Solmetric PV Analyzer

I-V Curve Tracer with SolSensor™

PVA-1000S, PVA-600+

User's Guide

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2. This license agreement may be modified only in writing and written documentation must be signed by Buyer and Solmetric.

3. In the event of litigation between Buyer and Solmetric concerning the PC Software, Embedded Software, Hardware, or Documentation, the prevailing party in the litigation will be entitled to recover attorney fees and expenses from the other party.

4. This license agreement is governed by the laws of the State of California.

5. Buyer agrees that the PC Software, Embedded Software, or Hardware will not be shipped, transferred or exported into any country or used in any manner prohibited by the United States Export Administration Act or any other export laws, restrictions, or regulations.

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1 Getting Started

Overview

The PV Analyzer is a portable 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 the built-in PV models. Measurement results are easily saved for future reference and analysis. The I-V Measurement Unit is controlled wirelessly by your portable PC via a wireless USB adapter. Wireless interfaces allow you to move around in the immediate work area, and eliminate the trip hazards associated with hard-wired interconnections.

Irradiance and module backside temperature are measured by SolSensor, a wireless PV reference sensor that streams irradiance and temperature data to your PC. The I-V Measurement and SolSensor share the same wireless USB adapter.

This User Guide covers the PVA-1000S and $PVA\text{-}600^+$ I-V Measurement Units and SolSensor.

NOTE: Version 3.x PVA software is not compatible with the Solmetric Wireless Sensor Kit, the predecessor of SolSensor.

Version 3.x PVA software cannot open projects that were created with version 2.x software.

When your PVA software has a wireless connection to a $PVA\text{-}600^+$ I-V Unit, the software does not allow taking fresh measurements (or recalling measurements from) a project created for the PVA-1000S. The same restriction applies in the other direction; when your PVA software has a wireless connection to a PVA-1000S I-V Unit, the software does not allow taking fresh measurements (or recalling measurements from) a project created for the $PVA\text{-}600^+$.

The current-voltage (I-V) curve of a PV module, string, or array provides a detailed description of its energy conversion ability. The curve ranges from the short circuit current (I_{sc}) at zero volts, to the open circuit voltage (V_{oc}) at zero current. At the 'knee' of a normal I-V curve are the maximum power current and voltage (I_{mp}, V_{mp}), the point at which the array generates maximum electrical power. 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 a measured I-V curve is greatly increased when it can be compared with a predicted I-V curve derived from an accurate PV model. Models take 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 models include 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 Array Navigator tool for saving and managing your measurement data. The New Project Wizard guides you in setting up the PV model and customizing the Array Navigator to your project.

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

Computer Minimum System Requirements

- Test and Supported Operating System: Windows 8® ,Windows 7® (32 and 64 bit versions), Windows Vista® (32 bit versions only), Windows XP® SP3
- Two USB Ports (or one USB port if wireless sensors will not be used). A portable USB hub may be used if only one port is available.
- 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: > 1 GB minimum, 2 GB recommended
- Available Disc Space: 100 Mbytes or more

Systems that do not meet these requirements may not operate correctly.

Equipment

Curve Tracer Equipment (PVA-1000S, PVA-600+)

- I-V Measurement Unit

- Soft Case
- Wireless USB Adapter
- PVA Software Application
- AC Wall Plug Charger
- MC-4 to MC-4 Connector-Saver Cable (2)
- MC-4 to MC-3 Adapter Cable (1 set)
- MC-4 connector tool
- User’s Guide (on Installation DVD and accessible via the PVA software)
- Quick Reference Card

SolSensor Equipment

- SolSensor unit
- K-type thermocouple temperature sensors (2)
- Wireless USB Adapter
- Soft Case
- 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-1000S Specifications

Safety Rating: Measuring Category CATIII 600V.

Table 1. PVA-1000S electrical and mechanical specifications

Parameter	Specification
Voltage range	0 – 1000 V
Current range [1]	0 – 20 A
Voltage accuracy (0 to 55C)	±0.5% ±0.25 V
Current accuracy (0 to 55C)	±0.5% ±0.04 A
Voltage resolution	25 mV
Current resolution	2 mA
Measurement duration	4s (typical) [2]
I-V sweep duration [3]	0.05 - 2s. Typically 0.2s for PV strings.
Minimum recommended repetition rate:	15s
Number of I-V trace points	100 or 500 (user controlled)
Wireless range	30 ft. (direct to PC, open line of sight)
Operating temperature range	-10 to +65ºC
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	12 hours of continuous operation; more than 1000 measurement sweeps
Protective features	Over-voltage, over-current, over-temperature, reverse polarity

Parameter	Specification
PV connector	MC-4
Weight	12 lb (including soft case, test leads & charger)
Height	15 in (not including primary PV leads)
Width	8 in (not including handle)
Depth	5 in (not including gear pouch)

[1] Conventional PV modules and strings may be measured in parallel, up to the current limit specified here. High-efficiency modules should NOT be measured in parallel.
[2] Time between pressing "Measure Now" and display of measurement result.
[3] Automatically selected. Measurement sweep time depends upon the characteristics of the test device (PV module, string, or array) electrical characteristics.

PVA-600⁺ Specifications

Safety Rating: Measuring Category CATIII 600V.

Table 2. PVA-600⁺ electrical and mechanical specifications

Parameter	Specification
Current Measurement Range[1]	0 to 20 A dc
Voltage Measurement Range (Voc)	20 to 600 V dc
Load Type	Capacitive (3 capacitance values, automatically selected)
Measurement Sweep Time[2]	50 ms to 240 ms
Measurement Points per Trace (typical)	100
PV Models	Sandia 5-Parameter Simple Datasheet Model (user enters datasheet values)
Wireless Communications Range	10 m typical
Battery Life	≈20 hours (normal use)
Charging Time	6 hours
Operating Temperature	+0 to +50ºC

Parameter	Specification
Storage Temperature	-20 to +60ºC
Operating Humidity	The normal humidity range is 80% relative humidity for temperatures up to 31ºC, decreasing linearly to 50% at 40ºC. Higher humidity levels should not affect the performance or safety of the PVA-600$^+$.
PV Connectors[3]	MC-4
Weight	9.2 lbs (not including weight of the soft case)
Height	15 in
Width	8 in
Depth	5 in

[1] Conventional PV modules and strings may be measured in parallel, up to the current limit specified here. High-efficiency modules should NOT be measured in parallel.
[2.] Automatically selected. Measurement sweep time depends upon the characteristics of the test device (PV module, string, or array) electrical characteristics.
[3] At ends of the primary test leads permanently attached to the I-V Measurement Unit.

SolSensor Specifications

Table 3. SolSensor irradiance specifications

Parameter	Specification
Irradiance	
Sensor type	Silicon photodiode with corrections for temperature, spectral, and angular effects
Measurement range	0 – 1,500 W/m^2
Accuracy	Typically ±2% when used to predict the performance of well characterized poly- and monocrystalline PV modules in mid-day direct sun conditions. 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
Resolution	0.1ºC
Measurement interval	1 s
Tilt	
Sensor type	Electronic
Measurement range	0 – 90 deg from horizontal
Accuracy (0 – 45 deg tilt)	±1 deg (typical)
General	
Measurement synchronization with I-V curve	Typically less than 1s
Wireless range	100m line of sight
Auto-power off time	15 min (after…..)

Parameter	Specification
Operating temperature range	-10 to 65ºC
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	2 lb (not including soft case and accessories)
Height	14 in
Width	4.5 in
Depth	3 in
Ingress protection	IP65

Safety and Regulatory

PVA-1000S Safety and Regulatory

Warnings, Cautions, and Notes

Before operating the PVA-1000S, 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-1000S, use a dry or slightly dampened cloth only.

WARNING	**To prevent electrical shock, disconnect the PVA-1000S 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-1000S have the following markings on the front and/or rear panel. Familiarize yourself with these markings before operating the PVA-1000S.

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

The TUV mark indicates compliance with USA/EU safety regulations.

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.

This symbol marks the position of the power switch.

PVA-600$^+$ Safety and Regulatory

Warnings, Cautions, and Notes

Before operating the PVA-600$^+$, 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-600$^+$, use a dry or slightly dampened cloth only.

WARNING	**To prevent electrical shock, disconnect the PVA-600$^+$ 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-600$^+$ have the following markings on the front and/or rear panel. Familiarize yourself with these markings before operating the PVA-600$^+$.

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

The TUV mark indicates compliance with USA/EU safety regulations.

This symbol indicates compliance with the requirements of CAN/CSA-C22.2 No. 61010-1, 2nd edition, including Amendment 1. This product has been tested to the requirements of CAN/CSA-C22.2 No. 61010-1, second edition, including Amendment 1, or a later version of the same standard incorporating the same level of testing requirements

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.

This symbol marks the position of the power switch.

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 enclosure, 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 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 Precautions/Cleaning section for the proper cleaning process.**

Instrument Markings

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

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.)

This symbol indicates compliance with Federal Communication Commission (FCC) regulations for commercial electronic devices.

Precautions

PVA-1000S Precautions

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-1000S 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 PVA-1000S's own PV connectors. Leave the connector-saver jumpers in place at all times. Make all of your PV circuit connections/disconnections to the connector-saver jumpers, not to the PVA-1000S's own 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-1000S's own 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-1000S in wet environments.
- Do not operate or subject the PVA-1000S 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-1000S.
- Do not use the PVA-1000S 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-1000S by installing connector-saver jumpers. Replace the connector-saver jumpers when they have reached 100 connections.
- Make sure that user-provided cables or clip leads used to extend the test leads of the PVA-1000S are rated to safely handle the PVA-1000S's specified maximum current and voltage.
- When using probes or clip leads, they should be of the insulated type with minimal exposed metal. Keep your fingers behind the insulating finger guards.

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.
- Inspect primary test leads and connectors for damage before using. 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-1000S 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 may produce very high instantaneous current levels at the start of an I-V measurement, and this high current pulse may cause the PVA-1000S's protections circuits to trigger and place the I-V Unit in "Disabled" mode. For this reason, modules of high-efficiency modules (or strings) should not be measured in parallel. Measure only one module or string at a time.

PVA-600$^+$ Precautions

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-600$^+$ 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 PVA-600$^+$ PV connectors. Leave the connector-saver jumpers in place at all times. Make all of your PV circuit connections/disconnections to the connector-saver jumpers, not to the PVA-600$^+$ 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-600$^+$ 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 the user 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-600$^+$ in wet environments.

- Do not operate or subject the PVA-600$^+$ 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-600$^+$.
- Do not use the PVA-600$^+$ 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-600$^+$ by installing connector-saver jumpers. Replace the connector-saver jumpers when they have reached 100 connections.
- Make sure that user-provided cables or clip leads used to extend the test leads of the PVA-600$^+$ are rated to safely handle the PVA-600$^+$ specified maximum current and voltage.
- When using probes or clip leads, they should be of the insulated type with minimal exposed metal. Keep your fingers behind the insulating finger guards.

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 Measurement Unit if it is damaged. Always inspect for damage before using.
- Inspect primary test leads and connectors for damage before using. Do not use if damaged.
- Do not use the I-V Measurement Unit if it is performing abnormally. Contact Solmetric for guidance or return the I-V Measurement Unit to the factory for service.

Battery Precautions

CAUTION	*The PVA-600+ 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 may produce very high instantaneous current levels at the start of an I-V measurement, and this high current pulse may cause the PVA-600+ protections circuits to trigger and place the I-V Measurement Unit in "Disabled" mode. For this reason, modules of high-efficiency modules (or strings) should not be measured in parallel. Measure only one module or string at a time.

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

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

1. Insert the PVA software DVD into the DVD drive on your Windows® computer.

2. If the welcome screen does not automatically open as shown in Figure 1, either double-click on the **setup.exe** file on the DVD or run **setup.exe** from the **Run** dialog. Alternately, the installation file is available at www.solmetric.com.

Figure 1. 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.

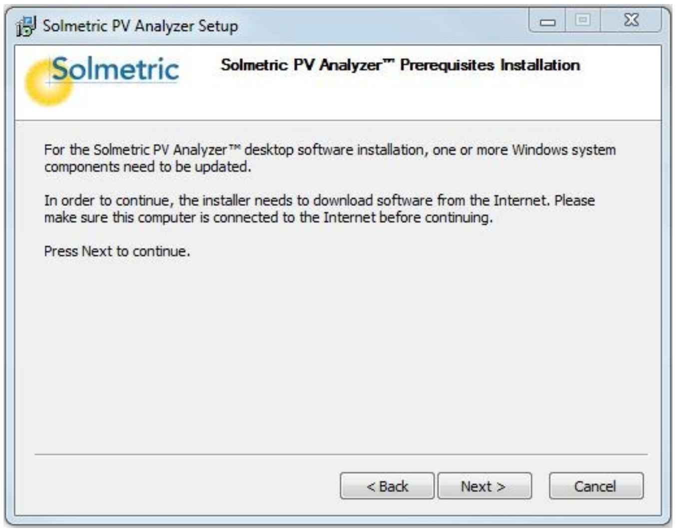

Figure 2. Prerequisites dialog

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

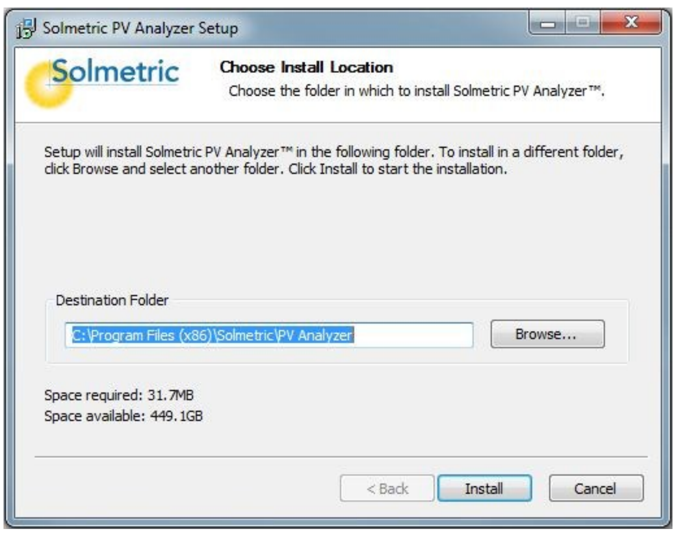

Figure 3. Installation default location dialog

6. Partway through the installation, the following screen will appear, asking you to insert the wireless USB adapter that will communicate with the I-V Unit.

