measured.

IV Measurements:		
VOLTS	AMPS	WATTS
19.39205301	4.695322551	91.05194381
37.82583013	4.65872928	176.2203024
56.13733349	4.636366726	260.2732651
74.14267981	4.618070091	342.3960921
92.20926973	4.599773455	424.1417512
110.1228116	4.585542739	504.9728592
127.8525617	4.567246104	583.9341142
145.5516595	4.546916509	661.8112433

Figure 46. The voltage, current, and power data from the I-V measurement

Basis of PV Performance Predictions

The PVA software predicts the electrical output of the PV source under test (module or string) based on the module performance model parameters, the existing irradiance and temperature, and a number of other factors. The following discussion outlines the process by which SolSensor is calibrated and measures irradiance, and the process by which the PVA software predicts the expected I-V curve.

SolSensor Irradiance Calibration

The SolSensor factory calibration process involves this sequence of steps:

1. Calibration of the electronic tilt sensor.

2. Calibration of the angular response of the irradiance sensor.

3. Calibration of irradiance measurement at air mass 1.0-1.5 and normal incidence, relative to a pair of matched reference sensors

4. The unique calibration coefficients are stored in SolSensor and are transmitted to the PC software on demand.

Irradiance Measurement

SolSensor measurement of irradiance involves these steps:

1. SolSensor is clamped to the module frame, which orients it in the plane of the array.
2. The position of the sun relative to the orientation of the irradiance sensor is calculated based on the array azimuth and tilt and the site latitude and longitude.
3. The irradiance value is temperature corrected based on the reading of a temperature sensor attached to the irradiance sensor and based on the angle of incidence of the irradiance.
4. One of four spectral corrections is applied, according to the array's PV module technology (poly-Si, c-Si, HIT-Si, or CdTe). The corrections are derived from module/sensor spectral overlap calculated by SMARTS atmosphere model as a function of air mass and elevation.

This process yields the effective irradiance incident on the cells in the PV module. Effective irradiance is the portion of the total irradiance that the module can convert into electricity.

Prediction of PV Performance

The PVA software compares the measured I-V curve to the predictions of built-in PV performance models. The Performance Factor is calculated from this comparison. The prediction process involves these steps:

1. User creates a Project and inputs all of the required parameters, including selection of their PV module from the built-in equipment database.
2. The model predicts Isc, Imp, Vmp, and Voc for the current values of irradiance and temperature.
3. Under low light conditions, the prediction is adjusted based on 200W/m2 performance data in the database.
4. The Performance Factor – the ratio of measured Pmax to predicted Pmax - is calculated and expressed in percent.

The Performance Factor is the most important metric of the performance of the PV module or string.

Translation of Measured Values to STC

Measured values of $_{Isc}$, I_{mp}, V_{mp}, and V_{oc} are translated to STC using irradiance and temperature dependence factors stored in the model database, and the translation equations from Chapter 8, Translation of I-V Data to Standard Test Conditions.

Measurement of I_{sc}

The PV Analyzer uses a pre-charge capacitor to start the I-V sweep at a slightly negative voltage, to overcome small voltage drops and transients inherent in the measurement loop and ensure that the true I_{sc} value is measured. Under certain circumstances of PV source under test, this pre-charge may not be sufficient to start the I-V trace at or below 0V. In such cases a small gap occurs between 0V and the first measured I-V pair, and the PVA software estimates I_{sc} by constructing a horizontal line from the first measured I-V point to the vertical axis. The intersection of the horizontal line with the vertical axis is reported as I_{sc}. In most cases this is an extremely close approximation.

There are two types of situations in which this gap near Isc occurs and the approximation is invoked. The first occurs with strings of conventional modules when using 100 point I-V curve resolution. The other occurs when measuring high efficiency modules. The high efficiency modules store a large amount of electrical charge. At the start of the sweep, this reservoir of charge quickly flows into the pre-charge capacitor, stepping its voltage such that the first I-V point is in positive voltage territory. In some instances, especially with 500 points, the first few I-V points may be slightly elevated due to the residual discharge of the PV module capacitance. In such cases you may see a slight, flat plateau in the I-V curve just above 0V. This deviation from actual Isc is typically extremely small.

Calibration Verification

The PV Analyzer includes a dialog called *Calibration Verification* as shown below. Accessed via the Utility menu, this dialog displays continuous measurements of voltage, irradiance, thermocouple 1, thermocouple 2, and tilt. These values can be used to verify the calibration and accuracy of the PVA sensors. Current is not displayed because it cannot be measured statically by the PVA the way the other values can. Adjustment to the calibrations mush be performed by Solmetric.
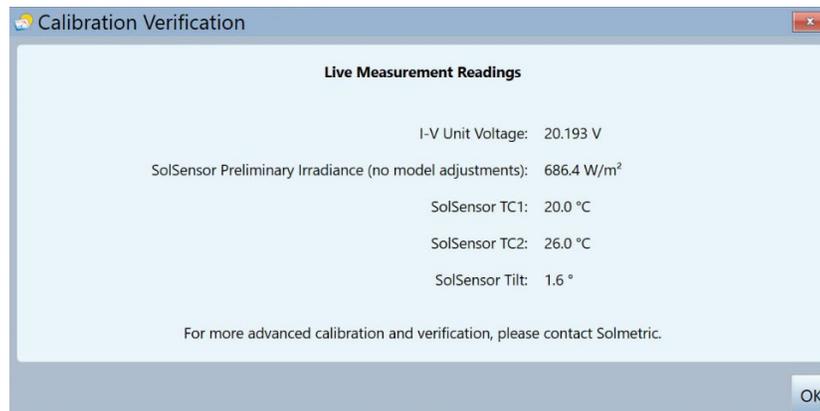
Figure 47. Calibration Verification dialog

PVA PC Software Updates

Solmetric website periodically posts notices of software updates. It's a good idea to check this from time to time by visiting Solmetric.com. Select Support, then Downloads, then select the link *PV Analyzer software and documentation*. You'll see a link to download the current software, and the current version number. Compare that version number with the version you are running, which is found by selecting Help, then About. If you want to update, just download the newer version and run the installer. It is free and takes only a few minutes.

PVA-1500 and SolSensor 300V2 Firmware Updates

The firmware of the PVA-1500 and SolSensor 300V2 can be updated in the field. The PVA-1500S and SolSensor 300 can be upgraded to a PVA-1500V2 and SolSensor 300V2 with a one-time return to factory for installation of field-upgrade-capable firmware and then they will be able to receive field firmware updates. Contact Solmetric *www.Solmetric.com* for assistance.

The field firmware update process works in the following way. When your PC is Internet connected and you launch PVA software version 4.5 or higher, the software downloads the most recently available firmware versions for the I-V Measurement Unit and SolSensor. Then the next time your PC is Wi-Fi connected to the two instruments, the PC software reads their current firmware versions and checks whether they are running the most recently available firmware. If not, the software recommends running the update, which takes less than 2 minutes per instrument and does not require an Internet connection. If your SolSensor is not with you, or is not turned on or within Wi-Fi range when you running the firmware update process, only the I-V Unit firmware will be updated, and you will have another chance to update SolSensor's firmware next time it is wirelessly connected to the I-V Unit.

If your instrument is a PVA-1500S with SolSensor 300, and your instrument's firmware is less than version 1.1 (the first version that's capable of field firmware update), the PC software recommends returning the instruments to Solmetric for installation of field update-capable firmware. You have the option to do so or not. The following table summarizes your options:

PVA PC Software Version	PVA-1500S IV-Measurement Unit Firmware Version	Firmware is Field Upgradeable	Requires return to factory for upgrade
≥ 4.5	1.1 or later	Yes	No
≥ 4.5	Earlier than 1.1	No	Yes*

* If you want to be able to upgrade your firmware in the field, you need to return your instruments to Solmetric for a one-time installation of the field-update capable firmware.

To manually check which versions of firmware your I-V Unit and SolSensor are running, launch your PVA software, wirelessly connect to the instruments, select Help, then selext Connected Measurement Devices. It is a good idea to frequently launch your PVA software while Internet connected, so that you'll see notices of PC software updates and your PC will be able to download recent firmware updates and have them ready to update your instruments in the field.

4 Making Measurements

Introduction

Follow these steps to perform measurements in the field. Also see the Quick Reference Card, located in the gear pouch of the I-V Measurement Unit.

Before you go to the field to make measurements

Charge the equipment

Before going to the field to make measurements, charge both the I-V Measurement Unit and SolSensor overnight. When the PVA-1500 I-V Unit and SolSensor are not connected (via Wifi) the LED will blink when it is charging and go solid when fully charged. If the I-V Unit and SolSensor are connected and the app is running, charging icons will appear in the upper right corner when charging as shown in Figure 48. If the internal temperature of the I-V unit is too hot (e.g. due to having taken many high voltage I-V sweeps and/or hot environmental conditions), the battery will not charge and the icon will have a red 'X' through it as shown in Figure 49. The SolSensor may also be in an over-temperature state, although its less common than for the I-V Unit. The equipment typically runs for 8 hours on a charge. Turn the equipment off when not in use.
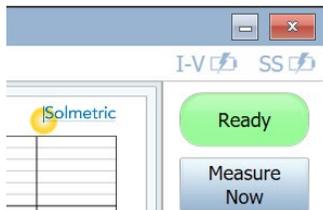
Figure 48. Charging icons
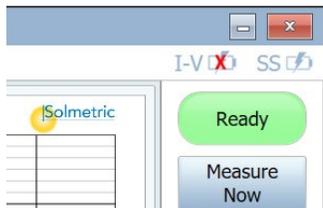
Figure 49. Over-temp charging icon

Check that you are using the latest PVA software

Double click the PVA icon on your PC and the software will start. Click on About in the Help menu to make sure that you have selected the right version of software for the version of PVA hardware that you will be using. The PVA-1500 uses version 4.x software or later. To check the latest available version number, visit *http://www.solmetric.com/downloads-pva.htmlhttp://www.solmetric.com/downloads-pva.html*.

Create a Project in the PVA software.

See the earlier chapters in this User Guide for instructions.

It is best to do this at the office where you have an internet connection and engineering drawings of the PV installation.

Make sure that the Array Tree you create accurately represents the architecture of the PV system. It is not practical to later make any major changes in the Tree of a large system; it is easier to start from scratch, but this will erase data you have already taken.

Make sure you have all your equipment

Personal Protective Equipment

I-V Measurement Unit in its soft case, with a complete set of Solmetric-provided gear either in its gear pouch or transit case. Check for PVA test leads and PV connector tools.

SolSensor with a complete set of Solmetric-provided gear either in its gear pouch or in the transit case. The pouch should contain, a special bar clamp for mounting SolSensor on the side of a PV module frame, thermocouples for measuring PV module backside temperature, discs of green high-temperature tape for attaching the tip of the thermocouple to the module backside, purified water and cleaning cloth for cleaning the irradiance sensor, and a special tool lanyard to secure SolSensor to the racking.

Windows Tablet or Laptop with WiFi and the PVA App loaded.

Assure adequate irradiance for your measurements

Performance measurements are best performed in the range of 700-1000 watts per square meter. If possible, choose a day when the skies will be clear. If there are clouds, try to trigger your measurements at moments when there are no clouds near the sun. Also try to do your measurements in a 6-hour window centered on solar noon.

If you are measuring a horizontal single-axis tracker, you can set up the Project to allow the tracker to keep running as you do your measurements. This provides a more consistently high irradiance during the day.

Making Measurements in the Field

Measure the open circuit voltage Voc

If the open circuit voltage Voc of the PV source circuit exceeds the I-V Measurement Unit's maximum DC input voltage specification, your instrument may be damaged. Before starting your measurements at a new PV field, make sure Voc is within the instrument's DC voltage range by measuring a string with a properly rated Digital Multimeter. This simple step can prevent damage to your instrument and save you a lot of time.

Place the I-V Unit near the PV circuits to be measured

Locate the I-V Unit at the combiner box or inverter.

It is ok to place the I-V Unit on the ground, or leaning against a post, or on top of a fiberglass enclosure. If you place the I-V Unit on an extended metal surface like a metal roof or HVAC unit, it may reduce the wireless range.

Connect the test leads to the PVA

With the PVA-1500HE, slide open the banana jack dust cover and connect the banana jacks to the I-V Unit: red to red and black to black. There are two types of test leads: banana to alligator clip and banana to MC-4.

With the PVA-1500S/V2/V3/V4/T connect the PVA test leads to the connector-saver PV jumpers that are already attached to the I-V Unit's main leads, red to red (positive polarity) and black to black (negative polarity). Do not remove these jumpers except to replace them after approximately every 100 connections. This will greatly extend the life of the main lead connectors. Also, keep all PV connectors out of the dirt.

Connect the alligator clips to the ends of the test leads. Be sure to use only the Staubli Dolphin Clips supplied by Solmetric with your PVA.

Launch the PVA software

Double click the PVA icon and the software will start.

Make sure that you are running the most recently available version of software. To check your current software version, click About in the Help menu. Compare it with the most recently available version, which you'll find at: *www.solmetric.com/downloads-pva.html*. You'll see a link to download the current software, and the current version number. All models of the PVA that use SolSensor use version 4.x software.

Load your Project

Select your Project from the File menu in the PVA software. This Project must have been created specifically for this PV installation.

Mount SolSensor

Attach SolSensor to a PV module frame using the provided bar clamp. It must face in the same direction as the PV module itself.

Remove the black rubber cover (like a lens cap) that protects the irradiance sensor (the small white disc). Never touch this disc, it is a highly sensitive optical instrument.

If there is dirt anywhere on the top or sides of the small white irradiance sensor disc, hold the body of SolSensor in your hand, rotate it so the irradiance sensor facing downward, spray up at the irradiance sensor with purified water, and let the water carry the dirt downwards, away from the irradiance sensor. Then use the special microfiber cloth to wipe away the excess moisture. A spray bottle of purified water and a microfiber cloth are provided in the SolSensor gear pouch.

Attach SolSensor thermocouple

You will need to use a thermocouple on the backside of the PV module even if you are using the SmartTemp temperature measurement method.

Unwind the thermocouple and straighten the lead. Avoid kinking the lead.

Insert its yellow plug in the T1 socket at the end of SolSensor.

Straighten the last few inches of the thermocouple lead. The tiny ball at the end is where temperature is measured.

Place the last few inches of the thermocouple wire against the back of the PV module. Choose a location that is away from the cooler outer edges of the array.

Apply the green disc of high temperature tape to the tip of the thermocouple. Role your thumb over the disc to work out any wrinkles. The tip should be near the center of the disc and in firm contact with the back of the module. Do not use ordinary electrical tape or duct tape, because these will sag with the heat of the module and allow the tip of the thermocouple to pull away from the backside of the module. This causes large temperature errors.

Turn on the I-V Measurement Unit, and connect wirelessly to your PC

Press and release the pushbutton LED.

The PVA-1500 creates a Wi-Fi hotspot. Find and connect to that hotspot in the network list of your PC.

Turn on SolSensor

Press and release the LED pushbutton. SolSensor powers up and starts looking for the wireless network. The LED blinks on and off while searching, and turns steady ON after it connects.

The original SolSensor connects to the wireless USB adapter plugged into your PC or communicates indirectly using the I-V Unit as a relay station.

The SolSensor 300xx (for the PVA-1500) communicates only through the I-V Unit (as a relay station) to the PC.

Prepare the PV source circuits for measurement

If measuring strings at a combiner box, it is safest practice to first turn off the inverter. Then open the DC disconnect to electrically isolate the combiner from the inverter and the rest of the array. Then lift all of the touch-safe string fuses in the combiner box.

If measuring strings at an inverter, shut down the inverter and lift all of the string fuses. You may be able to use the fuse clips as test points to attach the test lead alligator clip. If there is no convenient way to clip in the 'common' lead, you may be able to insert a short-insulated wire pigtail in a spare terminal, and connect the alligator clip to the pigtail.

Are you measuring strings in parallel?

If you are measuring multiple strings in parallel, be sure that the maximum PV current you plan to measure is always less than the specified maximum current of the I-V Measurement Unit. To estimate the maximum current the paralleled strings will produce, measure a single string in full sun, and multiply the measured short circuit current Isc by the number of strings you plan to measure in parallel. Be aware that the maximum total current will increase when the sun is more directly in front of the array, and that in the span of a few seconds, cloud edge effects can increase total current more than 25% above normal clear-sky conditions.

Are you measuring high-efficiency modules?

High efficiency modules have high capacitance which can cause a large in-rush current when I-V curves are measured. The PVA-1500HE is designed to tolerate this in-rush current from PV circuits up to 30 Amps short-circuit current.

The PVA-1500S/V2/V3/V4/T can tolerate this in-rush current from PV circuits up to 10 Amps short-circuit current when the module efficiency is ≥19%. The in-rush current is increased by higher efficiency, higher current strings, higher voltage strings, higher bifaciality, and higher irradiance. For example, a 1350V string of bifacial 21% efficiency modules with Isc of 18A at irradiance around 1000W/m2 will likely cause the over-current warning in a PVA-1500S/V2/V3/V4/T. Lower string voltages can allow currents higher than 10A, even with high efficiency modules, so breaking-up strings to reduce voltage and adjusting tracker orientation for lower irradiance can be an I-V measurement solution in most cases. For more information on high efficiency modules, see the Solmetric app note *I-V Curve Tracing of High Efficiency PV Modules*.

Connect the test leads to the PV equipment

Be sure to observe the correct polarities (connect the red test lead to DC positive, and the black test lead to DC negative).

If you will be measuring circuits at a combiner box, after lifting all the fuses, you can connect the PVA test leads to the positive and negative buss bars. This allows you to insert one string fuse at a time to select the PV circuit you want to test.

If measuring circuits in parallel (for example, strings that are 'harnessed' in parallel out in the array), make sure the combined current is within the specified current range of the I-V Measurement Unit. Note that in some locations, the irradiance can greatly exceed 1000 watts per square meter. If that is the case and the modules are directly facing the sun, the string currents can be significantly higher than the STC currents listed on the PV module label.

Select the first PV circuit to be measured

If you are using the string fuses to select PV circuits, insert the first fuse.

Make your first measurement

Refer to **Figure 50**.
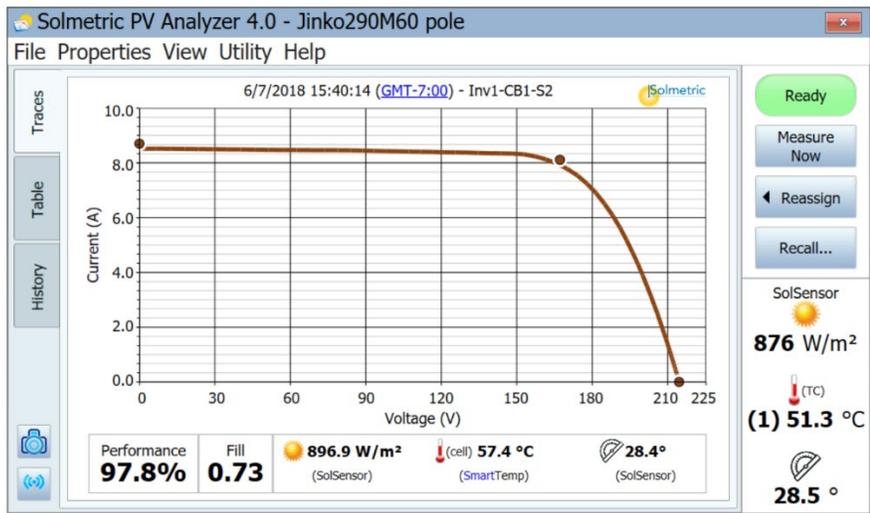
Figure 50. Results of an I-V curve measurement

Press the **Measure Now** button. The measured trace will typically appear in 5-20 seconds.

After the measured I-V curve trace appears, the I-V graph slides to the left and the PV system Array Tree appears at its right.

Navigate to the location in the tree that matches where you are making your measurement. Highlight that branch of the Tree and click the **Assign and Save** button. If you don't want to save the trace but do want the software to compare the measured trace with the predictions of the PV model, instead press the **Assign Only** button.

> When you **Assign and Save**, the software performs a number of checks to automatically detect problems. These are called Alerts. For more information, see the section Alerts.

The Array Tree closes and the I-V curve expands to its full width.

Inspect the curve for abnormal shapes. Also notice the values of the Fill Factor and the Performance Factor below the I-V curve graph. Fill Factor gets smaller if the I-V curve is badly shaped. Expect Performance Factors to be mostly in the 90-100% range for a new, clean array; if the values are way higher or lower than that, check that the irradiance sensor is mounted in the plane of the array, that the computer's date, time, and time zone are correct, and that the 17 PV module parameters are correct, and that your array azimuth and array type are correctly set.

Inspect the sensor values that were saved with the measurement. They appear directly below the I-V curve graph.

Select the next PV circuit and take another measurement

Lift the previous fuse and insert the next one.

Repeat the above steps to make and save your measurement.

Be aware that when your measurements are all finished and the data is exported from the PVA software, the software exports only the last measurement saved to each branch of the Array Tree. If you take some extra measurements while troubleshooting a string that's underperforming, be sure to take one final measurement of the repaired string, for export.

View the consistency of your data before moving on

Before moving to the next combiner box or inverter, click on the History tab and scroll left-to right to see the numerical results of the measurements at this combiner box. Your most recent measurement appears in the left column.

For example, the Voc values should be closely grouped, indicating that the strings all have the right number of modules.

The Isc values should be closely grouped as well, if it is a clear day and the irradiance is nearly constant.

A low Fill Factor means that the shape of the I-V curve is degraded. This can be caused by shading, soiling, or debris or equipment on the modules under test.

It is often helpful to clear the History table before moving on to the next combiner box.

Alerts

After making a measurement, when select **Assign and Save**, the software performs a number of automatic checks to detect potential problems with the measurement setup or with the circuit being measured. These are called Alerts. Table 16 lists the alert types. Some Alerts can be disabled from appearing again within the session (for example, they will not appear until the software is restarted again). The alerts only appear when a project with a model is loaded.