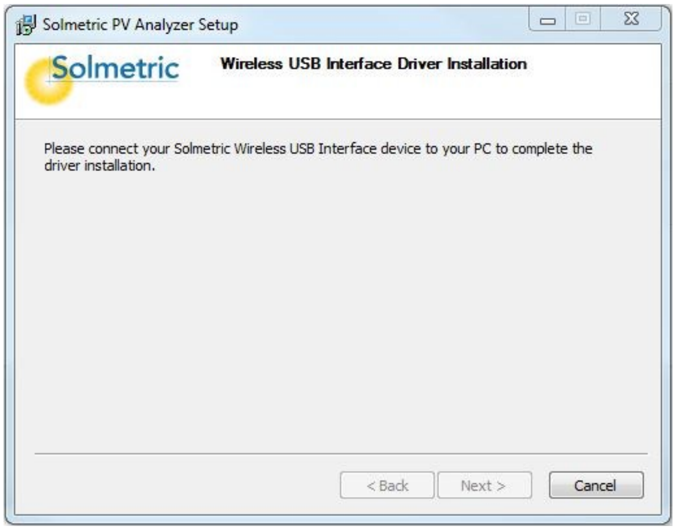

Figure 4. Insert wireless USB adapter dialog

7. Insert the wireless USB adapter shown below.

NOTE **If the Wireless USB Adapter is not available you can complete the basic software installation by clicking Cancel. You will be asked whether the software installed correctly. Click Yes. At this point the software will operate normally but will not be able to communicate with the I-V Measurement Unit or SolSensor. When you later insert the Wireless USB Adapter while the PVA software is running, driver software will be loaded from the Wireless USB Adapter. This completes the software installation.**

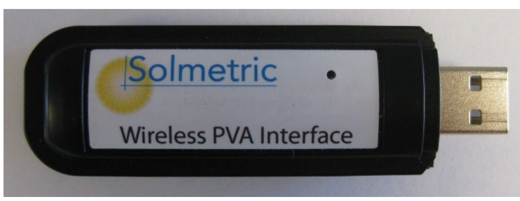

Figure 5. Insert wireless USB adapter

8. When the Wireless USB Adapter driver installation completes, you will be asked whether the software installed correctly. Click **Yes** if that seems to be the case.

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

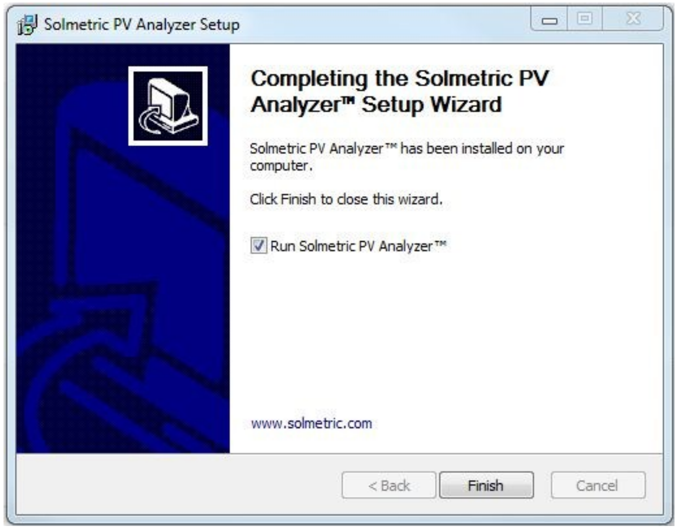

Figure 6. Installation complete dialog

10. 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 as shown in *Figure 7*. Or, select the list of programs in the **Start** menu, then select **Solmetric > PV analyzer >Solmetric PV Analyzer**.

Figure 7. Launching the PVA software

11. The screen shown in Figure 8 will appear while the software is accessing the PV model databases.

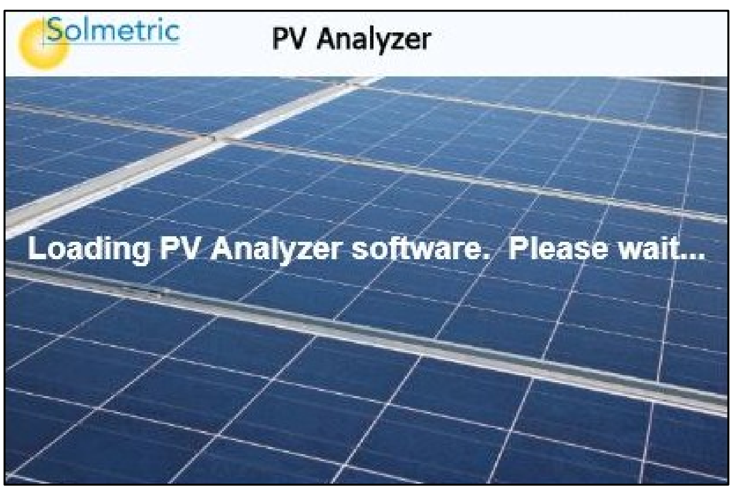

Figure 8. Splash screen

12. When the initialization is complete, the screen shown in Figure 9 will appear.

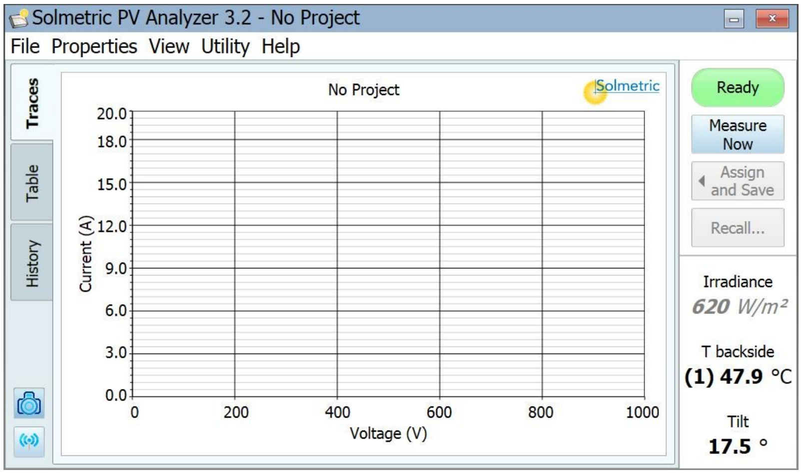

Figure 9. PVA software user interface

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.

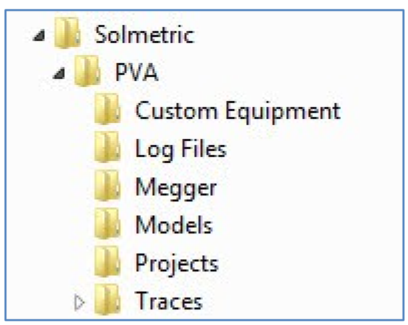

Figure 10. Directory structure of PVA software

Special XP Operating System Instructions

This section applies to computers running the XP operating system only.

Older computers running the XP operating system require special steps during the installation of the wireless USB driver. Please pay close attention to onscreen prompts.

In addition, please be aware that XP will require the reinstallation of the driver if you insert the wireless USB adapter in a different USB port. Therefore, we recommend one of the following when using the XP operating system:

- Select a single convenient USB port for the wireless interface and always use that port.

- Sequentially insert the wireless USB adapter into each USB port in your computer and follow the same installation process (as instructed on screen) for each port.

Updating the PV Equipment Databases

If your PC is connected to the internet when you start the PVA software, the software will check whether new PV module or inverter 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

Drivers for SolSensor

The SolSensor uses the same wireless USB adapter and driver as the I-V Unit. Therefore, once the PVA software has been installed, no additional installation is required for using the SolSensor.

Charging the Battery

Changing the Battery on the I-V Measurement Unit

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 11 and plugging the charger into an AC wall-plug.

Figure 11. Battery charger connector on the I-V Unit

Charging the battery can take up to 6 hours. If you are using your I-V Unit heavily, we suggest you charge it each night.

There is no visible indication of charging on the I-V Unit front panel. Because of the difficulties of determining the state of charge of the advanced lithium batteries, there is no user readout of charge level on the PVA software interface. However, the PVA software interface will warn you when approximately one hour of battery life remains. Also, you can check the battery voltage level by clicking on the **Ready** button following an I-V measurement.

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.

CAUTION *The I-V Unit should not be operated while the battery is charging.*

Changing the SolSensor Battery

The SolSensor battery is not removable. It may be recharged by attaching the battery charger to the charging connector on SolSensor shown in Figure 11 and plugging the charger into an AC wall-plug.

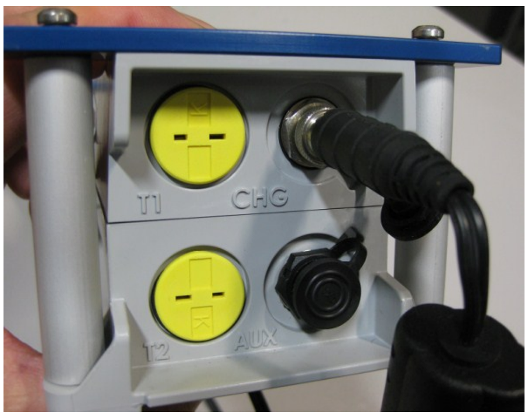

Figure 12. Charger connected

If you are using SolSensor heavily, we suggest you charge it each night.

There is no indicator on SolSensor to indicate that it is charging.

Your Wireless Network

The wireless network that interconnects your PC to the I-V Measurement Unit and SolSensor uses a Zigbee protocol and operates in the 2.4 GHz frequency band.

NOTE: Your I-V Unit, SolSensor and Wireless USB Adapter are shipped with matched Network ID numbers that look like this example:

Network ID
0F96E4A7

This protects their communication network from interference from any other sets of PVA equipment working nearby.

If you own multiple sets of PV Analyzer equipment, be aware that each is a matched set. This protects their communication network from interference from any other sets of PVA equipment working nearby. To avoid confusion and communications problems, avoid mixing the components between PVA systems.

To see a diagram of the network, click on the network icon at the lower left corner of your measurement screen, as shown in Figure 13.

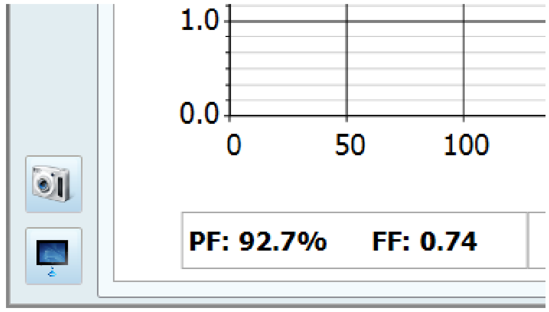

Figure 13. Network icon

The network diagram appears. There are four possible configurations, as shown in Figure 14.

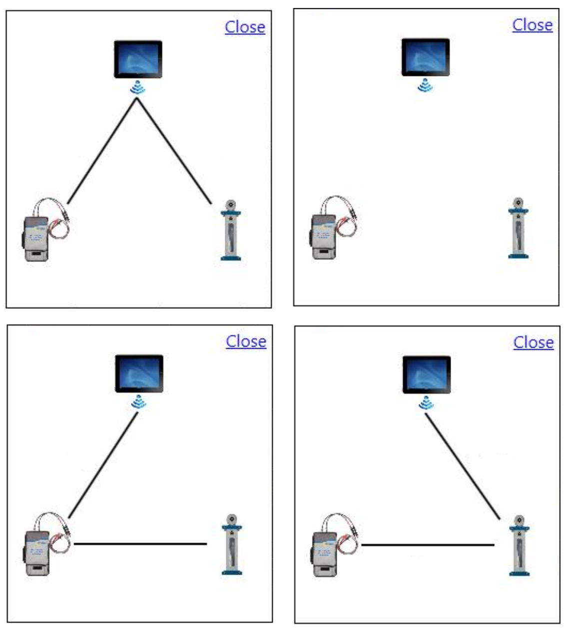

Figure 14. Network diagrams

A line represents a direct link. If two devices relay through a third device, communication between the two is an indirect link.

The network reconfigures itself automatically to achieve the longest transmission range between your devices. For example, suppose you are measuring at a combiner box and your PC is directly linked to both the I-V Unit and SolSensor. Then you move your PC and the I-V Unit to the next combiner box, which happens to be farther away from SolSensor. The mesh network may then switch to indirect communication to SolSensor, using the I-V Unit as the relay station.

The possible path combinations are listed in Table 4.

Table 4. Direct and indirect wireless links between PC, PVA, and SolSensor

Communication route	Interface to I-V Unit	Interface to SolSensor
PC to I-V Unit	Direct	
PC to SolSensor		Direct
PC to I-V Unit to SolSensor	Direct	Indirect
PC to SolSensor to I-V unit	Indirect	Direct

The network automatically determines which communication route to use in a given situation. If you turn on your I-V Unit first, it will directly link to your PC. If you turn on SolSensor first, it will link directly to the PC. The second unit to be turned on may link directly or indirectly.

As you move your components around the site and the distances between nodes increases, the communication route may automatically reconfigure to keep all the components linked.

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

System Controls and Settings

The LED-illuminated button switch on the top surface of the I-V Unit, shown in Figure 15, is used to control the state of the measurement system, to enable or disable the I-V Unit, and to reset the unit.

When the I-V Unit is turned on, it searches for the Wireless USB adapter. For the network to be established, the W-USB adapter must be plugged into your PC and the PV Analyzer software must be launched.

Figure 15. LED-illuminated button switch

I-V Unit Operational States

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

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

Table 5. I-V Measurement Unit operational states

PVA State	Description	Power Button State
Power Off	I-V Unit is turned off.	LED Off.
Network Search	Press the power button once. Communication between the I-V Unit and the Wireless USB adapter is attempted. If a network is not established within 15 minutes, the I-V Unit will turn off automatically. If the at any time wireless communication is lost, the network search is restarted and the LED again starts to blink.	LED Blinking.
Sweep Enabled	I-V network exists and sweep is enabled.	LED on.
Sweeping	I-V Measurement unit receives a sweep trigger from the PC application and a measurement is taken.	LED blinks momentarily at start of each I-V curve sweep.
Sweep Disabled (pause)	While the I-V Unit is on, press the power button once. The sweep is disabled. Disable the sweep before connecting or disconnecting the I-V Unit to or from the PV modules or strings. If left in Sweep Disabled mode for more than 15 minutes, the I-V Unit will turn off automatically.	LED off.
Reset	Press and hold the power button for more than 5 seconds to force a power-up reset. The system will attempt to reestablish communication between the I-V Measurement unit and the Wireless USB adapter.	LED blinking.

Setting Up the I-V Measurement Unit

1. Place the I-V Unit close to the PV device to be measured.
2. Ensure that the connector-saver jumpers are installed on the primary test leads.
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 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.
4. If long extension cables are connected to the I-V Unit to reach the test device, the cables should be laid alongside one another rather than in a loop, to minimize the inductance they add to the measurement circuit.
5. Connect the Wireless USB adapter to a USB port in your computer.
6. If you will be using the Solmetric SolSensor, refer to Setting Up SolSensor for setup information.

Setting Up SolSensor

The figure below shows the SolSensor Wireless PV Reference sensor mounted in the recommended location along the upper frame edge of a PV module.

Figure 16. SolSensor mounted along the upper frame edge 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

Figure 17 shows SolSensor attached to a PV module with the Module Frame Clamp, and secured with the Tool Lanyard.

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

Figure 17. SolSensor's 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 17.

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 18.

Figure 18. 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 19 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 19. 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 20).

Figure 20. 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 21. 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.

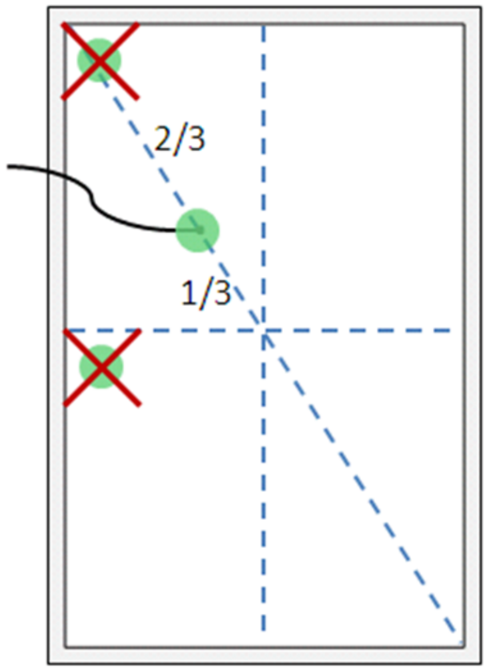


Figure 21. Locating the thermocouple tip on a single free-standing module.

9. Remove the protective cover from SolSensor irradiance sensor.

10. Press the button to turn SolSensor on, as shown in Figure 22. SolSensor will establish a communication link with the Wireless USB Adapter plugged into your PC, if the PC is within wireless range and the PVA software is running on the PC. The button's indicator light blinks while SolSensor is searching for the network, and glows solid red when the network is established.

Figure 22. Pushbutton with LED lit. LED blinks until wireless network is established, after which it remains on.

Optimizing wireless transmission range

SolSensor has a line-of-sight transmission range of over 100 meters. Follow these practices to realize as much of that transmission range as possible.

1. Position SolSensor in line-of-sight to your PC. Avoid locations where the signal must transmit through PV modules and racking.

2. Avoid placing the PC on a metal surface, which reduces wireless range

3. If it is not possible to achieve the required transmission range with SolSensor mounted along the edge of a PV module, 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 tripod 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 Figure 23.

Figure 23. 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

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 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.

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.

2. Press the button on the I-V 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 test leads with

alligator clips are required, use the Solmetric PVA test leads.

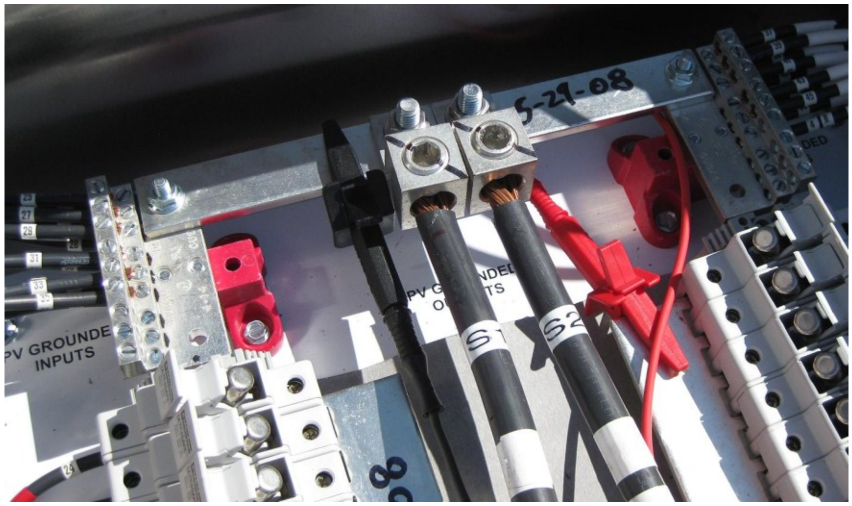


Figure 24. Example of I-V Unit test leads clipped to the buss bars of a PV combiner box

4. If the distance between the test device and the I-V Unit requires the use of extension cables, use rated PV cable with correctly installed connectors. Select a wire gauge that will result in a suitably small voltage drop.

5. When extension cables are longer than 10 feet (one-way), lay the cables close to one another to minimize added cable inductance.

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

Powering-Up the I-V Unit

NOTE: The I-V Unit can be turned on before or after starting the PC software, but the wireless USB adapter should be plugged into your PC prior to launching the PVA software.

Press the power button once on the I-V Unit. Refer to the figure below.

Figure 25. Powering-up the I-V Unit

The LED will begin to blink indicating that the I-V Unit is attempting to establish communication with the wireless USB adapter connected to the PC. If the wireless USB adapter is inserted into your PC and the PVA software is running, a network will be established and the LED will become continuously lit (no blinking). If a network is not established within 15 minutes, the I-V Unit will turn off to conserve the battery.

I-V Measurements

The I-V 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 Unit after it is transmitted.

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 red button on the front of the I-V Unit to disable the measurement sequence. Pressing the red button again restarts the measurement sequence. Manually disabling the I-V Unit in this way will assure that an I-V measurement is not accidentally taken when it is not expected.

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 Unit from operating at potentially damaging internal temperatures.

NOTE	The I-V Unit will automatically shut down if its internal temperature reaches a preset limit. Internal temperature is increased by PV energy collected during I-V sweeps, and also by heat absorbed from the environment, including high ambient air temperature, hot surfaces on which the I-V Unit is placed, and exposure to direct sunlight.

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

Thermal Shutdown

All battery powered measurement instruments have upper temperature limits. The operating temperature range of the I-V Unit is limited by the battery that powers the unit. When the internal temperature approaches the battery's high-temperature specification, the measurement unit automatically shuts down (disables itself) and the **Disabled** message is displayed below the **Measure Now** button. In thermal shutdown, PV power is no longer dissipated in the measurement unit. This removes one of the major internal heat sources. To recover from thermal shutdown, wait for the measurement unit to cool. Placing it in the shade or a cool place will speed the recovery.

NOTE The operating temperature rise inside the I-V Unit is primarily determined by several factors: outside air temperature, direct sunlight, temperature of the surface on which it is placed, and PV power dissipated in the instrument with each I-V measurement sweep. The PV power depends on the details of the PV module or array being tested, as well as the amount of measurements you are taking. Given these application-related factors, it is possible that thermal shutdown will occur at an ambient temperature at or lower than the specified maximum operating temperature.

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 Unit. Shade the measurement unit from direct sunlight, elevate it above hot surfaces, and allow more time between I-V sweeps.

Over-Voltage Protection

PVA-1000S Over-voltage Protection

If an input voltage greater than 1100 V but less than 1500 V is detected, the software warns you of an over-voltage condition, but the I-V Unit is not disabled. If the voltage is greater than 1500 V, the I-V unit is automatically disabled and you are instructed to return the unit and wireless USB adapter to Solmetric for service.

PVA-600+ Over-voltage Protection

If an input voltage greater than 650 V is detected, the I-V Unit is disabled and you are instructed to return the unit and wireless USB adapter to Solmetric for service.

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

Over-Current Protection

If greater than 20 A dc is applied to the I-V Unit, the I-V Unit detects the over-current condition and switches into disabled mode automatically and an I-V measurement does not take place.

The I-V Unit also has limited protection against the fast, high-current transients that can be produced by high-efficiency PV modules.

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

Reverse Polarity Protection

If the I-V Unit is connected with the wrong polarity across a string, an internal protection diode opens the circuit, the I-V Unit switches into disabled mode, and an I-V measurement does not take place.

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. You can use the same Project file each time you measure the array, so that over time you will accumulate a history of the performance of the array.

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 tilt and azimuth. Also, all of the strings must have the same number of modules.

Often a site will have multiple PV arrays with different modules, tilts, azimuths, or number of modules per string. 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. For example, there may be multiple arrays on different roof planes. In this example, create a Project for the first roof plane, clone and rename the Project for the second roof plane, then open the new Project and update the tilt and azimuth values.

NOTE Very large PV system can cause the PVA software to slow down, especially on slower computers. The result is a longer delay when you measure, save, or recall data. 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 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.

I-V measurements are automatically "stamped" with the date and time at the instant the measurement is performed. Date and time information is also required for predicting the position of the sun when using the Sandia model and an irradiance sensor. The date and time are automatically loaded from your PC.

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.

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 information enables 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 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 and is your interface for making measurements and storing, viewing, and exporting data. The main screen is shown below, with the Traces tab selected.

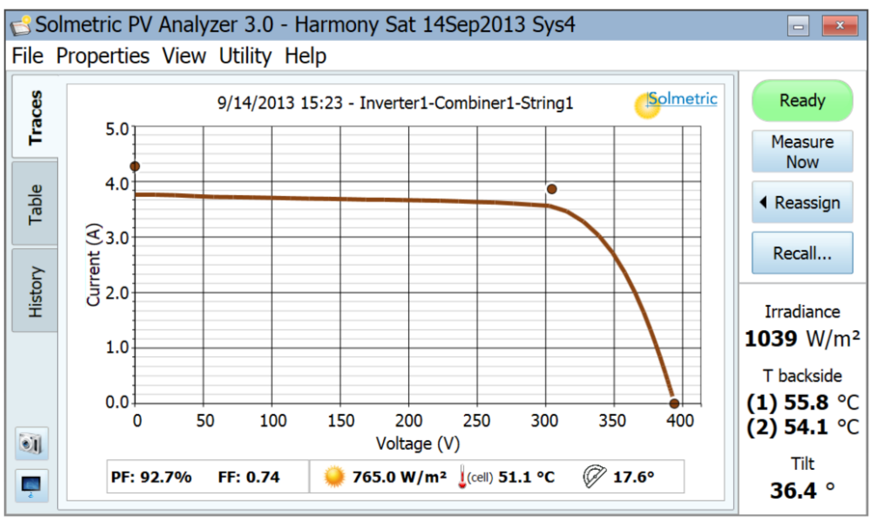


Figure 26. PVA software main screen

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 27, is used to create a new project, browse and load existing projects, load recent projects, and export measurement data.

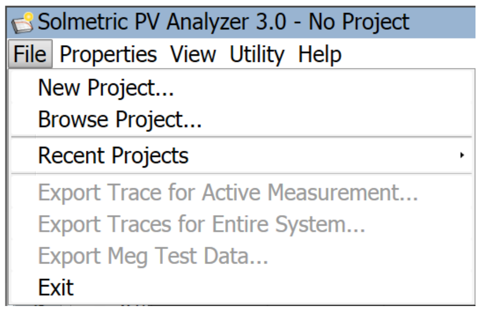


Figure 27. File Menu

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 Figure 28. This is the first of two screens of the New Project Wizard.

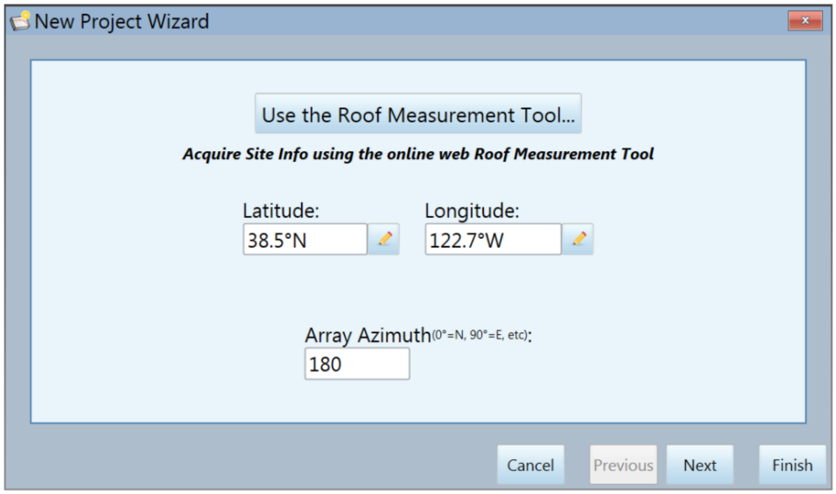


Figure 28. The Site Info screen of the New Project Wizard

In this screen you will enter the latitude, longitude, and azimuth (the true compass heading toward which the PV modules are tilted). You can use the number boxes, or (if your PC is on the web) click the button to use the **Roof Measurement Tool…**, shown in Figure 29.

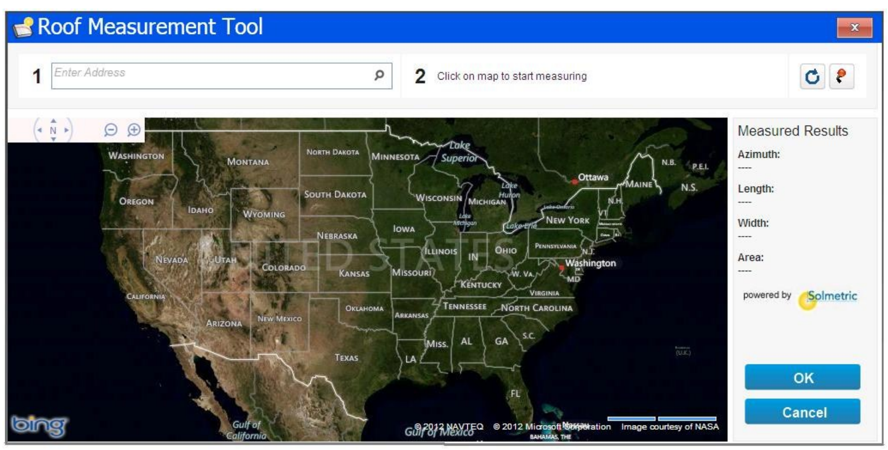


Figure 29. Roof Measurement Tool

The Roof Measurement Tool returns the latitude and longitude of your site. If your array is aligned with the edge of a building, the Tool can also return the azimuth of your array.

To use the Roof Measurement Tool, enter the address of your site. Then click the magnifying glass and you will see an image of your site. Zoom in to your building as shown in Figure 30.

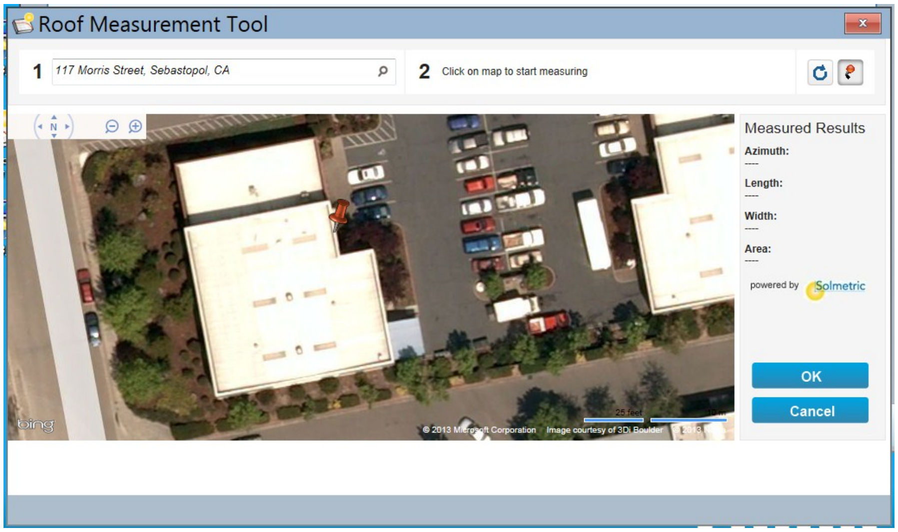


Figure 30. Roof Measurement Tool image of PV Site

To find the building azimuth, follow these steps:

1. Click on the lower left corner of the building
2. Click on the lower right corner of the building
3. Slide your cursor northward, creating a rectangle, and click to 'freeze' the rectangle.