Table 16. Measurement Alerts

Alert	Description
Large deviation in Effective vs Preliminary Irradiance	If the modeled effective irradiance deviates from the preliminary irradiance by more than 25%, the software will display a message like below. This can happen if the longitude, latitude, time/date, or azimuth is incorrect in the **Site Info** or if the SolSensor is not mounted in the plane-of-array. ⚠ The irradiance (modeled effective irradiance) of 0 W/m² deviates from the preliminary irradiance of 514.334 W/m² by more than 25%. This indicates a possible error in the project's properties or a misalignment of the SolSensor on the array. *Tip: Please review your settings in the Site Info window and make sure all settings are correct. Also verify that your computer is set to the correct date and time.* ☐ **Do not show potential project / system setup problem alerts again for this session** Close
Smart Temp Detected Problem	If the SmartTemp algorithm detects a deviation of more than 8°C between its blended temperature calculation versus the thermocouples, the software will display a message like below. ⚠ The SmartTemp algorithm has detected a potential problem. *Tips:* *• Confirm that any thermocouples being used are attached to the backside of the module.* *• Confirm the Voc and temperature coefficient of Voc in your Module Selection are correct.* *• Confirm that the number of modules specified in the location of the measured string in the Array Navigator is correct.* *• Common module failures that can lead to this include shorted bypass diodes or an incorrect number of modules in the physical string.* ☐ **Do not show potential project / system setup problem alerts again for this session** Close
Large Deviation between Thermocouples	If the deviation between thermoucouple readings is more than 5°C, the software will display a message like below. ⚠ The thermocouple measurements (TC1=28.3 °C, TC2=41.1 °C) differ by more than 5 °C. Confirm that both thermocouples are attached to the backside of the module. If you're using one of the thermocouples to measure ambient temperature, be sure to set the temperature sensor method to use only the thermocouple that is mounted on the module backside. ☐ **Do not show potential project / system setup problem alerts again for this session** Close
No SolSensor Readings	If the SolSensor is not acquiring data or not connected to the PVA App, the software will display a message like below.

Alert	Description
User-Set Threshold Exceeded	If one of the user-defined alert thresholds is exceeded, the software will display a message like below (this is an example of an Isc alert). User Alerts are configured by selecting **Configure Measurement Alert Thresholds** in the **Utility Menu**.
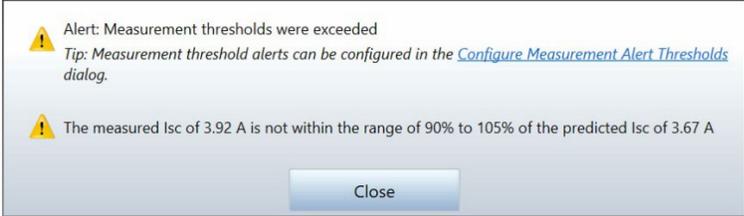
Data backup

The PVA software has an automatic backup feature. By default, it will back up your project every 20 times you save an IV trace. You can enable or disable this, change how often it backs up, or change the backup folder location by navigating to the File menu, then selecting Project Backup Settings… You can also manually create a backup by clicking Create Backup Now.
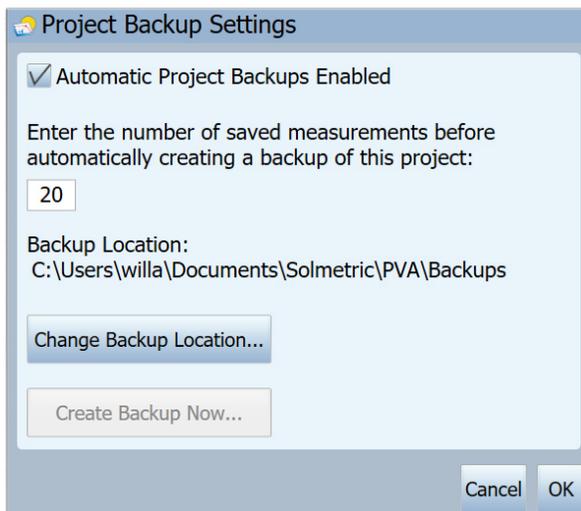
Figure 51. Project Backup Settings

5 Troubleshooting PVA Operation

This chapter describes steps to troubleshoot the operation of the PVA. Troubleshooting of actual PV systems is not included in this discussion.

For tips on setting up Windows for compatibility with the PVA app, and Windows troubleshooting see: *www.solmetric.com/downloads-pva.html*

Troubleshooting Using Status Messages

Your main tool for troubleshooting PVA operation is the Status indicator, shown in Figure 52 and discussed in this chapter.

Figure 52. Status indicator

WARNING	PV circuits will continue to present danger of electrical shock regardless of the active, paused, or disabled state of the I-V Measurement Unit. FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.

"Ready" message

When "Ready" appears in the Status indicator, the wireless link to the I-V Measurement Unit is established and the equipment is ready to take a measurement.

Clicking on the Status indicator in this state pops up a message indicating the present battery voltage compared with the shutdown battery voltage. If you are working with the PVA-1500, it will also indicate the SolSensor 300xx battery level.

"Initializing" message

When the message "Initializing" appears in the Status indicator, the link to the I-V Measurement Unit is established, but the PC software is waiting to receive calibration factors from the link. This typically occurs when the link is first established.

"Measuring" message

When "Measuring" appears in the Status indicator, the I-V Measurement Unit is processing a measurement request and performing an I-V measurement.

"Disabled" message

If the message "Disabled" appears in the indicator panel directly above the Measure Now button, it means that the I-V Measurement Unit has turned itself off because it detected one of the following conditions. Click on the "Disabled" message and follow the instructions. Also see Chapter 3 Software Overview for more details on status messages.

Wireless USB version is incompatible

If this is the case, clicking on the "Disabled" message provides instructions regarding the required version of Wireless USB Adapter. You may also need to update the I-V Measurement Unit firmware (contact Solmetric for support).

I-V Measurement Unit battery voltage is too low

In this case, clicking on the "Disabled" message pops up a caution that the battery level is critically low, and that the I-V Measurement Unit will now shut down. Recharge the battery before further use.

Current in excess of xxA was detected

In this case, clicking on the "Disabled" message pops up text advising that the maximum input current specification has been exceeded. If you are measuring strings in parallel, reduce the number of parallel strings. High-efficiency PV modules and some thin film technologies cause a high current pulse to flow at the start of an I-V measurement. If you are measuring these types of PV modules, do not measure strings in parallel.

Excess voltage was detected

In this case, clicking on the "Disabled" message pops up a warning that the voltage specification was exceeded.

The PVA software checks the DC voltage and will post a "Disabled" message in the status indicator if the voltage exceeds the specified maximum input voltage. If the overvoltage is severe, the software also disables the I-V measurement unit. This condition requires the I-V Measurement Unit to be returned to the factory for inspection and repair.

I-V Measurement Unit is too hot

In this case, clicking on the "Disabled" message pops up a caution message that the I-V Measurement Unit internal temperature is too high and the protection circuit has shut it down. Move the unit to a cooler location out of the direct sun, and allow time for the temperature to drop.

Current overload pulse

In this case, clicking on the "Disabled" message pops up a caution that a significant current overload pulse was detected. Check to be sure the inverter or other parts of the array were not inadvertently connected during the measurement. Also, certain high efficiency and thin film PV modules generate high discharge current pulses. Do not measure these types of modules in parallel or strings of high efficiency modules that are higher than 10 Amps.

"Paused" message

When the message "Paused" appears in the indicator the I-V Measurement Unit has been temporarily stopped because you pressed the LED pushbutton. It is a normal part of the operation of the Unit. In this Paused condition, PV source connections may be changed without interrupting a measurement. To return to the normal state, press the LED pushbutton again.

Clicking on the Status indicator in this state pops up a message listing the present battery voltage compared with the shutdown voltage level. It also advises that the measurement is paused and that PV source connections may be changed without interrupting a measurement.

"Searching for I-V Unit" message

With the PVA-1500 this message is displayed when the PC has not yet connected with the WiFi hotspot created by the PVA-1500 I-V Unit. The I-V Unit's pushbutton LED also blinks rapidly when it is not connected to the PC via WiFi. Make sure that the I-V Unit is turned on and is within wireless range.

"No WiFi connection"

This message appears when the PC WiFi network adapter is turned off. Turn on the Wifi adapter and connects to the PVA1500_yyyyyy hotspot.

"Searching for SolSensor" message and/or " ---- " in SolSensor data display

With the SolSensor, these messages appear in the SolSensor data display area when the SolSensor does not have a wireless link to the I-V Unit (via WiFi for PVA-1500). Make sure the SolSensor is turned on and that it is within wireless range. Obstructions in the line-of-sight can also reduce wireless range.

The SolSensor may recover by performing a hard reset of the SolSensor and I-V unit by holding down the power button for at least 12 seconds on each.

With the SolSensor 300xx it is also possible that it is not properly "paired" to your I-V unit. The SolSensor 300xx units are paired at the factory to the specific I-V unit that shipped with your SolSensor. If you have a new SolSensor that was never paired to your I-V unit, or it has lost its pairing, it may be re-paired to the I-V unit by following the steps in *Operational States of the PVA-1500 I-V Measurement Units*.

Troubleshooting by Symptom

"No I-V Measurement Unit" message

This message in the Status indicator (upper right corner of measurement screen) means that the I-V Measurement Unit is either turned off or is out of wireless communication range.

The message will also appear if the Network ID number of the I-V Measurement Unit and Wireless USB Adapter do not match. See Your Wireless Network for details.

Reduced wireless range can be caused by objects (especially metal) blocking the line-of-sight from PC to I-V Measurement Unit, or by placing either the PC or the I-V Measurement Unit on top of or near metal objects like metal roof surfaces, equipment housings and so on. The corrective action is to clear the line-of-sight and to raise the equipment above the metal surfaces. If these steps do not solve the problem, move the PC closer to the I-V Measurement Unit.

SolSensor parameter values are not displayed

The PVA software displays dashes in place of data in the sensor displays when SolSensor is turned off or out of wireless communication range, or when a thermocouple is not plugged into the yellow sockets labeled TC1 and TC2.

Reduced wireless range can be caused by objects (especially metal) blocking the line-of-sight from PC to SolSensor, or by placing either the PC or SolSensor on top of or near metal objects like metal roof surfaces, equipment housings and so on. The corrective action is to clear the line-of-sight and to raise the equipment above the metal surfaces. If these steps do not solve the problem, move the PC closer to the I-V Measurement Unit. Mounting SolSensor on a tripod in a location with good line of sight to your PC is another alternative.

The SolSensor may recover by performing a hard reset of the SolSensor and I-V unit by holding down the power button for at least 12 seconds on each.

Communication to I-V Measurement Unit or SolSensor briefly drops out

A brief dropout can also occur between the PVA-1500 and your PC. If the link does not restore in 2 minutes, you may be out of wireless range. Similarly, communication with the SolSensor 300xx can also briefly drop out, but should restore momentarily if SolSensor 300xx and the I-V Unit are within wireless range of one another. If the I-V Unit is not wirelessly connected to the PC, the software will also show "Searching for SolSensor" because SolSensor 300xx communicates through the I-V Unit to the PC.