When you freeze the rectangle, an arrow and azimuth value appear at the bottom of the view, as shown in Figure 31. When you click **OK**, the azimuth value is returned to the New Project Wizard, along with the latitude and longitude of the site.

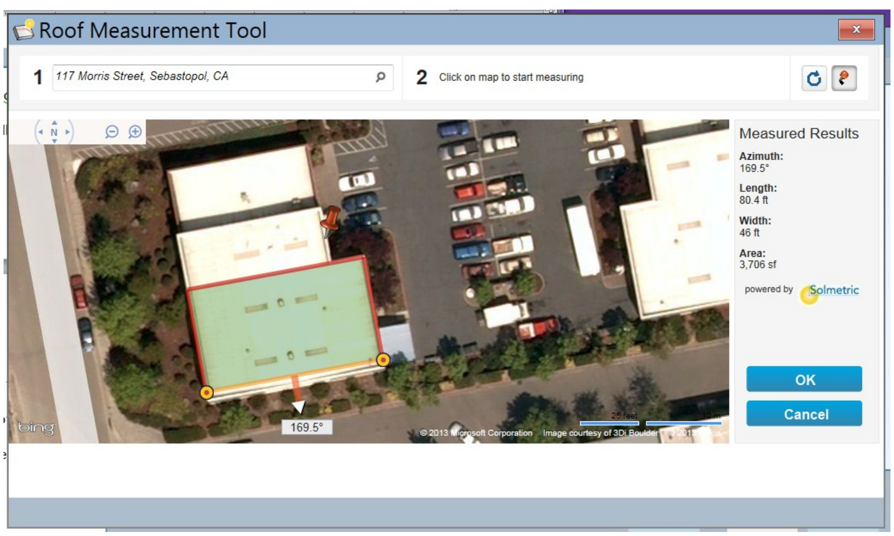


Figure 31. Finding the Azimuth Value Using the Roof Measurement Tool

When the latitude, longitude, and azimuth have been entered in the Site Info screen of the New Project Wizard, click **Next** to advance to the Array Navigator screen, shown in Figure 32.

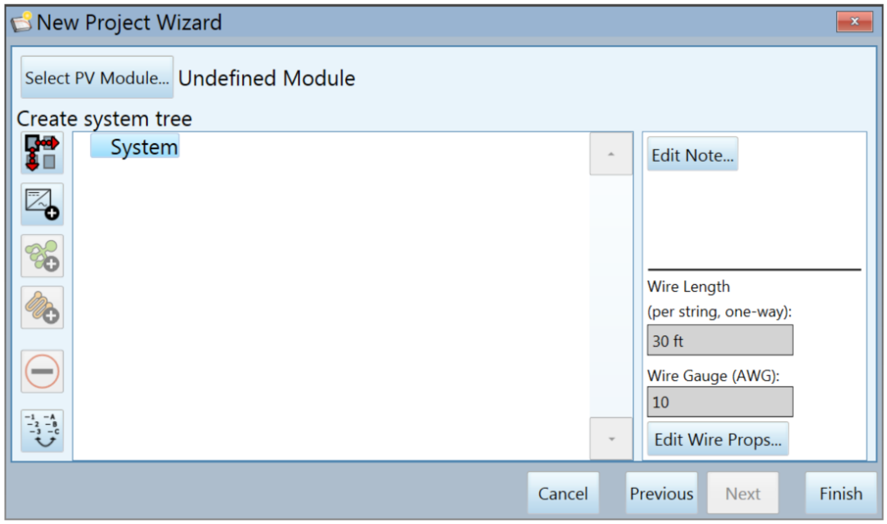


Figure 32. The Array Navigator screen of the New Project Wizard

This screen is used to describe your PV system hardware. The information you enter here is used for two purposes: 1) to create the PV model that the software uses to predict expected performance and 2) to create a visual representation of your array that you can 'touch' to save and recall your measurement data.

Selecting your PV Module

Click the **Select PV Module…** button to load the PV model parameters for your module from the built-in equipment database. The **Change Module** screen appears, as shown in Figure 33.

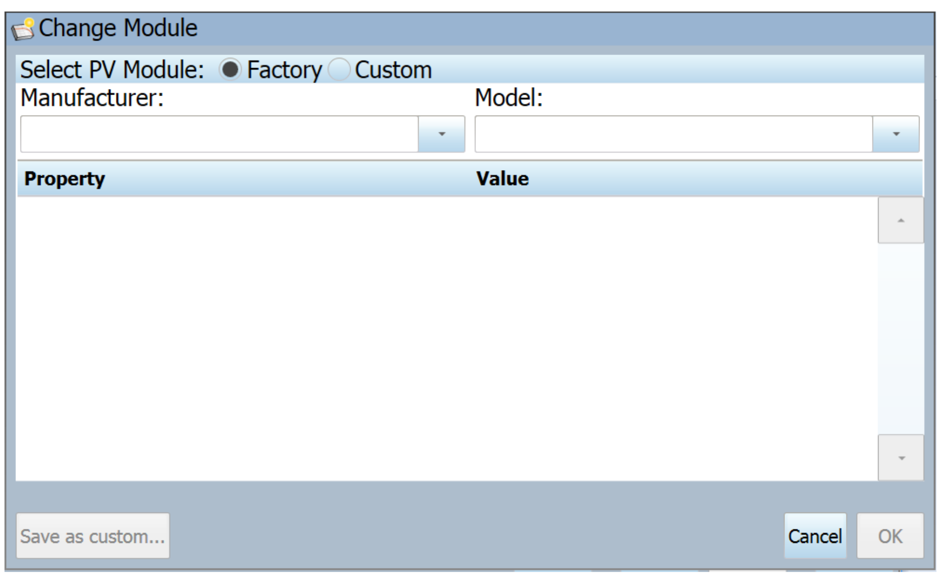


Figure 33. Change Module screen

The Change Module screen functions are explained below in Table 6.

Table 6. Change Module Screen Description

Name	Description
Factory	Click **Factory** to select a PV module from the built-in module database.
Save as custom…	After you select a PV module using the drop down lists, the **Save as custom...** button is enabled. Click this button if you want to edit the values of the currently selected PV module. When you have made your changes, you can save the parameters under the original name or a different name of your choice.
Custom	After clicking on **Custom**, the **Select...**, **New...**, and **Edit...** buttons appear. Click **Select...** to load a previously created custom model. Click **Edit...** to modify the parameters of the currently loaded custom model. Click **New...** to create a new custom module by entering all of the module parameter values. In most cases, you will enter your custom parameters from the PV module datasheet. A full Solmetric PV Model features a much larger number of parameters. Please contact support@solmetric.com for additional guidance about working with the Solmetric model.
Manufacturer	Use this list first, to choose your module manufacturer.
Model	Use this list second, to choose your module model number.
Property and Value	Displays the model parameters pulled from the built-in database for your selected PV module. These are specialized parameters, many of which are not found on PV module datasheets.
OK	Accept the choices shown.
Cancel	Leaves this form without impact to the prior settings.

When you have finished selecting your module, click **OK**.

Creating the System Tree

The next step is to create your system tree, an electrical description of the DC side of the PV system that you will be testing, like the example shown in the central area of this figure. You create or edit the tree using the icons at the left of the system tree. When you click on an element of the system tree, the column at the right hand side of Figure 34 displays controls you can use to modify that element. If you click on a string, a control appears for changing the number of modules in that string, as shown in this example. If you click on an inverter, controls appear for selecting the inverter. The right hand column also displays controls for selecting the wire length and wire gauge of conductors between the PV analyzer and the string or module under test. You can change the wire properties at any level of the system, and a change made at any given level will update all of the strings at and below that level.

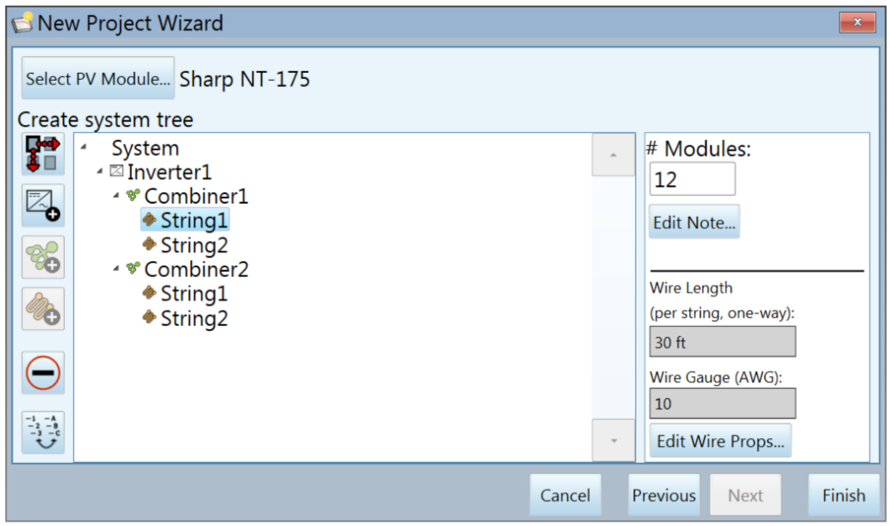
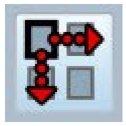
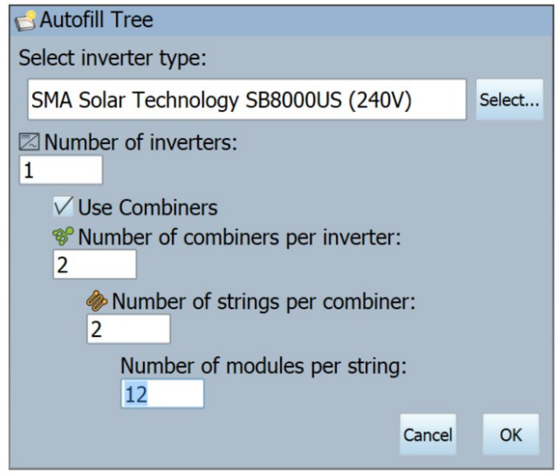
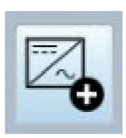
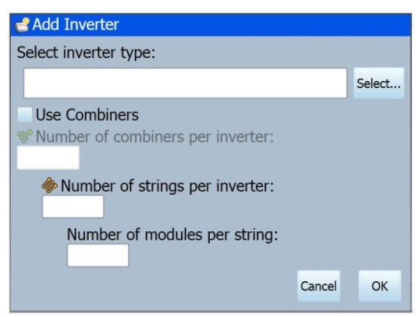
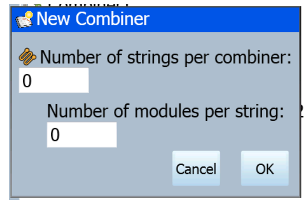
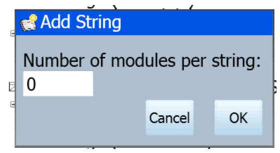
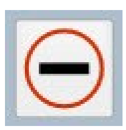
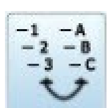
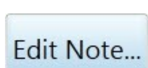
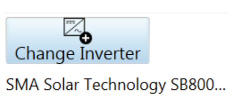
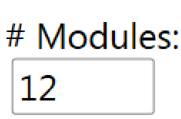
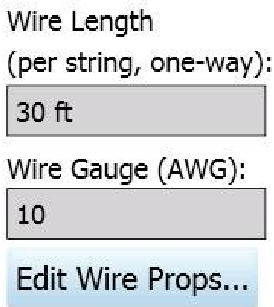


Figure 34. Array Navigator Screen with Example System Tree

Table 7. Array navigator screen description

Name	**Description**
	The Autofill Tree icon accesses a form for you to specify the entire architecture of the PV system. This control is useful in simple cases where all the inverters are identical and the details of their arrays are the same.  **Select Inverter** – Select your inverter from the built-in database. **Use Combiners** – Select if one or more combiners will be used. **Number of inverters, combiners, strings and modules** – Enter the appropriate values.
	The Add Inverter icon accesses a form for you to specify an inverter type and specify the architecture of its PV array. This control is useful when the inverters differ, or when arrays differ between inverters.  **Select Inverter** – Select an inverter from the built in database. The selected inverter can be different from other inverters in the system. **Use Combiners** – Select if combiners will be used. **Number of combiners, strings, modules** – Fill in these boxes with appropriate numbers.

Name	Description
	The Add Combiner icon accesses a form for you to add another combiner at a level just below a selected inverter or combiner.  Enter the number of strings and modules. The number of strings can differ from other combiners. The number of modules per string should match the rest of the combiners feeding a given inverter.
	The Add String icon accesses a form for you to add another string to a selected inverter or combiner box.  Enter the number of modules in the string. The number of modules per string should match the rest of the strings feeding a given inverter.
	The Delete Selected icon deletes a selected item from the system tree.
	The Array Navigator Naming icon is used to select between numeric or alphabetic naming convention.
	Edit Note… is used to add or edit notes for a specific inverter, combiner, or string.
	Change Inverter accesses the screen used to change to a different inverter. This only appears when an inverter is selected.
	# Modules is used to change the number of modules for the selected string. This control appears only when a string is selected. The number of modules per string must be the same across the entire Project.

Name	Description
	These controls input the wire properties of conductors between the I-V Unit and the string or module under test. These values are used to account for the resistance of the conductors in the predictive PV model and have no effect on the actual measurement of the I-V curve. You can change the wire properties at any level of the system, and a change made at any given level will update all of the strings at and below that level. PV output circuit conductors are usually sized for minimal loss. In most cases, entering a nominal wire gauge and length for the system is sufficient. However, if you have particularly long runs, you will get slightly better agreement between the model and the actual measurement if you use these controls. **Default Wire Length Per String (one-way)** Enter the one-way wire length between the I-V Unit and the PV module or string under test that is typical for this Project. This information, combined with the wire gauge, allows the PV analyzer software to adjust the PV model for the nominal resistance of the conductors. This improves the agreement between predicted and measured I-V curves. The default one-way wire length is 30 feet. The wire length can be set at any level of the system tree, and any changes will automatically be applied to all tree levels below your selected level. For example, if you change the wire length with a combiner box highlighted, all strings within that combiner will be set to the new length.
	Wire Gauge (AWG) Enter the wire gauge of the conductors between the I-V Unit and the PV module or string under test. This information, combined with the wire length, allows the PV analyzer software to adjust the PV model for the nominal resistance of the conductors. This improves the agreement between predicted and measured I-V curves. The resistance of the wiring is calculated using this formula and the resistance table below. R_{series} = (Resistance per foot) * (Wire length, one way) * 2 Resistance Per Foot is calculated from the table below: The first column is Wire Gauge (AWG); the second column is Resistance per Foot. 4 AWG (0.2043 in, 5.189 mm) → 0.0002485 Ω/foot 6 AWG (0.1620 in, 4.115 mm) → 0.0003951 Ω/foot 8 AWG (0.1285 in, 3.264 mm) → 0.0006282 Ω/foot

Name	Description
	10 AWG (0.1019 in, 2.588 mm) → 0.0009989 Ω/foot 12 AWG (0.0808 in, 2.053 mm) → 0.001588 Ω/foot 14 AWG (0.0641 in, 1.628 mm) → 0.002525 Ω/foot 16 AWG (0.0508 in, 1.291 mm) → 0.004016 Ω/foot The temperature of the wiring is not taken into account in calculating wire resistance. Room temperature is assumed.