It takes more time than usual to return and save a measurement

The speed depends on the number of I-V trace points selected. Use 100 points for most work, and 500 points when high resolution is required. The resolution can be changed back and forth any time throughout your Project. The resolution control is located in the Utility menu.

The minimum time from measurement to measurement for the PVA-1500 I-V Unit is also affected by the open circuit voltage of the strings under test. Higher voltages mean more energy transferred to the I-V Unit with each measurement, and therefore more rapid temperature rise within the I-V Unit. To allow this heat to dissipate, a delay is inserted by the software in between I-V sweeps. The delay increases with higher Voc.

I-V curve does not reach down to the X-axis

This type of trace may be seen if you have been measuring an I-V curve with a large step in the current.

I-V trace consists of straight line segments

This is normally a result of the PVA software not having a prior I-V curve upon which to base the optimization of internal circuits. Just re-take the measurement and the I-V curve will be normal.

Trace is noisy

Noisy I-V curve traces may be a result of low irradiance, especially for PV technologies with very low short circuit current. For best results, perform measurements of fixed arrays during the hours of maximum irradiance. Strings of low I_{sc} modules can be tested in parallel to increase current and reduce noise.

I-V curve drops to zero current at one or more points

This can occur if there is an unstable electrical connection in the PV circuit being measured. This is not a problem with the I-V Measurement Unit. In stages, remove modules and cables from the PV source circuit to locate the unstable connection.

Short circuit current is much higher, or lower, than predicted by the model

Verify that the irradiance sensor is mounted in the plane of the array. Check for array soiling. Check that the latitude, longitude, and azimuth are correctly entered in the Site Info screen, and that the computer date and time are correct.

Unstable voltage message

Before performing a sweep, the PVA measures V_{oc} 10 times to get an average value. If there is a large variation of values across these 10 measurements, the software posts a warning. Check for poor connections anywhere in the measurement loop.

I-V Measurement Unit cannot be turned on

Check that the Unit has been charged.

Thermal fuse

The I-V Measurement Unit contains a thermal fuse set to trip if the inside of the I-V unit exceeds 85°C. This is an uncommon occurrence because the software is programmed to dis-allow measurements when the internal temperature exceeds approximately 70°C. However, if the thermal fuse trips, it irreversibly shuts down the Unit and requires a return to factory. If you suspect that this has occurred, contact Solmetric Technical Support.

For un-answered questions or guidance, feel free to contact us.

Solmetric Technical Support
Phone: 707-823-4600
Toll Free: 877-263-5026
Email: _support@solmetric.com_

6 Measuring Irradiance, Temperature, and Tilt

Introduction

Thorough evaluation of array performance by any measurement method (I-V curve tracing or conventional methods) always involves comparing measured I-V data to some form of reference. That reference may be anything from a simple STC maximum power value to a detailed PV performance model. In any case, you will need to know the irradiance in the plane of the array and the array temperature in order to properly evaluate array performance against your reference.

Measuring irradiance and array temperature sounds easy, but in practice, a number of factors must be considered in order to assure good measurement results. This chapter provides the background you'll need to make informed choices for your specific application.

Measuring irradiance presents a number of requirements and challenges:

- Irradiance must be measured in the plane of the array (POA)
- Irradiance may not be uniform across the surface of the array due to shading and albedo effects, as well as local cloud effects
- Irradiance can vary rapidly
- Irradiance sensors may have different spectral responses than the PV modules themselves
- The solar spectrum is shifted significantly early and late in the day
- The shape of the PV module I-V curve changes at low irradiance levels

Each of the above topics is discussed in this chapter.

The temperature parameter of interest to the PV model is the average temperature of the PV cells in the string or module under test. In practice, determining the average cell temperature poses a number of challenges:

- The PV cell is embedded in other materials, so measuring the cell temperature by direct contact is not possible.
- The materials in which the PV cell is embedded have poor thermal conductivity, so there can be substantial temperature drop between the cells and the module's front side or back side.
- Temperature offset between PV cell and module backsheet depends on racking configuration and ventilation as well as current irradiance.
- Temperature is not uniform across a PV module or array, due to variations in racking configuration and ventilation.
- Temperature at a given location may vary with time, even at constant irradiance, due to convection currents and wind.
- An air gap between a backside temperature sensor and the actual backside surface results in significant temperature error.
- Massive temperature sensors, particularly bulky RTD devices, do not track rapid changes in module temperature.

- Surface and material issues limit the accuracy of infrared temperature measurements.

Each of the above topics is discussed in this chapter.

The PVA software provides multiple methods for measuring irradiance, temperature, and tilt, as shown in Table 17.

Table 17. Sensor Choices

Irradiance	Temperature	Tilt
SolSensor	SmartTemp	SolSensor
From I-V curve	From I-V curve	Manual entry
Manual entry	Thermocouple 1	
	Thermocouple 2	
	Average of TC1 and TC2	
	Manual entry	

You can use any combination of methods depending on the requirements of your application.

Measuring Irradiance with SolSensor

SolSensor irradiance sensor

SolSensor irradiance sensing element is a silicon photodiode with temperature correction. Its spectral response is corrected to match silicon solar cells and its angular response is corrected to provide enhanced accuracy over a broader part of the day.

Preliminary vs Effective Irradiance

SolSensor irradiance measurement is further corrected according to the PV model parameters for the selected PV module. If a Project and model have not yet been created, SolSensor values do not receive this further correction, and are considered 'preliminary irradiance' values. In this situation, the irradiance value displayed in the live Solsensor readings section on the right of the screen is rounded to the nearest $10W/m^2$ and printed in italics. Once the Project and model are created, the irradiance is displayed in normal font with a resolution of $1W/m^2$. Expect to see slight differences between preliminary and final irradiance based on the corrections. To see the measured (preliminary) irradiance with 1W/m2 resolution go to the *Calibration Verification dialog* under the Utilities menu.

SolSensor Precautions

Protecting the Irradiance Sensor Element

When not in use, always keep the irradiance sensor (white acrylic disc) covered using the supplied black rubber cover. Remove the cover after mounting SolSensor in the plane of the array, and replace the cover again before moving SolSensor to another location.

WARNING	**The white acrylic 'eye' of the irradiance sensor is a precision optical element which must be kept in 'like new' condition to assure accurate measurements. It is easily damaged by impact or abrasion, and its accuracy is also compromised by soiling. Keep the cover on when not in use.**

Cleaning the Irradiance Sensor

The irradiance sensor (white acrylic disc) should be cleaned using only a soft cloth and distilled water. Tip the SolSensor unit on its side so that the irradiance sensor is facing horizontally. Spray the white acrylic disc with a fine mist of distilled water. Let the excess water runoff, carrying dust and dirt with it. Dry the white acrylic disc with a soft, clean, dry cloth. Never use soap or chemical solutions or abrasive cloths.

WARNING	**To clean the irradiance sensor, use only distilled water and a clean, soft, dry cloth. You may damage the sensor element and degrade its accuracy if you use soap or chemical cleaners, or coarse or dirty cloth.**

Orienting and mounting the irradiance sensor

To provide a valid reference irradiance value, the sensor must be mounted in the plane of the array. This assures that the PV modules and the irradiance sensors present the same proportion of their area to the sun at all times of day (a cosine effect) and that reflective albedo effects are as similar as possible.

See for details on mounting SolSensor on the module frame.

NOTE	Mount SolSensor along the upper horizontal edge of the module whenever possible. This allows you to achieve better irradiance accuracy earlier and later in the day, extending the useful work day. It also generally improves wireless transmission distance.

When mounting SolSensor overhead, it is recommended that it be secured to the racking structure using the provided tool lanyard, to prevent injury or sensor damage in the event that SolSensor is dropped.

SolSensor can also be oriented correctly by simply placing it on the surface of a PV module. If you take this approach, be aware that SolSensor is shading cells, which will cause a step in the I-V curve of that string.

Another mounting approach is to place the irradiance sensor on a tripod and orient the sensor to the correct azimuth and tilt. See Mounting SolSensor on a tripod for details.

Albedo effects

PV arrays – and irradiance sensors – can pick up significant amounts of irradiance reflected off of surrounding surfaces. Examples of albedo effects include reflections from adjacent roof surfaces, building walls, and other PV arrays. The strength of the albedo effect is not as much a function of the perceived color of the surface as one might think. Even the surface of a blacktop parking lot reflects substantially.

If your array under test is located in a built-up environment with lots of reflective surfaces, there is not much you can do about it, other than selecting an irradiance sensor location that represents the typical irradiance conditions. Of course, the I-V curve measurements themselves will register the albedo effects. This is another reason for conducting your important performance measurements in the central four hours of the day, when albedo effects are likely to be minimized in relation to the direct irradiance.

Diffuse light

As sky conditions become hazier, a greater fraction of the sunlight is scattered. This scattered or 'diffuse' portion of the irradiance is incident on the array from all directions and angles. Depending on the irradiance sensor construction, highly diffuse irradiance may seriously degrade the accuracy of irradiance measurements. For example, some hand-held irradiance sensors have poor cosine response and their accuracy is specified only for direct normal irradiance, that is, clear days and pointed directly at the sun. Using a similar-technology reference cell will reduce this error, but not eliminate it. The SolSensor irradiance sensor is corrected for angular effects. One of the benefits of this correction is better performance under diffuse light conditions.

Determining Irradiance from the Measured I-V Curve

When you select the **From I-V** option, the PVA software calculates irradiance from the measured I-V curve. This option has several benefits and limitations.

The **From I-V** option provides several benefits:

- There is no time delay between measurement of the I-V curve and determination of irradiance. This is helpful when irradiance is changing rapidly (ramping) due to moving clouds, a condition under which any time delay between I-V and irradiance measurements translates into irradiance error.
- It is useful when measuring cell technologies that have a poor spectral match to the SolSensor silicon irradiance sensor.
- Since the predicted Isc value is forced to agree with the measured Isc value, it is easy to notice any deviations between the shapes of the measured and predicted I-V curves.

The **From I-V** irradiance option also has certain limitations:

- Uniform soiling is interpreted as reduced irradiance and thus does not cause a deviation between the measured and predicted I-V curves. You can mitigate this risk by inspecting the array before measuring, and cleaning it if needed.
- Similarly, uniform degradation of module Isc is also interpreted as reduced irradiance, and thus is not detected. The From I-V temperature option provides several benefits:
- The From I-V irradiance value is used by the predictive PV model to calculate the expected value of Isc. Using a measured value to calculate the expected value is circular, forcing the expected value of Isc to agree with the measured value.

Entering Irradiance Manually

When this option is selected, the user manually enters an irradiance value obtained by another method such as a hand-held sensor or an array mounted reference cell. This option has several disadvantages:

- It is often difficult to accurately orient hand-held irradiance sensors in the plane of the array.
- A greater and more variable time delay between the I-V curve and irradiance measurements translates into irradiance error under conditions of rapidly changing irradiance.
- Hand-held irradiance sensors may have poor accuracy, especially in their cosine response. This introduces very significant irradiance error when the sun is off axis of the array and under diffuse light conditions.

Measuring PV Module Backside Temperature with a Thermocouple

Measurement of backside temperature is one of the traditional methods used by I-V curve tracers. It has several benefits and limitations.

The **Backside Thermocouple** method provides these benefits:

- It is a direct method with no dependence on a PV model.
- It enables you to choose the location for temperature measurement; it's best to choose an average temperature location and avoid locations that are much hotter or much closer to the cooler edges of the array.
- The Backside Thermocouple method has these limitations:
- The predictive PV model wants to know the cell temperature, but the thermocouple measures the slightly cooler backside temperature. The PVA software partially compensates for this by adding up to 3-degrees Celsius to the measured backside temperature. The amount of compensation varies in proportion to irradiance, since at high irradiance the difference between cell and backside temperature is higher.
- Backside temperature varies substantially across a PV module, string, or array. This variation is caused by patterns of convective cooling that depend on degree of ventilation, relative location in the array, and exposure to wind. For this reason, your temperature measurements can be biased higher or lower than actual.

Selecting a thermocouple wire gauge

Choose a relatively fine thermocouple wire gauge, ideally #24 or #30. Some users prefer #24 for extra ruggedness and handle-ability.

There are three reasons for using one of these finer wire gauges.

1. The first reason for this choice is that for accurate temperature measurements, the tip of the thermocouple must be kept in good physical contact with the backside surface. An air gap between thermocouple and backside surface translates into a lower temperature reading. We typically use tape to hold the thermocouple in place, and stiff thermocouple wire is not compliant enough to allow the tape to do its job.

2. The second reason is that because heavier gauge thermocouple wires are more massive, the thermocouple is not able to respond as quickly to temperature variations caused by wind or changes in irradiance. Under changing conditions, a measurement delay translates into a measurement error.

3. The third reason for using a relatively fine wire gauge is that the thermocouple wires themselves drain a small amount of heat away from the tip of the thermocouple. This heat drain causes a slight temperature drop in the module backside material, which has very poor thermal conductivity.

Selecting a thermocouple tip

A variety of tip styles are available. The simple beaded tip is a good choice because it is very rugged and reliable and has relatively low mass, allowing it to quickly track variations in temperature. Lower-mass tips with integral adhesive strips can also be used, but experience has shown that these devices are easily damaged.

Selecting a tape for thermocouple attachment

A good tape for this application will:

- strongly adhere to the backsheet
- keep the thermocouple in physical contact with the backsheet
- meet these objectives at temperatures up to 70 C

A good choice for this application is high-temperature polyester tape (for example: Kapton). The tape should be approximately 2 inches wide, so that you can capture not just the tip of the thermocouple, but also an inch of the thermocouple lead. This tape is also available from Solmetric in spools of 1.75-inch disks for added convenience.

Do not use cheap duct tape, as it sags when hot, allowing the thermocouple tip to pull away from the surface.

Attaching the thermocouple to the module backside

Cut a fresh 2" length of tape or use a fresh tape disk. Place the thermocouple bead in the center of the tape. Press the tape firmly against the backside of the PV module, applying pressure first over the thermocouple, then over the thermocouple lead, and then press down the rest of the tape. Press once more on the thermocouple bead to be sure it is in firm contact with the module.

When testing flush mounted arrays, you will be reaching under modules to attach the thermocouple. Since you can't inspect the attachment, it's a good idea to practice your technique on a free-standing module. Make sure that your tape is always fully adhered, and that the thermocouple bead is always firmly pressed against the surface. If there is a wrinkle in the tape at the location of the thermocouple bead, start over.

Choosing a location to mount the thermocouple on the module or array

Even on a windless day with steady irradiance, there will be a temperature gradient across the module or array, with the edges typically run cooler than the middle. Some guidelines apply.

When testing a single, isolated, tilted-up module, mount the thermocouple on a diagonal line of the module, 2/3 of the distance from the corner to the middle of the module. Experience has shown this to be representative of the average cell temperature.

When testing a flush-mounted array in which you have access only to the outer modules, mount the thermocouple at the middle of a module. If you are reaching under from the narrow end of the module, mount the thermocouple as far under as you can comfortably reach and manage a good attachment.

When testing a tilt-up array, mount the thermocouple well away from the edges of the array.

If you are measuring multiple subarrays, strings, or modules and plan to compare their results, your comparison will be more reliable if you always mount the thermocouple in the same relative position. Even though the resulting temperature may not exactly represent the average cell temperature, you will at least avoid introducing a random, location-related temperature error to the family of measurement results.

Measuring PV module temperature with an infrared thermometer

Some competing measurement solutions rely on infrared measurements of module temperature. This approach has serious limitations, which are discussed here because the PVA software allows the user to manually enter temperature values from hand-held sensor devices.

Since the IR thermometer determines temperature by sensing radiant energy emitted by the object being measured, the accuracy of the temperature measurement depends on how closely the emissivity control setting of the instrument matches the actual emissivity of the object. The emissivity of a material is a measure of its relative ability to emit energy through radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature. A true black body would

have an ε = 1 while any real object would have ε < 1. In general, the duller and blacker a material is, the closer its emissivity is to 1. The more reflective a material is, the lower its emissivity. Highly polished silver has an emissivity of about 0.02.

Some IR thermometers allow continuous adjustment for emissivity. Some models provide only a high/medium/low setting, which limits your accuracy. Some use a factory preset emissivity and are not user-adjustable.

PV module backsides do not all have the same emissivity, so you much either adjust the emissivity control of the instrument to match the backside surface or change the emissivity of the backside surface to match the instrument. Flat black electrician's tape is commonly used to achieve high emissivity. Using this technique, you can set your instrument's emissivity control at 1 and have reasonable accuracy.

If you do not use tape, you can calibrate your instrument against another measurement method, usually a thermocouple taped to the back of the same PV cell (see guidelines discussed earlier). Adjust the emissivity until the temperature readings are the same. Keep in mind that this emissivity setting is calibrated only for this particular type of module backside.

When using infrared techniques, module temperature should not be measured from the front side of the module. Glass reflects the heat of other objects, especially the sun. Also, the glass may not be completely transparent to the wavelength of the IR instrument; as a result, the temperature reading will be some function of both the glass temperature and the PV cell temperature.

Determining Cell Temperature from the Measured I-V Curve

When you select the From I-V option, the PVA software calculates the equivalent cell temperature from the measured I-V curve. This option has several benefits and several limitations, all due to the fact that since temperature is calculated mainly from the measured Voc and the resulting temperature value is an input to the PV model, the model dot representing Voc is forced to agree with the measured value of Voc.

The **From I-V** temperature option provides several benefits:

- The resulting temperature value represents the average cell temperature, which is what the PV model needs. The method properly accounts for temperature variation across the module or string under test.
- There is no time delay between measurement of the I-V curve and determination of temperature. This is helpful when module temperature is changing rapidly, a condition under which a time delay translates into a temperature error. Rapid temperature changes can result from variable cloudiness and also from gusty wind.
- Since the predicted Voc value (the right-hand red dot superimposed on the displayed I-V curve) is forced to is forced to agree with the measured Voc value, it is easier to notice any deviations between the shapes of the measured and predicted I-V curves.

The **From I-V** temperature option also has certain limitations:

- The model by which temperature is determined from Voc is valid only at relatively high irradiance. At low irradiance, there is substantial error in the derivation of temperature.
- If the PV source under test has one or more shorted or conducting bypass diodes, the software will calculate a lower-than-actual cell temperature. You can mitigate this risk by comparing Voc values between strings or modules under test. Values should be fairly consistent. If a single string shows a deviation of more than about 10-12 volts, a bypass diode may be turned on or shorted.

- The From I-V cell temperature value is used by the predictive PV model to calculate the expected value of Voc. Using a measured value to calculate the expected value is circular, forcing the expected value of Voc to agree with the measured value.

Using SmartTemp to Measure Cell Temperature

The SmartTemp method uses a blend of the **From I-V** and backside thermocouple methods, taking best advantage of each while avoiding the biggest limitations of each. The blend changes as a function of irradiance:

- At irradiance values lower than 400W/m2, temperature is obtained from the backside thermocouple.
- At irradiance values greater than 800W/m2, temperature is calculated using the From I-V method.
- At irradiance values between 400 and 800W/m2, the PVA software progressively shifts between the thermocouple and From I-V methods.

This strategy employs the From I-V method at high irradiance values where it is most accurate, and relies on the backside thermocouple at low irradiance values where there is a relatively small temperature offset between module backside and cell.

If the software detects a temperature difference of more than 5C between the thermocouple and From I-V methods, it switches to to use just the thermocouple. This reduces the likelihood of temperature errors caused by a missing module or shorted bypass diode.

7 Interpreting Measured I-V Curves

Introduction

A PV module, string, or array has a characteristic curve of current versus voltage; the "I-V curve". The I-V curve represents the entire family of current and voltage pairs at which the PV circuit can operate at the corresponding irradiance and temperature. The PV analyzer's mathematical models predict the shape for this curve for thousands of different PV modules and configurations. Occasionally the shape of the measured I-V curve will deviate substantially from the shape predicted by the model. These deviations contain information about the performance of the PV System and provide important clues for troubleshooting performance issues. This section describes the most common patterns of deviation and identifies the most likely causes for these deviations.

Inputs to the PV Model

The modeling features of the PV analyzer predict the shape of the I-V curve for comparison with measured results. For the prediction to be valid, the inputs to the model must be valid. The model inputs are:

- PV model parameters stored in the PVA PC software
- Number of PV modules in series
- Number of PV modules or strings being measured in parallel
- Length and gauge of wire between the PV modules and the PV analyzer
- Irradiance
- PV cell temperature
- Array azimuth and tilt
- Latitude and longitude
- Date, time, time zone, and daylight savings information

I-V Curve Terminology

These abbreviations will be used in the following discussion:

Isc   Short circuit current

Imp   Max power current

Vmp   Max power voltage

Voc   Open circuit voltage

PF   Performance Factor (PF, %) = 100 * (Measured Pmax/Predicted Pmax)

FF   Fill Factor = Imp * Vmp / (Isc * Voc)

Performance Factor

The Performance Factor is the most important figure of merit for PV array performance. The Performance Factor is defined as the measured maximum power value divided by the predicted (modeled) maximum power value. Its range is 0 to 100%.

The predicted maximum power value is determined by the PV model, which takes into account the existing values of irradiance and temperature. This means that Performance Factor is meaningful over a range of irradiance and temperature. Like most array performance measurements, the comparison is more accurate if the irradiance levels are high. Performance measurements taken at less than 400W/m2 irradiance are not good predictors of how the string will perform at high irradiance.

If a PV string or module is operating correctly and is not shaded, soiled, or age-degraded, and is measured at high irradiance, the measured Performance Factor will typically be in the range of 90-100%. If the irradiance is stable and the array temperature is not changing rapidly, the measured I-V curves should be very consistent from string to string.