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… discussion for details on the use of these screens.

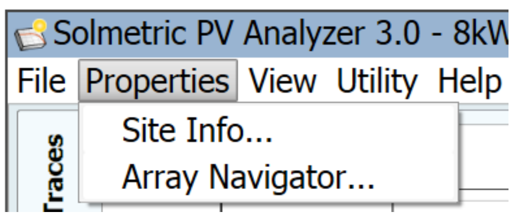


Figure 35. Properties Menu

Site Info…

Clicking on the **Site Info…** menu item brings up the following screen.

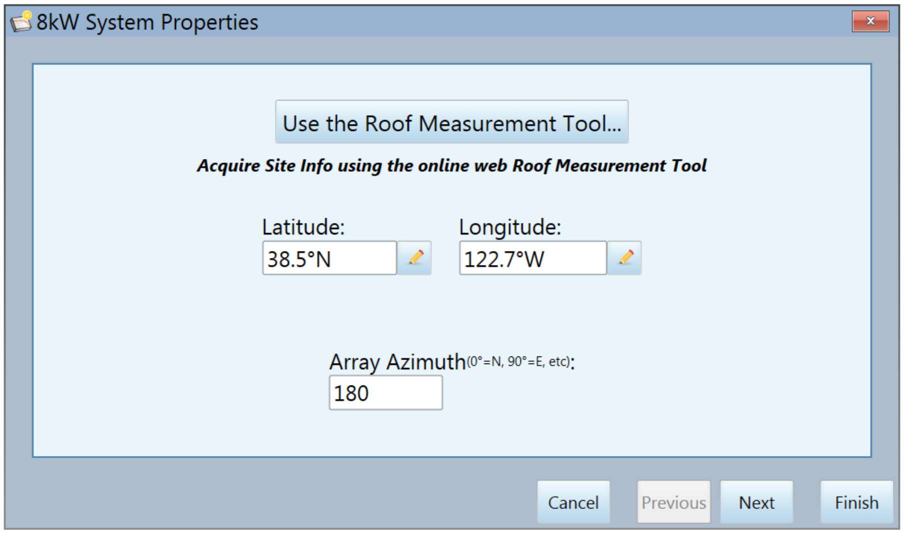


Figure 36. Site Information Screen

Use these controls to edit the latitude and longitude of your construction site, and the azimuth (true compass heading) of your PV modules. Alternatively, you can use the Roof Measurement Tool to update these values.

Array Navigator…

Clicking on the **Array Navigator…** menu item brings up the following screen.

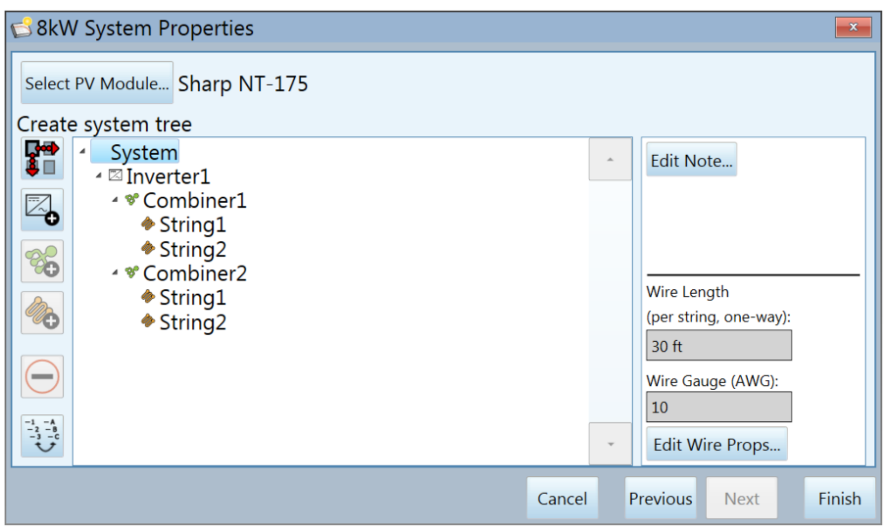


Figure 37. Array Navigator Screen

In this screen you can change your PV module or inverter, edit your system tree, and edit your wire properties.

Utility Menu

The Utility Menu provides access to housekeeping functions and miscellaneous tools. The Utility Menu is shown in Figure 38 and described in Table 8.

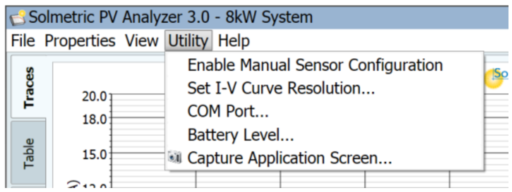
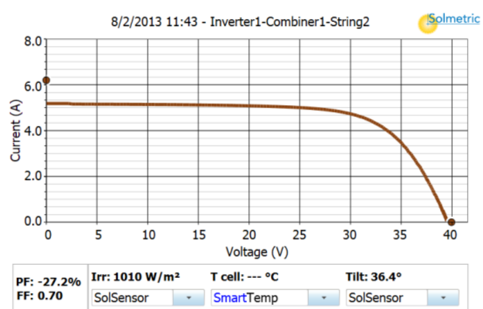
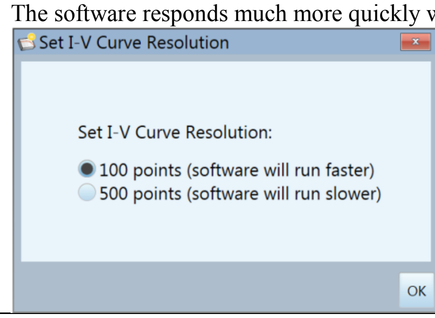


Figure 38. Utility Menu

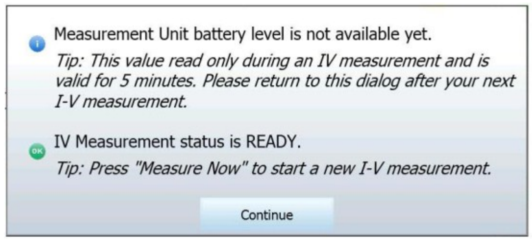
Table 8. Utility menu description

Name	Description
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 { } for guidance on 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. 

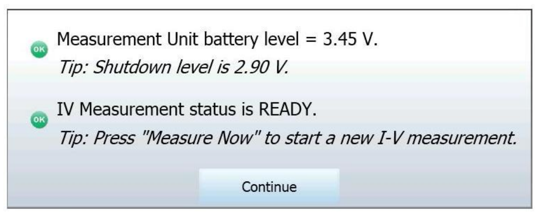
<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>COM Port...</td><td>Used to manually select the COM port in which you have inserted the wireless USB adapter that is used to communicate with the I-V Unit and SolSensor. From the drop down list, select the COM port that is followed by a “+” sign.

NOTE – If the Wireless USB adapter is installed into the PC before starting the PVA software, the communication port is selected automatically.</td></tr>
<tr><td>Battery Level…</td><td>Updated during each I-V measurement and displayed for the next 5 minutes only, to assure that it remains valid.

If you check the battery level more than 5 minutes after the most recent measurement, you will see the following prompt:


</td></tr>
<tr><td>Battery Level…

(Continued)</td><td>Within 5 minutes of the most recent measurement, you will see this type of report:


</td></tr>
<tr><td>Capture Application Screen</td><td>Captures and saves the currently displayed measurement results.</td></tr>
</table>

Help Menu

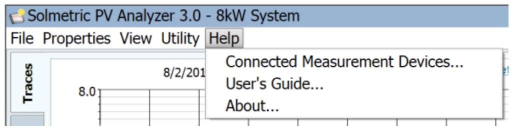
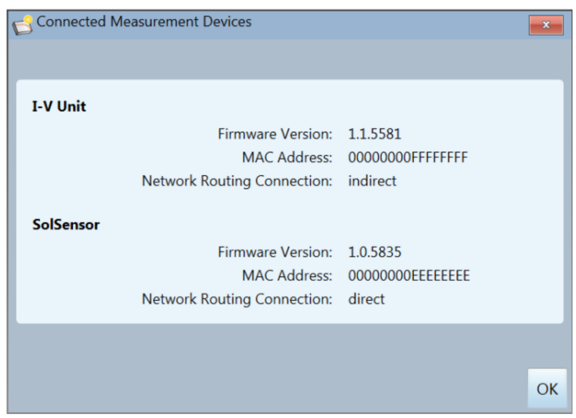


Figure 39. Help Menu

Table 9. Help menu description

Name	Description
Connected Measurement Devices...	Presents three types of information useful in certain product support situations: • Firmware versions (code for the embedded computers) • MAC address (unique identifiers of instruments in the network) • Network routing connection (indicates whether communication is direct or indirect to the PC. Indirect means that the other instrument is acting as a relay) 
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.
About	Accesses the software version number and software build date.

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 40 is an example of the Traces tab screen.

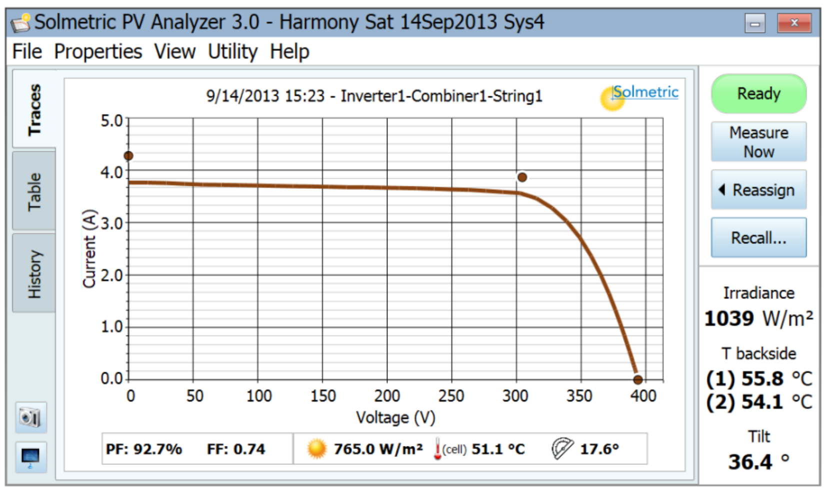


Figure 40. Traces tab

There are four main datasets displayed in the Traces screen:

- I-V curve. This solid red curve displays the measured I-V points transmitted from the I-V Unit. Points below 0 V are not displayed.
- 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 yellow 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 yellow marker is not derived from the PV model.
- I-V curve prediction markers. The three red dots are the predicted I-V points for the short circuit current I_{sc} (I_{sc}, 0), the maximum power point (I_{mp}, V_{mp}), and the

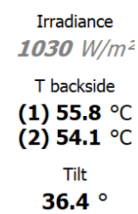
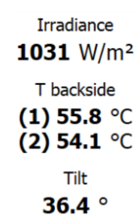
open circuit voltage V_{oc} (0, V_{oc}). If the actual I-V curve goes through or near the predicted five points, then the array is functioning as predicted.

- The green shaded area indicates the maximum power point tracking (MPPT) voltage range of your selected inverter. This feature is provided to help the user identify situations in which the number of modules in a string is not well matched to the inverter. If the knee of the I-V curve is close to the right-hand edge of the green region, the inverter may clip at cold ambient temperatures. If the knee of the I-V curve is close to the left-hand edge of the green region, the inverter may drop out at high ambient temperatures.

Table 10. 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 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 and 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 and time and the location and the system tree.
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.
Show STC Translation	When selected, an STC-translated version of the I-V curve will be added to the existing display. Standard Test Conditions are 1000W/m2 and 25 degrees C . To simplify the display, the P-V curve (power versus voltage) is not displayed when the STC-translated I-V curve is on-screen. In general, the STC curve will have different endpoints and scaling than the originally displayed curve.
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.

Name	Description
Measure Now	Highlighted 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.
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. 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. **WARNING - 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 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. When "Disabled" is displayed, click on the status indicator or the question mark icon for information to aid in

Name	Description
	troubleshooting the problem.
No USB Wireless (indicator)	When displayed, click on the question mark icon for information to aid in troubleshooting the problem.
No I-V Unit (in Status indicator)	Displayed when communication between the I-V Unit and the USB wireless adapter at the PC is not established. When displayed, clicking on this indicator accesses information to aid in troubleshooting the problem. Click on the question mark icon for information to aid in troubleshooting the problem. **NOTE** – The most common reasons for this state include wireless out-of-range, or the I-V Unit has turned itself off after 15 minutes of inactivity to conserve battery power.
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 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 shown here:  The preliminary irradiance value is an estimate of the actual irradiance, because without a Project, the software does not know where the sensor is located and cannot apply full correction for sun angle effects. Once a Project is created and loaded, irradiance is displayed in black, regular font, as shown here:  If SolSensor is turned off or out of wireless range, the sensor displays will show "---" instead of numerical values. This could mean that an incorrect COM port is selected. Check this by clicking **COM Port...** under the Utility menu. Select the COM port with the "+" sign following it. If that is not the problem, SolSensor may be out of wireless range. Move SolSensor closer to your PC, or improve the line of sight between them.

Name	Description
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. 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

Presents summaries of the predicted and measured I-V data and a translation of the measurement results to Standard Test Conditions. Figure 41 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.