Fill Factor

The Fill Factor is a valuable measure of the square-ness of the knee of the I-V curve. It is defined by three points on the I-V curve, as shown in the figure below. The Fill Factor range is 0 to 1.0, and the closer the Fill Factor is to 1.0, the closer the shape of the I-V curve approaches a perfect rectangle. Each PV technology has its own nominal range of fill factor values, and each module model number typically has a narrow nominal range.
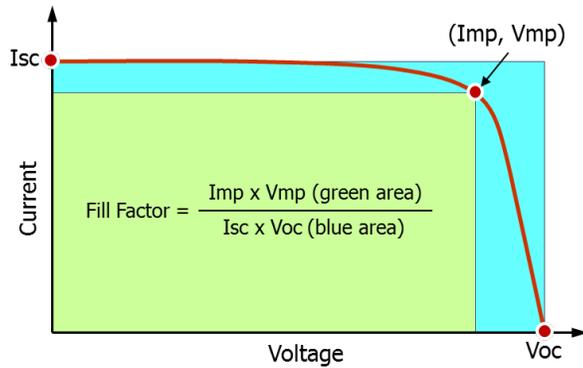
Figure 53. Definition of the Fill Factor.

Fill Factor does not vary much with irradiance so long as the irradiance is high, which means that comparing Fill Factor values is a good way to assess the consistency of I-V curve shapes in variable (but high) irradiance situations.

The Shape of a Normal I-V Curve

The figure below shows a normal I-V curve (red line), as a starting point for the discussion. The predicted I-V curve shape, determined by the PVA built-in PV model, is shown by the three dots representing Isc, (Imp, Vmp), and Voc. The power versus voltage curve can also be displayed. Like the I-V curve itself, the P-V curve represents the entire family of points at which the PV circuit could be operated at the measured irradiance and temperature. The P-V curve is generated by multiplying I x V for at every point on the I-V curve.
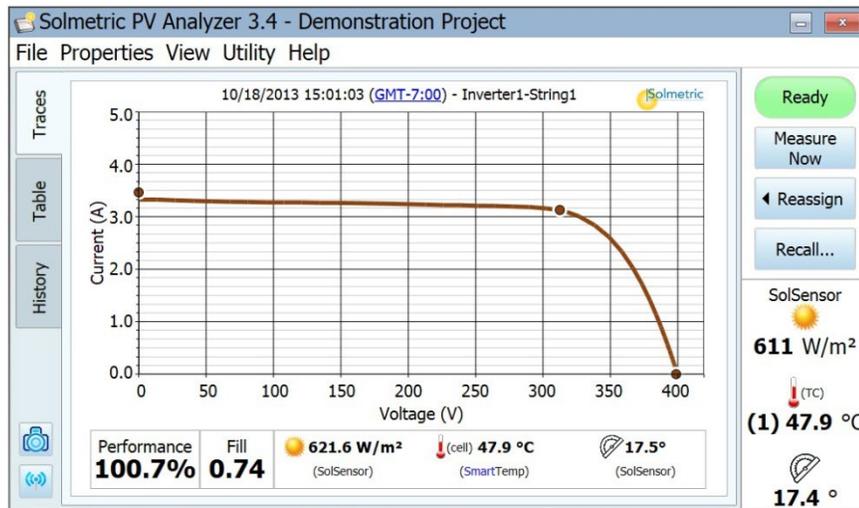
Figure 54. A normal I-V curve for the parallel combination of two strings of eight 175-watt modules, compared with the three points predicted by the PV model.

A normal I-V curve has a smooth shape with three distinct regions as shown in the figure above.

1. A slightly sloped horizontal leg of the curve

2. A steeply sloped leg of the curve, often informally referred to as the 'vertical' leg

3. A 'knee' in the curve between these two regions

In a normal curve, the three regions are smooth and continuous. The shape and location of the knee depends on cell technology and manufacturer.

The three PV model points are defined, from left to right, as follows:

1. Isc – First point, at the predicted short circuit current Isc

2. MPP – Second point, the predicted maximum power point Imp, Vmp

3. Voc – Third point, at the predicted open circuit voltage Voc

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Interpreting I-V Curves

PV module or string performance problems will cause deviations between the measured and predicted I-V curves. There are six distinct types of deviation, listed below and in the following figure. A given PV source under test may show no deviation, one deviation, or a combination of two or more deviations.

1. Notches or steps

2. Low current

3. Low voltage

4. Rounder knee

5. Steeper slope in horizontal leg

6. Less steep slope in vertical leg
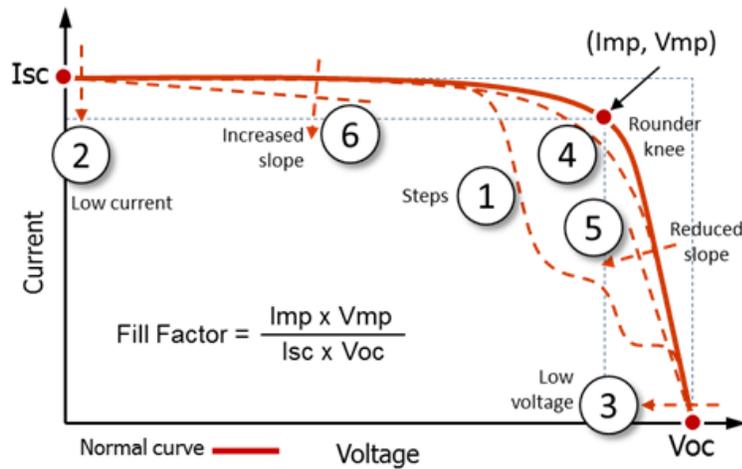
Figure 55. Deviations in the shape of the I-V curve fall into one (or a combination) of these six categories

It would be convenient if each of the I-V curve deviations illustrated in Figure 55 corresponded to a unique physical cause. In fact, there are multiple possible causes for each.

NOTE	Deviations from the predicted IV curve may be due to physical problems with the PV array under test or may be the result of incorrect model values, instrument settings, or measurement connections. Always select the correct PV module from the on-board PV module list, double check the measurement connection, and ensure that irradiance measurements are taken in the plane of the array and are as simultaneous with the I-V sweep as possible.

Small deviations between the measured and predicted I-V curves are very common given the uncertainty associated with the irradiance and temperature measurements and the fact that PV modules, even of a given manufacturer and model number, are not all identical. Shading and soiling will also have effects, which are not taken into account in the PV model.

Potential causes of substantial deviations between measured and predicted I-V curves are discussed below.

1. Notches or steps

Examples of this type of deviation are shown in Figure 56, Figure 57, and Figure 58.
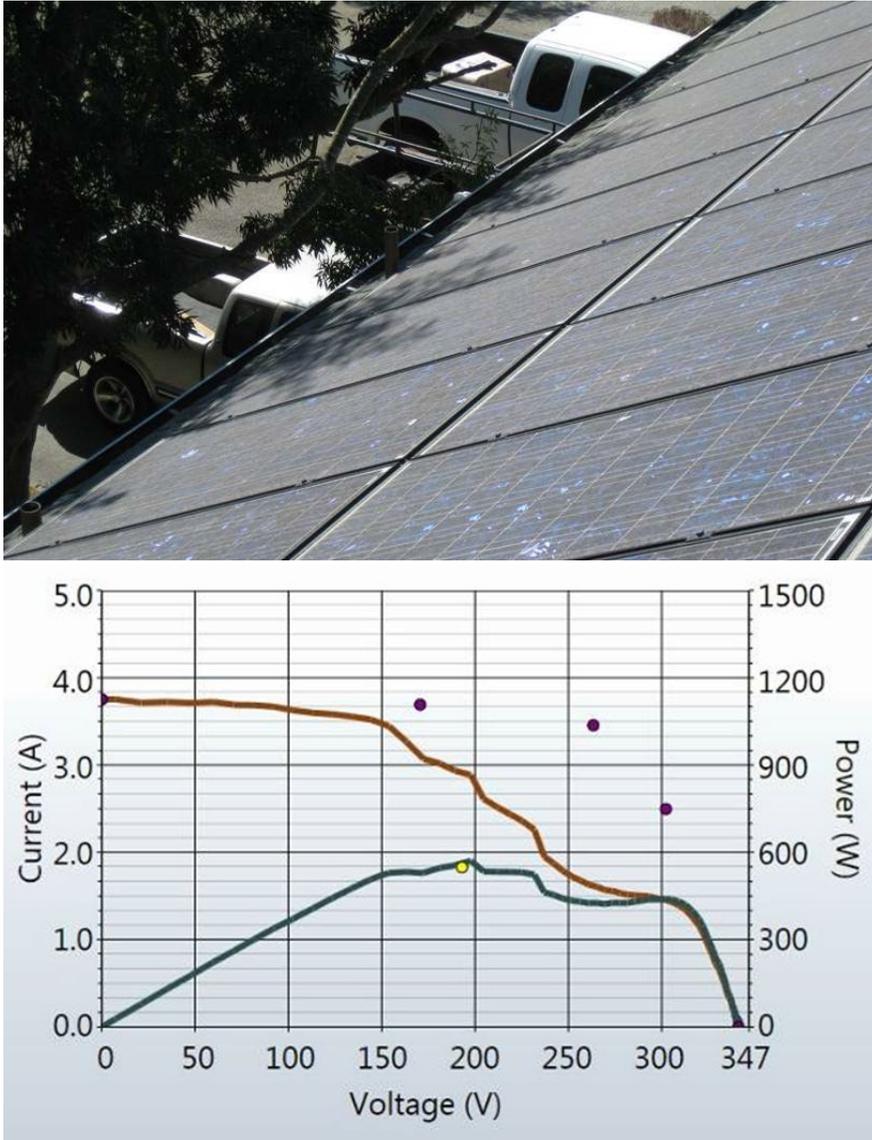
Figure 56. The effect of partial shading on a string I-V curve.
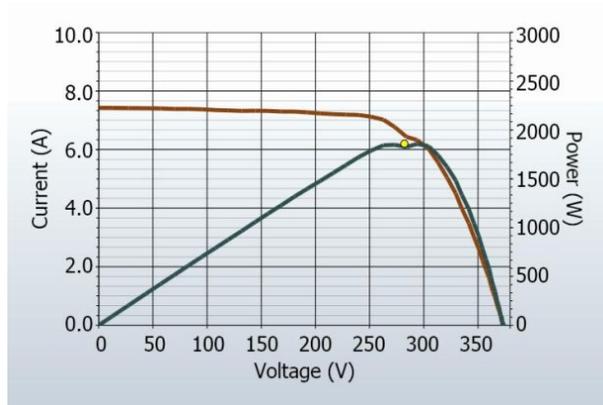
Figure 57. The shading impact of placing a business card on a single cell in a string of fifteen 180-watt modules
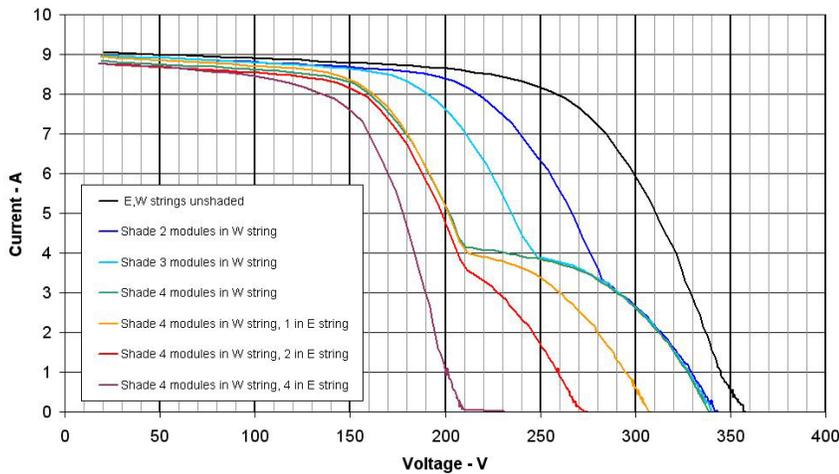
Figure 58. The effect of intentionally shading entire modules in different combinations, in two parallel-connected strings (overlay of several measurements)

In single-string measurements, steps indicate current mismatch between the modules (or cell groups within modules) of the string under test. Although the figures shown above all involve shading, mismatch can have other causes. The notches in the I-V curve are associated with conduction of bypass diodes that protect individual cell groups within modules that are not able to pass the full current of the stronger modules and cell groups.

Potential causes are summarized below, and then discussed in more detail.

- Array is partially shaded, or non-uniformly soiled, or debris is present
- A mix of different PV module specs within the same string
- PV cells are damaged
- Bypass diode is short-circuited (only if measuring strings in parallel)

Array Is Partially Shaded, or non-uniform soiling or debris is present

Partial shading of a PV cell reduces the current capacity of that cell, which, if there were no bypass diodes, would limit the current in the entire string to that level. For example, slightly shading one cell in a 72, 3-bypass diode module will cause that cell's bypass diode to conduct enough current to maintain string current, and avoid damage to the weak cell. Without the bypass diode present, the weak cell would become reverse biased, which could generate potentially damaging reverse breakdown voltage and hotspot failure. The impact of partial shading on the I-V curve is to create a notch. In a single PV string, the depth of the step from normal I-V curve height indicates the severity of the current mismatch, and the width of the step indicates how many cell groups are involved.

PV Cells Are Damaged

There are cell-level failure modes that can reduce the ability of a cell to produce current. Also, cracking of the cell can electrically isolate sections of the cell, This has the same effect on the I-V curve as shading of an equivalent area of a normal cell.

2. Low Current

Potential causes for the measured I_{sc} being higher or lower than predicted are summarized below, and then discussed in more detail:

- Uniform soiling
- Strip shade (uniformly, across all cell groups)
- Dirt dam (uniformly, across all cell groups)
- Module degradation
- Potential causes associated with setup of the PVA Project (related to the PV model that predicts performance
    - Incorrect module is selected for the PV model, or key values are wrong
    - Number of PV strings measured in parallel does not match where the measurement was saved in the array tree
    - Latitude or longitude are not correct
    - The controlling computer's date, time, time zone or daylight savings settings are not right when measurements are taken

- Potential causes associated with irradiance or temperature measurements include:

    - Irradiance sensor is not oriented in the plane of the array
    - Due to cloud effects, the irradianc sensor and the string under test were not seeing the same amount of irradiance
    - Albedo effects (reflection)
    - Irradiance has changed between I-V measurement and manual entry of irradiance value (only an issue if using the Manual irradiance method)

Uniform soiling

The effect of uniform soiling is like pulling a window screen over the PV modules; the overall shape of the I-V curve is correct, but the current at each voltage is reduced.

Strip shade

A constant-width band of dirt across an entire string can also reduce current. Over time, a band of dirt collects at the lower edge of each module. When the band of dirt reaches the bottom row of cells, it begins to limit current. If the dirt bands are similar enough from module to module, the effect is like uniform soiling.

Dirt dam

A constant-width band of dirt across an entire string can also reduce current. The most common example is a low-tilt array with modules in portrait orientation. Over time, a band of dirt collects at the lower edge of each module. When the band of dirt reaches the bottom row of cells, it begins to limit current. If the dirt bands are similar enough from module to module, the effect is like uniform soiling.

Module Degradation

Degradation of PV module performance with time and environmental stress is normally a very slow process. Given the number of measurement technique-related factors that can affect the height of the I-V curve, the operator should consider these factors before concluding that the modules have degraded.

Incorrect PV Module Is Selected for the PV Model

PV modules with similar PV model numbers may have different I_{sc} specifications. Check that the module you selected from the on-board module list matches the nameplate on the back of the PV modules. If the array is known to have a mix of PV modules of different types, this can also contribute to changes in I_{sc}. Mixed modules can also cause a mismatch effect, another class of deviation discussed later.

Number of PV Strings in Parallel Is Not Entered Correctly in the Model

The measured value of I_{sc} scales directly with the number of strings in parallel. Check that the correct value is entered into the model, and that the measurement was saved to the correct branch of the array tree.

Irradiance Changed Between Irradiance and I-V Measurements

The time delay between the irradiance measurement and the I-V measurement can translate into measurement error. The error is greatest when the sky conditions are not stable (for example, partially cloudy) and a manual irradiance sensor is being used. The process of orienting the manual sensor,

noting the value, and entering the value into the PVA software takes much more time than the automated process used by SolSensor.

Irradiance Sensor Is Not Oriented in the Plane of Array

The accuracy of the irradiance measurement is very sensitive to the orientation of the sensor. The PV analyzer's model assumes that the irradiance sensor is oriented in the plane of the array. It is difficult to consistently position hand-held sensors in the plane of the array. To see how much error this can introduce, orient the sensor to match the plane of the array and note the irradiance value. Then remove the sensor and repeat several times within a minute, and examine the consistency of the recorded values. This experiment works only under stable irradiance conditions.

Albedo Effects (reflection)

The energy production of PV modules can be increased by reflection or scattering of light from nearby buildings, automobiles, and other surfaces (the Albedo effect). If the reflection seen by the PV modules under test is the same for all modules, the I-V curve may look normal but I_{sc} may be elevated. If the reflection is not uniform from module to module, the I-V curve may have a mismatch type of shape, discussed later.

Also, in arrays using bifacial modules, the PV model under-predicts Isc because backside irradiance is not measured and not accounted in the model.

Manual Irradiance Sensor Is Not Accurate

Hand-held irradiance sensors vary widely in their calibration accuracy, response to off-angle light, and spectral match to the array being measured. All of these variables affect accuracy.

3. Low voltage

An example of this type of deviation is shown in below.
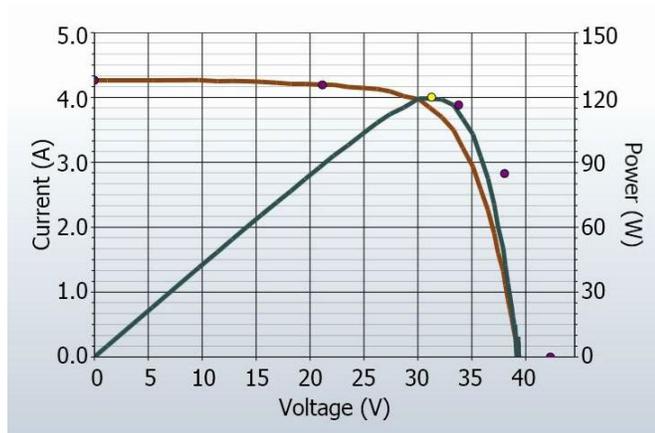
Figure 59. Measurement with less steep than predicted slope in the vertical leg of the I-V curve.

Potential causes are summarized below, and then discussed in more detail:

- Tapered shade or dirt dams extending across all cell groups
- Increase 'shunting' in PV cells

PV Cell Temperature Measurement Is Incorrect

The module V_{oc} is dependent on the temperature of the solar cells, with higher temperatures resulting in a lower V_{oc}. It is possible that a poor thermal connection exists between the thermocouple and the back of the module.

Also, if two thermocouples are plugged into SolSensor an only one of them is attached to the back of a module, the PVA will average the two thermocouple temperatures.

Placement of the thermocouple is also important. It should be placed at a location that represents the average temperature of the modules. Avoid the edges of the table/array; they run cooler because of better air circulation.

One or More Bypass Diodes Are Shorted

This is a possible cause in single-string measurements. In parallel-string measurements it causes a step in the I-V curve.

4. Rounder knee

An example of this type of deviation is shown below.
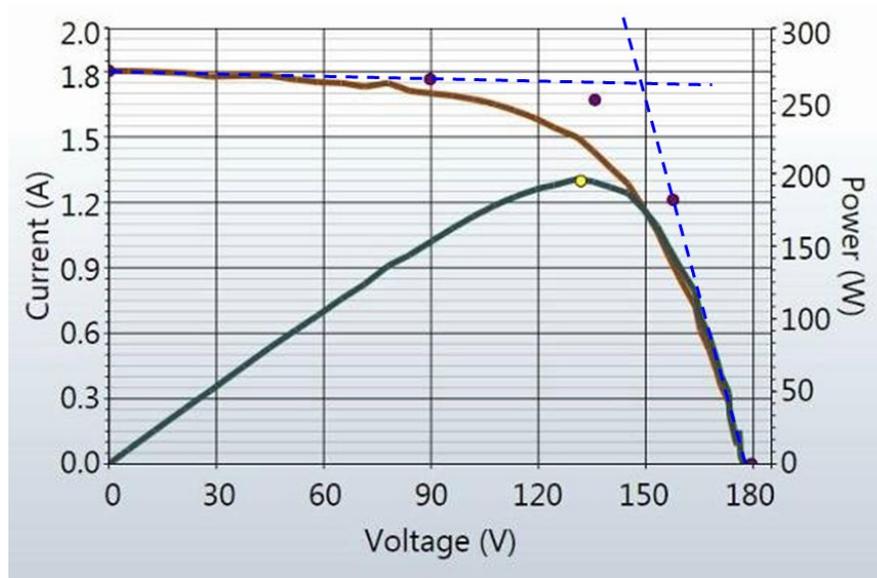
Figure 60. I-V curve measurement showing rounder knee than predicted by the PV model.

Rounding of the knee of the I-V curve can be a manifestation of the aging process. However, this effect is rarely seen, and is usually a side-effect of changes in the slopes of the legs of the curve.

5. Steeper slope in horizontal leg

An example of this deviation is shown below.
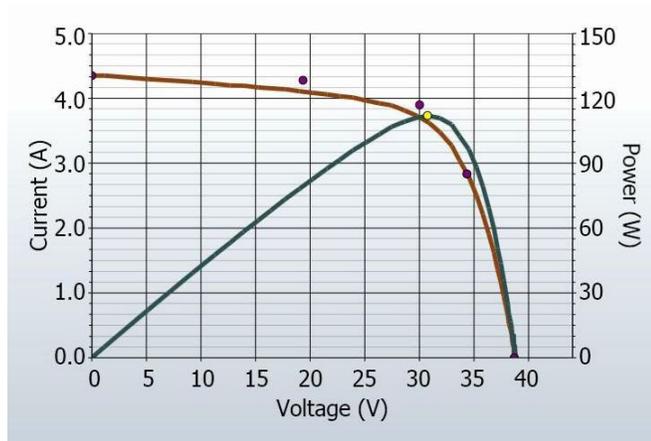
Figure 61. An I-V curve showing steeper slope in the horizontal leg of the I-V curve.