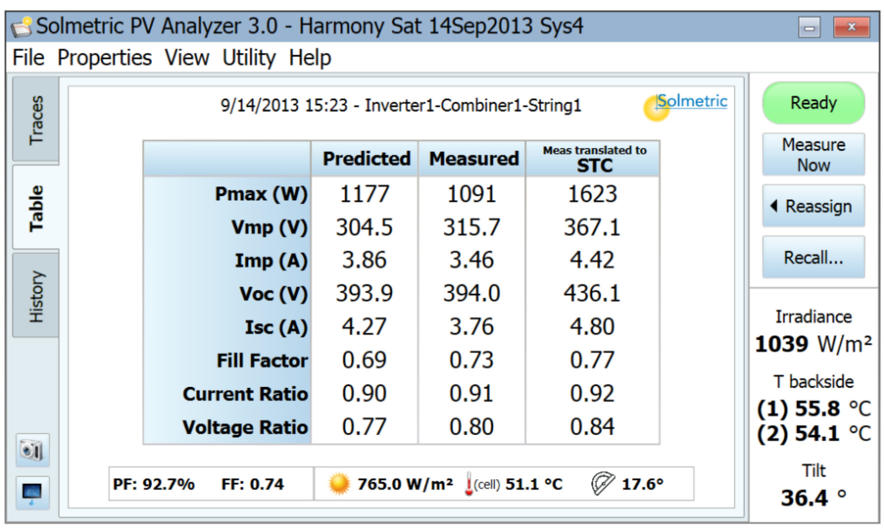


Figure 41. Table tab

Table 11. Table tab description

Name	Description
Predicted	Displays the predicted values from the selected performance model.
Measured	Displays actual measured values most recently measured.
Meas Translated to STC	Displays a translation of the measured parameters to Standard Test Conditions, 1000W/m2 and 25 C .
P_{max} (W)	Measured maximum power values in Watts.
V_{mp} (V)	Voltage at the maximum power point.
I_{mp} (A)	Current at the maximum power point.
V_{oc} (V)	Open circuit voltage.
I_{sc} (A)	Short circuit current.
Fill Factor	The Fill Factor (FF) is an indication of the squareness of the I-V curve. 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.
Current Ratio	The current ratio is an 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 an 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.
Irradiance, temperature and tilt	The irradiance, temperature, and tilt associated with the current measurement are displayed in the Summary Bar, directly below the table.

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 20 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.

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 odd result corresponds with shading the bad module.

The contents of the History table are saved in your Project file, but are not exported along with your I-V trace data.

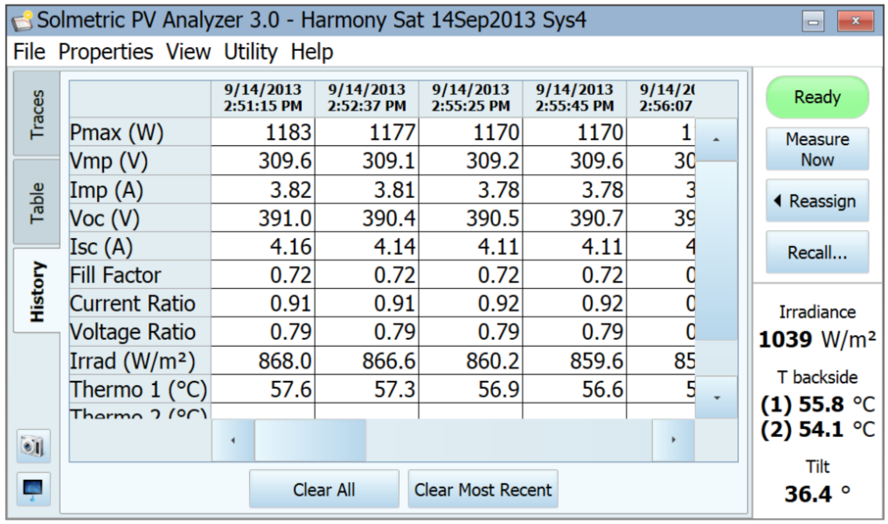


Figure 42. History tab

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.

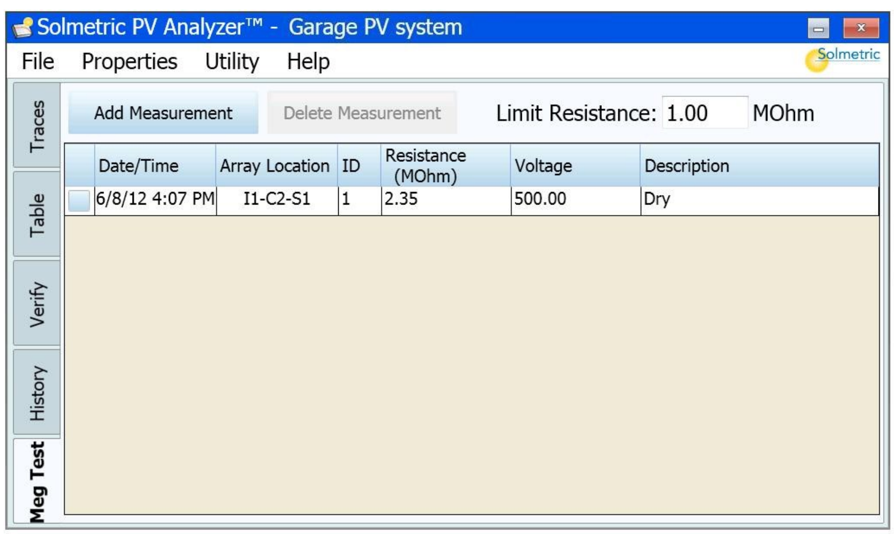


Figure 43. Meg Test tab

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. 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 44 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 44. 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 45 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.

	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 45. The Measurement vs. Model section of the exported csv file

Figure 46 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 46. 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

Figure 47 shows the Model Details section of the exported csv file, and the table 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 47. 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

Item	Description
	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.
Inverter Mfr	Manufacturer of the inverter.
Inverter Model	Model number of the inverter.
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 48 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.

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 48. 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:

- Calibration of the electronic tilt sensor.
- Calibration of the angular response of the irradiance sensor.
- Calibration of irradiance measurement at air mass 1.0-1.5 and normal incidence, relative to a pair of matched reference sensors
- 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:

- SolSensor is clamped to the module frame, which orients it in the plane of the array.
- 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.
- The irradiance value is temperature corrected based on the reading of a temperature sensor attached to the irradiance sensor and on the angle of incidence of the irradiance.
- 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 PV module. Effective irradiance is that portion of the total irradiance that the module can convert into electricity.

PVA Prediction of Electrical Output

The PVA software compares the measured I-V curve to the predictions of built-in PV performance models. The prediction process involves these steps:

- User selects their PV module from the built-in database.
- The model predicts I_{sc}, I_{mp}, V_{mp}, and V_{oc} for the current values of irradiance and temperature.
- Under low light conditions, the prediction is adjusted based on 200W/m2 performance data in the database.
- The Performance Factor – the ratio of measured P_{max} to predicted P_{max} - 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.

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 situation in which this gap near I_{sc} 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 I_{sc} is typically extremely small.

4 Making Measurements

Introduction

This chapter describes the steps for making measurements. For instructions on setting up equipment, see Chapters 1 - Getting Started and Chapter 2 - Setting Up and Using the I-V Measurement Unit and SolSensor. For background on the software controls and data displays, see Chapter 3 - Software Overview.

This chapter starts with instructions for creating a new Project. You can make and display I-V measurements without creating a Project, but you will need to create a Project in order to save measurements and compare results with the predictions of the built-in PV models.

Setting up a Project is quick and easy, and if you are web connected you can further simplify the process using the Solmetric Roof Measurement Tool to obtain most of the site information.

NOTE: The PV Analyzer automatically configures its internal settings to provide the optimal accuracy for the type of PV device you are measuring. It bases this adjustment on the voltage and current values of its most recent measurement. The first measurement that you make after launching the PVA software does not have this information, so for the first trace it uses default values that represent a typical grid tie string. If you are testing a PV source with much higher or lower voltage or current, your measured I-V curve may have fewer points and show straight line segments, or may not reach all the way to V_{oc}. If your first trace looks that way, do not save it, and simply take another trace.

Creating a New Project

The following procedure shows how to set up the PVA software to measure a particular PV system, using the New Project wizard.

In PVA terminology, a "Project" is essentially a container (a computer file) that holds all of the PVA setup information and measurement data for your PV installation. The Project file simplifies data management, allowing you to easily share both setup and results with other offices and stakeholders.

Note that these array parameters must by identical across the Project:

- PV module manufacturer and model number
- Number of PV modules per string
- Array azimuth (true compass heading)
- Nominal tilt

The actual tilt of the module SolSensor is mounted on is reported by SolSensor and is saved with each I-V measurement.

Start the PVA Software

1. On the PC, double-click on the **Solmetric PV analyzer** icon to start the PVA application. The Traces screen appears as shown below.

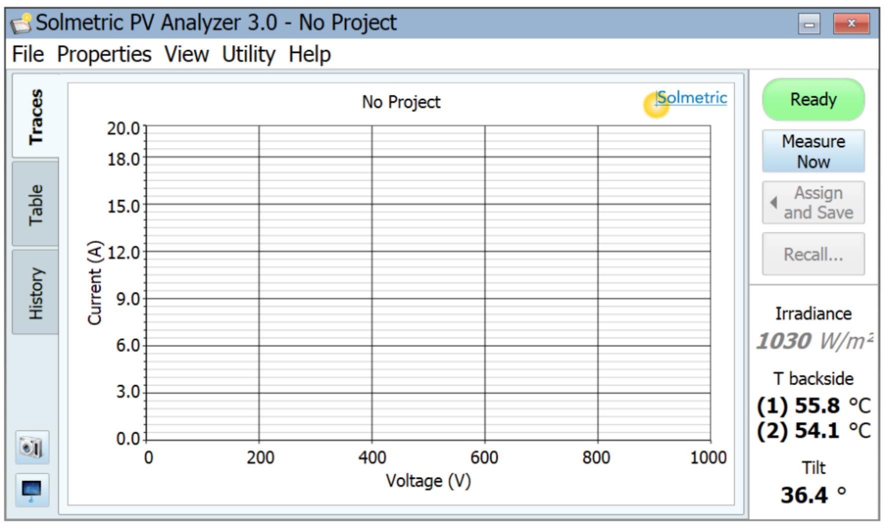


Figure 49. Traces screen

SolSensor does not need to be installed for creating a Project. If SolSensor is wirelessly connected and supplying real time sensor data, the sensor displays in the lower right corner of the screen will display the current values. If SolSensor is not connected, these displays will just show "---".

Select New Project

1. In the **File** menu, select **New Project…** to launch the New Project Wizard. The Site Information screen of the New Project Wizard appears as shown below.

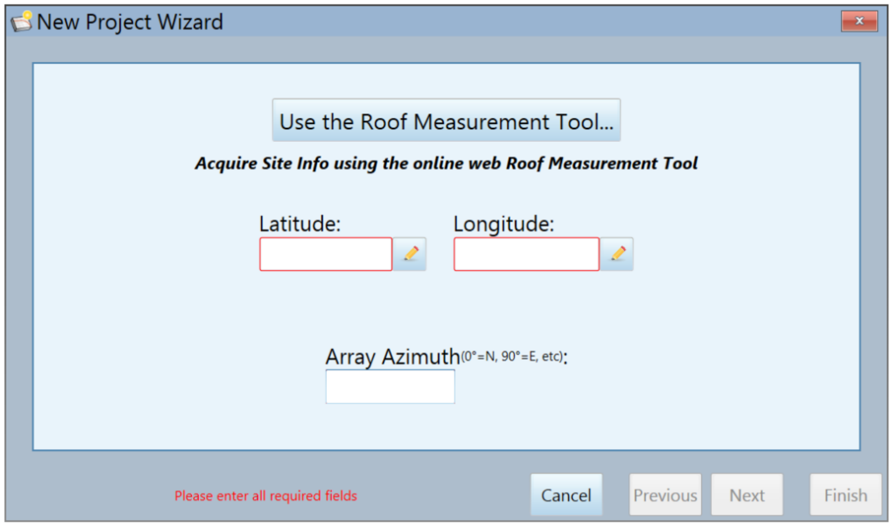


Figure 50. Site Information screen of the New Project Wizard

Enter the Site Information

1. You can enter the site information manually using the entry boxes, or click on **Use the Roof Measurement Tool…** to obtain the values using the Solmetric web based utility.

   If your site does not have a roof ridge or edge or other feature that you can use to identify the azimuth in the satellite image, you can still use the Roof Measurement Tool to return the latitude and longitude of your site, and enter the azimuth manually.

2. Click on **Use the Roof Measurement Tool…**.

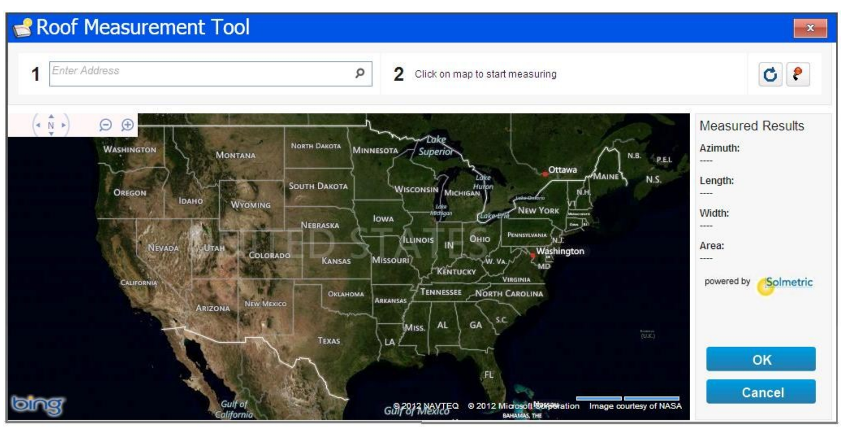


Figure 51. Roof Measurement Tool screen

3. Perform the following steps to use the Roof Measurement Tool:

   a. Enter the address of the building of interest.

b. Use the map controls to zoom in on the roof plane of interest.

c. The next step is to identify the orientation of the roof by drawing a line along the appropriate roof ridge or roof edge/eave. In this example, we draw our line along an eave that runs approximately east-west.

   Click at one end of the eave to establish a base point, and drag to the other end of the eave to create the line along the eave.

d. Next, click on the line you just created and drag it up the roof plane. This forms a rectangular outline on the roof as shown below, and an arrow appears, annotated with the true compass orientation of your roof.

Figure 52. Measuring your roof orientation

e. If necessary, adjust the alignment of the 'eave line' with the actual eave by dragging the endpoints.

f. The PVA software does not require the area of your roof surface, so the height and width of the rectangle you create is not important. However, if you need to know the area (projected onto the horizontal plane), you can adjust the height and width of the rectangle by dragging the edges.

g. Review the measured value of azimuth (this is true, not magnetic bearing).

h. Click **OK** to transfer the results to the PVA New Project Wizard.

If you are not web connected and can't use the Roof Measurement Tool, enter the values manually following these steps.

   a. Click **Latitude** and enter the latitude of your site in decimal form.

   b. Click **Longitude** and enter the longitude of your site in decimal form.

   c. Click **Array Azimuth** and enter the true compass orientation of your roof surface. This is the direction toward which the roof is tilted.

4. When you are finished, click **Next**, and the second screen of the New Project Wizard appears, as shown in Figure 53.

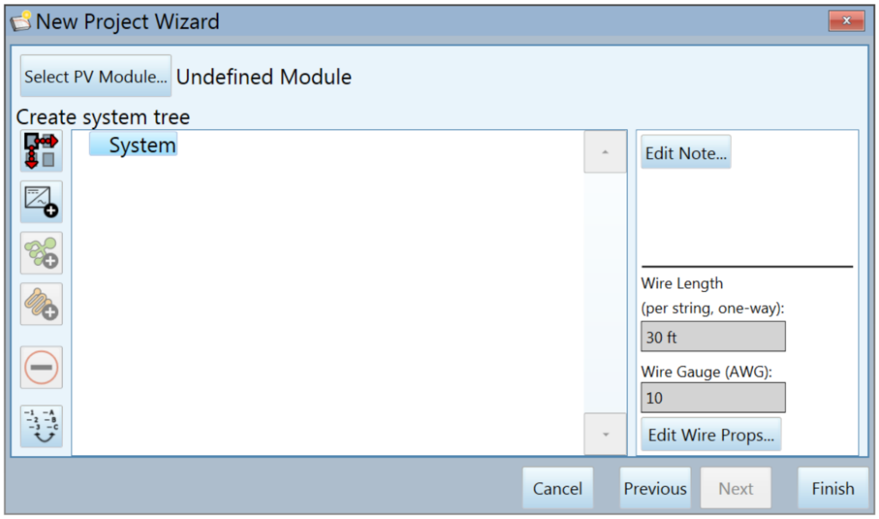


Figure 53. Second screen of the new project wizard, unpopulated

Select PV Module

1. Click on **Select PV Module...** and the Change Module screen appears, as shown in Figure 54.

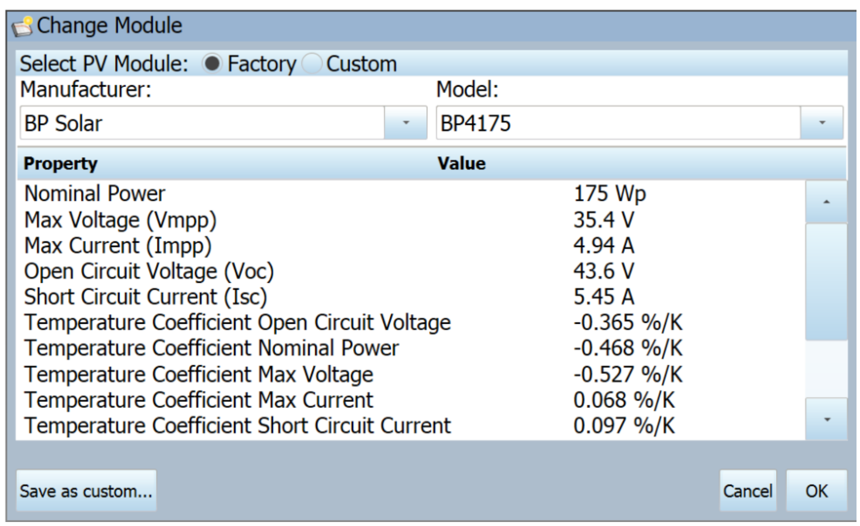


Figure 54. Change Module screen

2. Select **Factory** to invoke model parameters from the built-in database.

3. Click **Manufacturer** and select the manufacturer.

4. Click **Model** and select the model number. Parameter values for the available PV model appear in the Property and Value columns as shown in Figure 54.

5. If your module make and model number are not in the equipment database, check that your database is updated. This is checked automatically each time you launch the PVA software when web connected.

6. Click on **OK**.

Create the System Tree

1. After selecting your PV module, your Array Navigator screen will look similar to Figure 55.

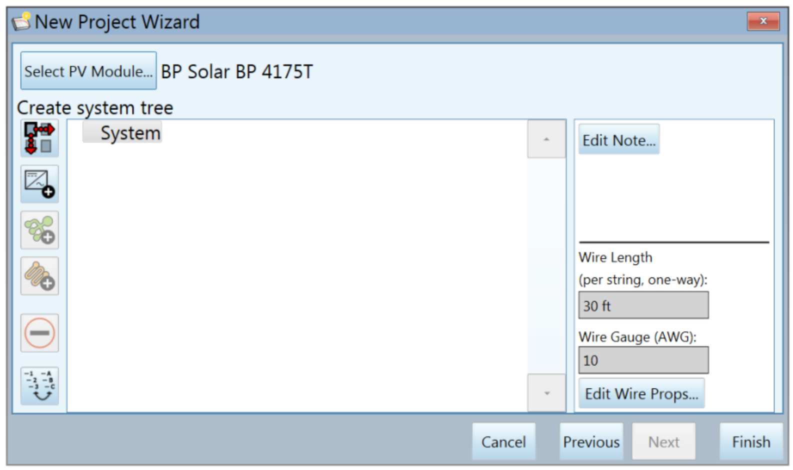


Figure 55. The second screen of the New Project Wizard, prior to creating your system tree

2. If your PV system has multiple identical inverters with identical arrays, click on **Autofill Tree** icon (the icon at the top of the column) to access the screen shown below.

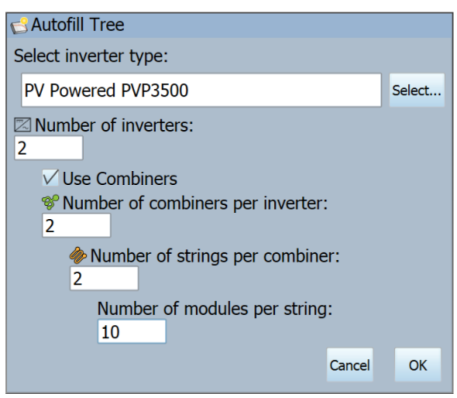


Figure 56. Autofill tree screen

3. Click **Select Inverter** to select your inverter from the inverter equipment database.

4. Click and enter the number of inverters.

5. If you are using combiners, check the box.

6. Click and enter the number of combiners per inverter.

7. Click and enter the number of strings per combiner.

8. Click and enter the number of modules per string.

9. Click **OK**.

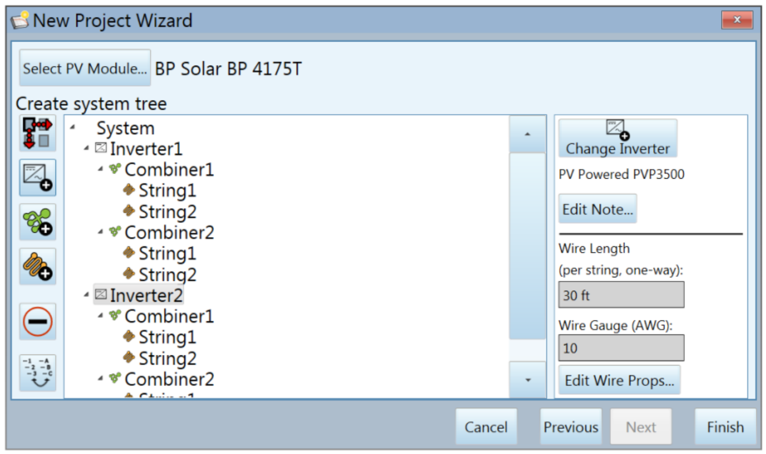


Figure 57. Populated Array Navigator screen

Add a New Inverter

Often a large rooftop project will involve several electrically identical inverters and arrays, and one smaller system to take advantage of remaining space. To add another inverter and array to your Project, follow the directions below.

1. Click the **Add Inverter** icon to access the Add Inverter screen below.

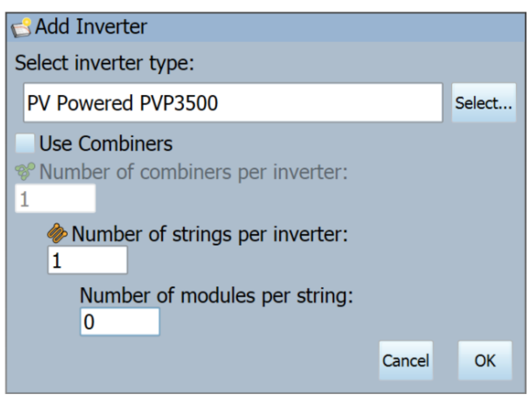


Figure 58. Add inverter screen

2. Click **Select…** to select the inverter from the built-in database.

3. Check the **Use Combiners** box if one or more combiners will be used.

4. Click in the **Number of combiners per inverter** (or combiner) field and enter the appropriate value.

5. Click in the **Number of strings per inverter** field and enter the appropriate value.

6. Click in the **Number of modules per string** field and enter the appropriate value.

7. Click on the **OK** button.

Add a New Combiner

The following procedure is used to add a combiner to an inverter, or to add a second level of combiners to the tree.

1. Highlight the inverter to which you want to add a combiner.

2. Click on the **New Combiner** icon to access the New Combiner screen shown below.

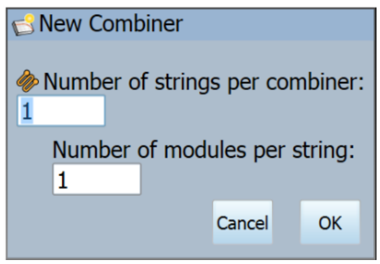


Figure 59. New combiner screen

3. Click in the **Number of strings per combiner** field and enter the appropriate value. The number of strings can differ from other combiners.

4. Click in the **Number of modules per string** field and enter the appropriate value. The number of modules per string should match the rest of the combiners feeding a given inverter.

5. Click **OK**.

Add a New String

The following procedure is used to add a new string in the system.

1. Highlight the inverter or combiner to which you want to add a string.

2. Click on the **Add String** icon to access the Add String screen shown in below.

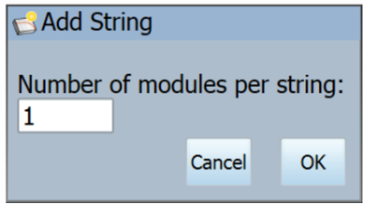


Figure 60. Add string screen

3. Click in the **Number of modules per string** field and enter the appropriate value.

Edit Wire Properties

The final step in creating your Project is to review and edit, if needed, the properties of the conductors that connect your PV string (or module) to the point at which the PV Analyzer I-V Unit is connected. The default properties are #10 AWG and 30ft (one way) wire length.

See Chapter 3, Software Overview, for general guidance about editing wire properties.

Editing the wire properties at any level of the system tree will update the wire properties for all of the strings at and below that level of the tree. Follow these steps:

1. Click on the desired level of the system tree.
2. Click on **Edit Wire Properties**
3. Select your wire gauge
4. Enter your wire length (one-way).
5. Click **OK**.

Create a Custom PV Model

If the latest database does not have your module, select the Custom option at the top of the screen, and then click **New...** to enter parameters from your PV module datasheet. When the New Custom Module screen opens, enter the model number of your module, then enter the required parameter values from your PV module datasheet, and click **Done**.

Creating a New Project that is Similar to an Existing 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 61.

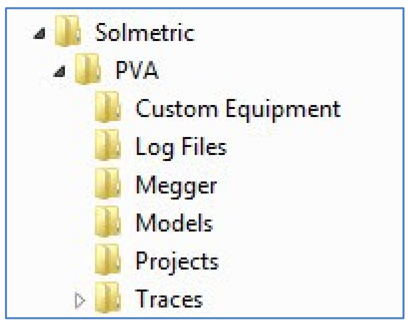


Figure 61. Directory structure used by the PVA software

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.

Making Measurements

See the following chapters for more detail on setting up the instrument and using the software:

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

- Chapter 3 Software Overview

Follow these steps to make typical measurements.

1. Set up and turn on your measurement system.
2. If you want to be able to compare your measured I-V curves with the predictions of the built-in PV modules and save your results, create a Project before starting your measurements.
3. Verify that the SolSensor wireless sensor data is being received. If the link is not established, the sensor displays will be blank. In that case, verify that SolSensor is turned ON and is within wireless range. Wireless range is reduced by obstructions in the line of sight between your PC and SolSensor. Setting your PC on a metal surface also reduces wireless range.
4. To open an existing project, select **Browse Project...** from the File menu.
5. Click **Measure Now** to take a measurement. The red pushbutton on the I-V Measurement unit will blink once at approximately the time the I-V sweep occurs.

Note: The PV Analyzer automatically makes adjustments to its internal settings to optimize measurement accuracy. The adjustments are based on currents and voltages that the instrument observed during the previous measurement. Since this history does not exist for the first I-V trace that is taken after starting the software, the PVA software used default values based on a typical grid tie PV string. Depending on your PV source under test, you may observe that the first trace you measure appears to consist of straight line segments, or the trace may not reach down to the horizontal axis of the I-V graph. These are typically the result of the default settings not being ideal for the PV source under test. Re-take the measurement to get a good clean trace.

6. When the measured I-V curve is displayed, the graph slides to the left and the Array Navigator appears. Click on the system tree at the location where the measurement was taken (if you were measuring two strings in parallel, click on both locations).
7. If you want to save the measurement, click on the **Assign and Save** button. If you want to compare the I-V curve to the predictions of the model but do not want to save it, click on **Assign Only**. The measurement ID display above the I-V curve graph indicated the location at which you saved or assigned your data. If the location is incorrect, click the **Reassign** button, click the correct location in the tree, and re-save or re-assign.
8. To If you want to recall a measurement result from the system tree to the display screens, click on the **Recall…** button and select the location on the system tree. If there are multiple measurements for that location, click on the result with the date/time of interest. Then click **Recall**.
9. If you want to compare the key performance parameters between the measured and predicted I-V curves, or to see the measured parameters translated to STC, click on the **Table** tab.

10. Repeat the measurement process for all of the strings (or modules) to be tested. .

Using the History Tab

The results of recent measurements are displayed in the table in the History tab. The table holds up to 20 measurements, with the most recent in the left column. Once the table is full, the table drops the oldest measurement to make room for the newest. The History tab is useful for checking the consistency of string performance at a combiner box, and for capturing the results of the steps in a troubleshooting sequence.

The contents of the History tab are saved in the Project file, but are not exported along with your I-V curve data.

Saving a Screen Image

To save a jpg image of the current measurement screen, click the **Camera** icon at the lower left corner of the screen.

Exporting Measurement Data

Saved measurement data can be exported for further analysis by means of two controls under the File menu.

To export all of the data for the currently loaded Project:

1. From the **File** menu, select **Export Traces for Entire System...**.

2. When the dialog box appears, choose the location to save your results.

When the active trace is exported, a csv file containing the trace and sensor data is saved at the selected location.

When traces for the entire system are exported, csv files for each string are saved in a folder directory that replicates the architecture of the PV system as described in the Array Navigator system tree.

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.

Troubleshooting Using Status Messages

Your main tool for troubleshooting PVA and its wireless link to your PC is the Status indicator, shown below. It appears in each of the measurement screens. The Status indicator indicates the state of the measurement system, and in some conditions clicking on the Status indicator will open a popup with additional information. The Status indicator labels and their meanings, as well as the contents of the popup messages, are listed below.

Figure 62. 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 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 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 level of 2.9 V.

"Initializing" message

When the message "Initializing" appears in the Status indicator, the link to the I-V 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.