The horizontal leg of the I-V curve may exhibit a steeper slope than the PV model predicts.

Potential causes of this deviation are summarized below, and then discussed in more detail.

- Tapered shade or dirt dams
- Module Isc mismatch
- Shunt paths exist in PV cells

Tapered shade or dirt dam across all cell groups

A tapered band of shade or dirt across the all cell groups can cause the steeper slope in the horizontal leg of the curve.

Increased Shunting in PV Cells

Shunting is the flow of PV current backwards across the cell junction. This is a current loop internal to the cell, which subtracts from the current that it is able to contribute to the string. Some amount of shunt current within a solar cell is normal, and is the cause of the slight slope in the horizontal leg of the curve. But if the shunt resistance of cells degrades to a lower value across the array, the slope of the horizontal leg becomes steeper.

Localized shunt failures cause local heat dissipation, and can lead to runaway thermal failures of the cell and module.

6. Less steep slope in vertical leg

An example of this type of deviation is shown below.
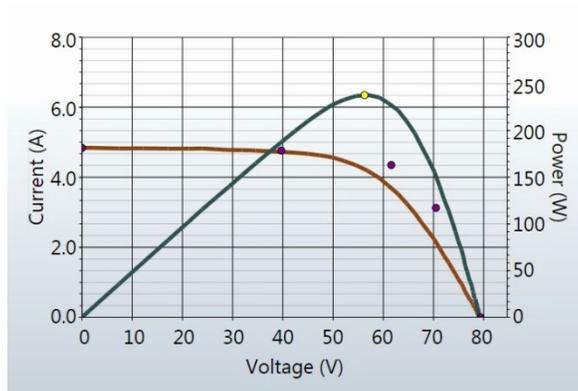
Figure 62. Measurement with less steep slope in the vertical leg of the I-V curve.

The slope of the vertical leg of the I-V curve is affected by the amount of series resistance internal to the PV modules and in the array wiring. Increased resistance reduces the steepness of the slope and decreases the fill factor.

Potential causes are summarized below, and then discussed in more detail:

- PV wiring has excess resistance or is insufficiently sized
- Electrical interconnections in the array are resistive
- Series resistance of PV modules has increased

PV Wiring Has Excess Resistance

During setup of the Project in the PVA software, the user enters the length and gauge of the external, string-related wiring, most commonly the home-run cabling to a combiner box. During measurements, the PV model uses this information to account for expected voltage and power loss in this external wiring, so that it is not associated with the performance of the PV modules. The wire length does not include the length of the cords of the modules themselves. A major difference between entered and actual wire length can introduce excess resistance. To see the effect of wire resistance on the predicted I-V curve, enter 500 feet (1-way) of #10 wire. This adds approximately 1 ohm of series resistance. Notice the change of slope in the I-V curve near V_{oc}.

The resistance of the test leads of the PV analyzer is extremely low and can be neglected.

Electrical Interconnections in the Array Are Resistive

Electrical connections anywhere along the current path can add resistance to the circuit. Assure that connectors between modules are fully inserted. Also check for signs of corrosion in J-boxes and combiners.

Series Resistance of PV Modules Has Increased

Certain degradation mechanisms can increase the amount of series resistance of a particular module. Corrosion of metal terminals in the module connectors, in the module junction box, or on the interconnects between cells may increase series resistance.

Troubleshooting PV Arrays

The following chart shows a method of troubleshooting PV arrays.   For a detailed article on interpreting I-V curve deviations, see SolarPro article, "Solar I-V Curves--Interpreting Trace Deviations"

PV Array Performance Troubleshooting Flowchart

Brought to you by Solmetric
www.solmetric.com

TROUBLESHOOTING TIPS

↓ For best performance measurement accuracy, measure with irradiance > 700W/m² in the plane of the array.

↓ A bad PV module can often be identified without disconnecting modules from one another, using the Selective Shading Method. For a string of N modules, measure the I-V curve N times, applying hard shade to a different module each time. Cover at least two cells in each cell group. Shading the bad module bypasses it and returns a normal curve shape. In the case of a shorted bypass diode, shading the bad module causes a smaller drop in Voc.

↓ See the NREL module inspection checklist at www.nrel.gov/docs/fy12osti/56151.pdf. To contribute to NREL research, send failure observations to Corinne.Packard@nrel.gov.

Mismatched modules?

YES → Cracked cells? — Cracked cells may not be visible to the eye. Find the bad module using the Selective Shading Method. May be cause for module replacement if irradiance appears electrically opaque. Cracked glass is always cause for replacement.

YES → Burn marks? → Replace module

NO → A string of modules with significant current mismatch will show steps along the I-V curve.

Random soiling debris or snow?
YES → Clean modules and re-test

Shading?
YES → Remove obstructions or re-test when un-shaded

Check again for shade. Diffuse shade is hard to detect by eye. Look for more distinct shadows alongside the array. Light reflected from nearby objects can also cause steps. When testing strings is possible a step in the curve can also be caused by a shorted bypass diode.

Save Data & Test Next String

SunEye 210 Shade Measurement Tool

CURRENT
Isc
Max Power Point
VOLTAGE
Voc

Possible cell degradation
(Modality factor) Re-test in future to reveal trend.

Smooth curve but **Low Fill Factor?**

PF > 90% and normal shape?
YES

Steps in the I-V curve?
NO

Low Isc?
NO

Low Voc?
NO

Rounder knee?
NO

Low Voltage Ratio? Vmp/Voc
NO

Low Current Ratio? Imp/Isc
NO

START

Does measurement return a useful I-V curve?
YES / NO

PF = Performance Factor = Pmax (measured) / Pmax (predicted)

Are the test leads connected? Are PV modules interconnected?
YES → No I-V curve? → NO → Drop-outs in I-V curve? → YES → Narrow vertical dropouts (downward spikes) in the I-V curve may be caused by intermittent electrical connections in the PV source circuit. Troubleshoot to locations and repair.

Check for missing or blown fuse, and for open circuit in external string conductors, conductors, overheated module j-boxes, or bad PV connectors. Replace affected modules.

Indicates Possible PV Module Replacement

Possible high series resistance. Check modules and string wiring for bad connections or overheating. Replace affected modules.

Are the home run wire length & gauge correctly accounted for in the PV model?

Tapered shade or soiling across modules?
YES → Re-test clean and un-shaded
NO → Slightly current-mismatched modules? YES / NO

Low by multiple of cell group Voc?
YES → Possibly shorted bypass diode(s), especially if Voc is reduced by a multiple of the Voc of a cell group. Locate shorted modules using Selective Shading Method. Replace affected modules.
NO → Combined with other deviations? YES / NO

Uniform soiling?
YES → Clean modules and re-test
NO → Dirt dams? NO → Strip-shade? YES / NO

Is the irradiance sensor oriented in the plane of the array? Does it have the same view of the sky as the strings under test? Is the correct module selected for the PV model?

A strip of shade or soiling that is consistent across the string can reduce current without causing steps in the curve. Re-test after cleaning or removing shade.

A strip of shade or soiling that is consistent across the string can reduce current without causing steps in the curve.

Is the thermocouple attached at a typical temperature location, and is it contacting the module backside? Is the irradiance high enough for a reliable Voc test?

Tip: Voc normally ages very slowly (adjusted for temperature). Check for other causes before concluding that Voc has degraded.

Possibly Potential Induced Degradation (PID), especially if contributed to with reduced Fill Factor. Replace affected modules.

Replace module or re-test in future to reveal trend.

Possible degradation of cell shunt resistance. Serious shading may be visible to IR imaging or to the eye. May also be symptom of PID. Possible module replacement.

Possible performance degradation. Re-test in future to reveal trend.

Solmetric PV Analyzer™ 1000V I-V Curve Tracer SolSensor™ Wireless PV Reference Sensor Windows™ tablet is user supplied.

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8 Translation of I-V Data to Standard Test Conditions

The PVA PC software provides a feature for translating the displayed I-V curve to Standard Test Conditions (STC) of 1000W/m2 and 25 °C. The software also translates the key performance parameters in the Table view (tab).

The primary application for these features is the analysis of I-V data collected during the commissioning of commercial scale PV arrays. As these measurements are usually performed in a 4-hour time span centered about solar noon, the measured I-V curves reflect the changes in irradiance and cell temperature that take place over this time period. The translation features remove these effects to a first order by translating key performance parameters derived from the I-V curves to STC conditions. Fast changes in irradiance and temperature caused by rapidly moving clouds will be difficult to correct accurately, so clear days are still required for quality end results.

Translation will introduce error in proportion to the span of the translation. This should be taken into account when assessing the consistency of performance across a population of PV strings.

Parameter definitions

The following definitions are extracted from the Sandia PV Array Model (D. L. King) paper:

I_{sc} = Short-circuit current (A)

I_{mp} = Current at the maximum-power point (A)

V_{mp} = Voltage at maximum-power point (V)

V_{oc} = Open-circuit voltage (V)

P_{mp} = Power at the maximum power point (W)

α_{Isc} = Normalized temperature coefficient for I_{sc}, (%/°C). This parameter is 'normalized' by dividing the temperature dependence (A/°C) measured for a particular standard solar spectrum and irradiance level by the module short-circuit current at the standard reference condition, I_{sco}. Using these (%/°C) units makes the same value applicable for both individual modules and for parallel strings of modules.

α_{Imp} = Normalized temperature coefficient for Imp, (%/°C). Normalized in the same manner as α_{Isc}.

β_{Voc}, (%/°C) = Temperature coefficient for module open-circuit-voltage.

γ_{mpp}, (%/°C) = Temperature coefficient for module maximum power point voltage.

T_c = Cell temperature inside module, °C. Obtained by taking the back-surface module temperature from the sensor and adding the temperature differential (typically 3 degrees)

Translation equations

The basic translation model used here makes the following approximations:

P_{mp} is proportional to E, the irradiance

I_{mp} does not depend on temperature

V_{mp} is independent of E

P_{mp} varies with temperature according to γmpp. (taken from the datasheet)

V_{oc} is independent of E

In light of these approximations, we make these assumptions:

I_{sc} scales directly with E and with temperature.

V_{oc} varies linearly with temperature according to β_{Voc}.

P_{mp} scales with E and varies with temperature according to γ_{mpp}

V_{mp} changes with temperature depending on γ_{mpp} only, since α_{Imp} is much smaller than α_{Isc} and is assumed to be zero.

The translation equations are as follows, where the subscripts are defined as m = measured, and trans = translated:

$I_{sctrans} = I_{scmeas} * (E_{trans} / E_{meas}) / (1 + (\alpha_{Isc}/100) * (T_{meas} - T_{trans}))$

$V_{octrans} = V_{ocmeas} / (1 + (\beta_{Voc}/ 100) * (T_{meas} - T_{trans}))$

$I_{mptrans} = I_{mpmeas} * (E_{trans} / E_{meas})$

$V_{mptrans} = V_{mpmeas} / (1+ (\gamma_{mpp}/ 100) * (T_{meas} - T_{trans}))$

$P_{mptrans} = P_{mpmeas} * [E_{trans} / E_{meas}] / (1+ (\gamma_{mpp} / 100) * (T_{meas} - T_{trans}))$