"Optimizing" message

When "Optimizing" appears in the Status indicator, the I-V Unit internal settings are being optimized. This typically occurs during the first measurement that is performed after the link between the PC and the I-V Unit is established. This operation involves taking an initial trial I-V curve measurement and then optimizing the internal settings of the I-V Unit. The results of this first measurement are not displayed. The optimizing process roughly doubles the time required to perform the first measurement only.

"Measuring" message

When "Measuring" appears in the Status indicator, the I-V 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 Unit has turned itself off because it detected one of the following conditions. Click on the "Disabled" message and follow the instructions.

- 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 Unit firmware (contact Solmetric for support).

- I-V 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 Unit will now shut down. Recharge the battery before further use.

- Current in excess of 20 A 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.

- Voltage in excess of 1000 V was detected

  In this case, clicking on the "Disabled" message pops up a warning that the voltage specification was exceeded and the I-V Unit may have been damaged.

  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 Unit to be returned to the factory for inspection and repair.

- I-V Unit is too hot

  In this case, clicking on the "Disabled" message pops up a caution message that the I-V Unit's 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 measurement 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.

"Paused" message

When the message “Paused” appears in the indicator the I-V 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 level of 2.90 V. It also advises that the measurement is paused and that PV source connections may be changed without interrupting a measurement.

“No USB Wireless” message

This means that the PC cannot find the wireless USB adapter used to communicate with the I-V Unit. Plug the USB adapter into an open USB port. You may need to go to the Utilities menu, select Settings, and follow the instructions to locate the USB adapter. Be aware that each I-V Unit is matched with the USB adapter it was shipped with; mixing them up will make communications impossible. Matching USB adapters to I-V Units allows multiple PV analyzers to be used on large projects without disturbing each other's wireless links.

“No I-V Unit” message

In this case, the PC has found the wireless USB adapter, but cannot communicate with the I-V Unit. If the I-V Unit is switched off, turn it ON. If the LED is blinking quickly, the I-V Unit is trying to link. Check that the correct (matched) USB wireless adapter is plugged into the PC, and that the PC and I-V Unit are within wireless range of one another.

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 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 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 Unit, or by placing either the PC or the I-V 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 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 unit. Mounting SolSensor on a tripod in a location with good line of sight to your PC is another alternative.

SolSensor parameters will also be absent if the Network ID number of SolSensor and your Wireless USB Adapter do not match. See Your Wireless Network for details.

Communication to I-V Unit or SolSensor briefly drops out

This may occur when the I-V Unit or SolSensor or both are being physically relocated. The communication path from the PC to each of the instruments may be direct or indirect (one instrument relays the signal to the other). Indirect links allow operation at greater distances from the PC, but the network may be unavailable for 10-20 seconds during the switch between direct and indirect.

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 only when extreme 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.

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

This type of trace may be seen if you have been measuring strings or modules with a certain level of current and voltage, and then switch to measuring devices that have much higher or lower currents or voltages. The solution is to re-take the measurement. This is normal behavior under such circumstances because the PV Analyzer automatically reconfigures its circuitry for best measurement accuracy, and to save measurement time, it bases this reconfiguration decision on the previous measurement result.

This symptom may also occur in the first measurement made after starting the PVA software. This is due to the fact that the PVA did not have a prior measurement on which to base its automatic optimization of its internal circuit settings. Simply take a new curve.

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.

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.

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 Unit cannot be turned on

Check that the Unit has been charged.

Thermal fuse

The I-V Unit contains a thermal fuse set to trip at 85C. This is an uncommon occurrence, but it irreversibly shuts down the Unit. If you suspect that this has occurred, contact Solmetric Technical Support.

Solmetric Technical Support
Phone: 707-823-4600 X2
Toll Free: 877-263-5026
Email: support@solmetric.com

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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 capacity 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
- 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 these 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 a surface temperature measurement 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 outer surfaces.
- Temperature offset between PV cell and module backsheet depends on racking configuration and ventilation.
- 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.

These topics are all discussed in this chapter.

The PVA software provides multiple methods for measuring irradiance, temperature, and tilt, as shown in Table 16.

Table 16. 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 Irradiance

SolSensor's irradiance measurement is further calibrated 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 calibration, and are considered 'preliminary irradiance' values. In this situation, the irradiance value is displayed in italics. Once the Project and model are created, the irradiance is displayed in normal font. Expect to see slight differences between preliminary and final irradiance.

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.**

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 Setting Up SolSensor 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 limitations are due to the fact that because the resulting irradiance value is an input to the PV model, the dot locating the predicted value of I_{sc} is forced to agree with the measured value of I_{sc}.

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 I_{sc} value is forced to agree with the measured I_{sc} 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 I_{sc} is also interpreted as reduced irradiance, and thus is not detected. The From I-V temperature option provides several benefits:

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

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 V_{oc} and the resulting temperature value is an input to the PV model, the model dot representing V_{oc} is forced to agree with the measured value of V_{oc}.

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 V_{oc} value is forced to agree with the measured V_{oc} 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 V_{oc} is valid only at relatively high irradiance. At low irradiance, there is substantial error in the derivation of temperature.

- Shorted bypass diodes are interpreted as lower cell temperature. You can mitigate this risk by comparing V_{oc} 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.

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. 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.

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.

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 (e.g., 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 $\varepsilon = 1$ while any real object would have $\varepsilon < 1$. 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 V_{oc} and the resulting temperature value is an input to the PV model, the model dot representing V_{oc} is forced to agree with the measured value of V_{oc}.

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 V_{oc} value is forced to agree with the measured V_{oc} 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 V_{oc} is valid only at relatively high irradiance. At low irradiance, there is substantial error in the derivation of temperature.
- Shorted or conducting bypass diodes are interpreted as lower cell temperature. You can mitigate this risk by comparing V_{oc} 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.

Using SmartTemp to Measure Cell Temperature

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

- At irradiance values lower than 400W/m2, temperature is calculated 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 shifting blend of the thermocouple and From I-V method.

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.

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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 be operated or loaded. 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 substantial deviations from the predicted I-V curve shape contain information about the performance of the PV System. This section describes the most common patterns of deviation and identifies possible 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 measured strings in parallel
- Length and gauge of wire between the PV modules and the PV analyzer
- Irradiance
- PV cell temperature
- For some PV models it is also necessary to provide:
    - .Array azimuth and tilt
    - Latitude and longitude
    - Date, time, time zone, and daylight savings information.

An inverter database is included in the PVA software only to display the inverter's max power tracking range on the I-V curve graph. The inverter characteristics do not affect the measurement of the I-V curves and are not used in creating the PV model.

I-V Curve Terminology

These abbreviations will be used in the following discussion:

- I_{sc} Short circuit current
- I_{mp} Max power current
- V_{mp} Max power voltage
- V_{oc} Open circuit voltage
- PF Performance Factor (PF, %) = 100 * (Measured P_{max}/Predicted P_{max})
- FF Fill Factor = $I_{mp} * V_{mp} / (I_{sc} * V_{oc})$

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 current values of irradiance and temperature. This means that Performance Factor values taken at different irradiances and temperatures can be directly compared. 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 I-V curve. It is defined by three points on the I-V curve, as shown in Figure 1. Its range is 0 to 1.0, and the closer the Fill Factor is to 1.0, the more square is the shape of the I-V curve. Each PV technology has its own nominal range of fill factor values, and each module model number typically has an even narrow nominal range.

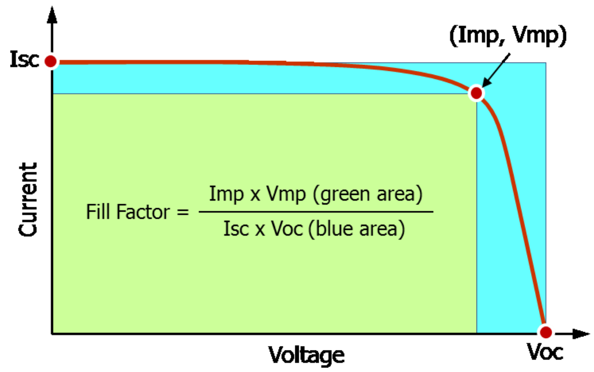

Figure 63. Definition of the Fill Factor.

Fill Factor does not very 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. The power versus voltage curve is also displayed (blue line). Like the I-V curve itself, the P-V curve represents the entire family of points at which the PV circuit could be operated or loaded. The P-V curve is generated by multiplying I x V for at every point on the I-V curve.

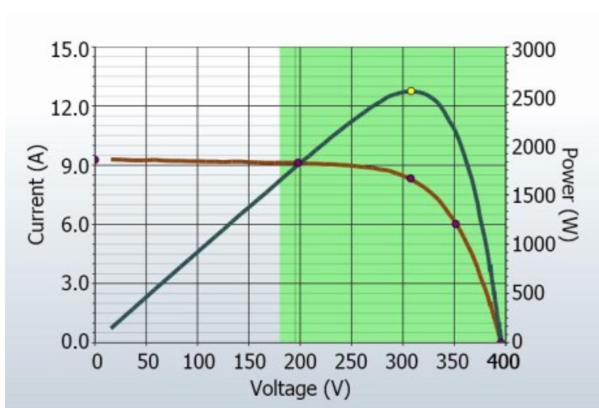

Figure 64. A normal I-V curve for the parallel combination of two strings of eight 175-watt modules, showing conformance with five points predicted by the PV model.

A normal I-V curve has a smooth shape with three distinct voltage regions as shown in Figure 64:

1. A slightly sloped region above 0 V (the horizontal leg of the curve)
2. A steeply sloped region below V_{oc} (the downward leg of the curve)
3. A bend or '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. Crystalline silicon cells have sharper knees; thin film modules usually have more gradual knees.

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

- SC – First point, at the predicted short circuit current I_{sc}
- MP – Second point, the predicted maximum power point I_{mp}, V_{mp}
- OC – Third point, at the predicted open circuit voltage V_{oc}

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

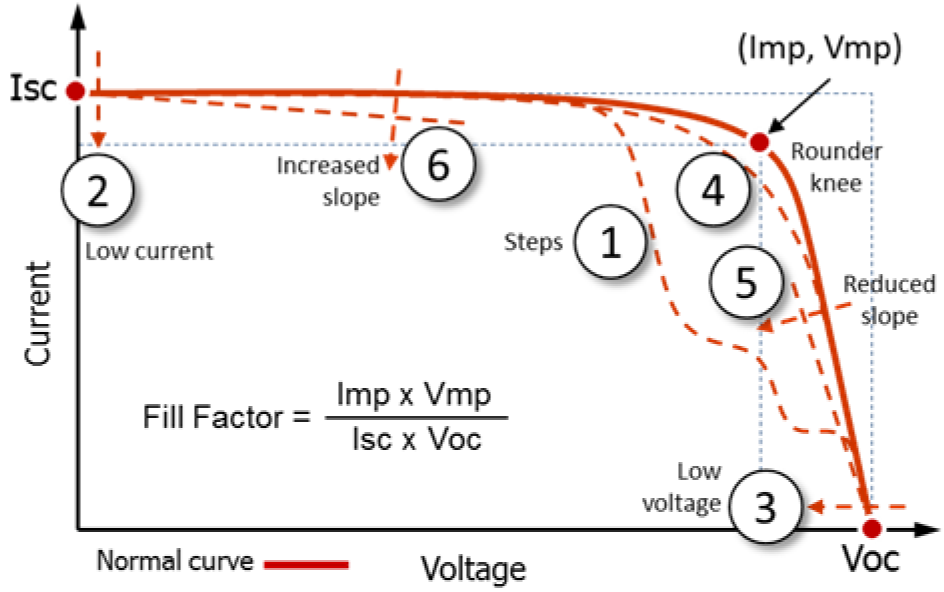

Figure 65. Deviations in the shape of the I-V curve fall into one (or a combination) of these six categories

It would be convenient if each of the I-V curve deviations illustrated in Figure 65 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 included 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 66, Figure 67, and Figure 68.

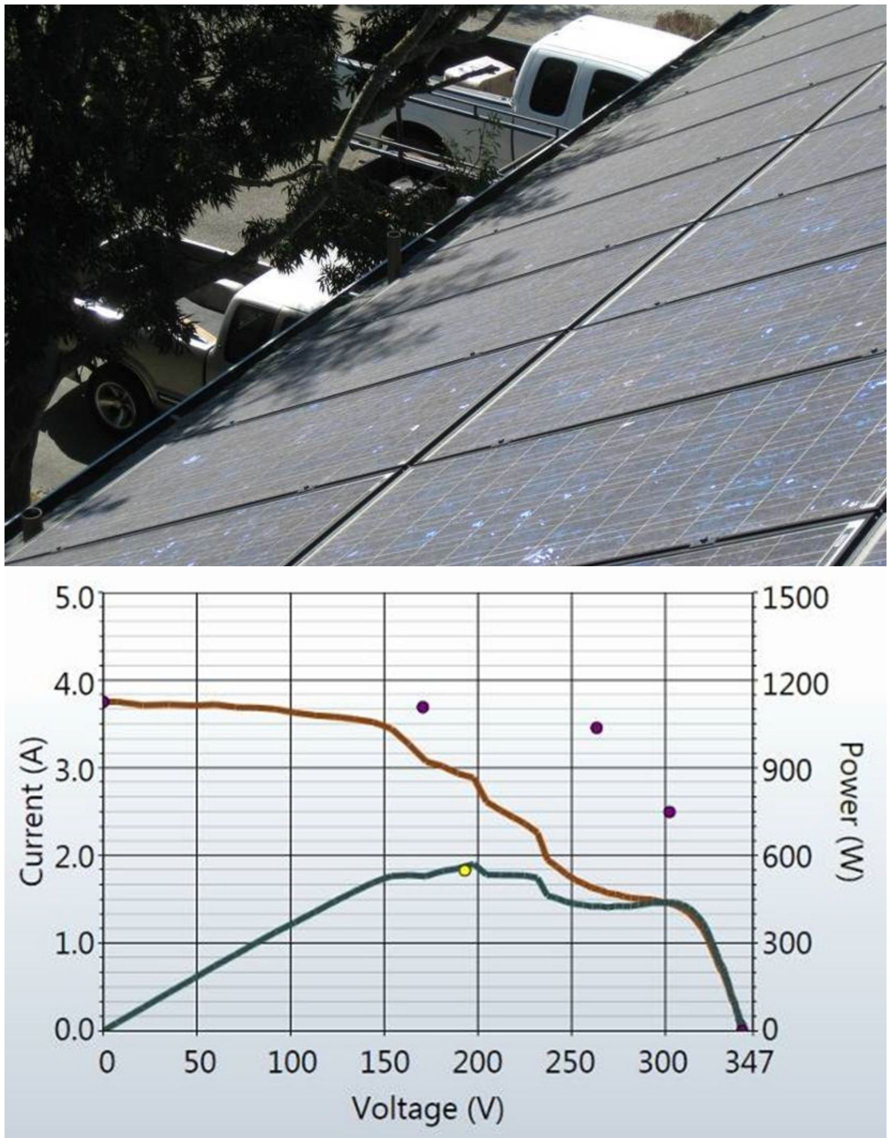

Figure 66. The effect of partial shading on a string I-V curve.

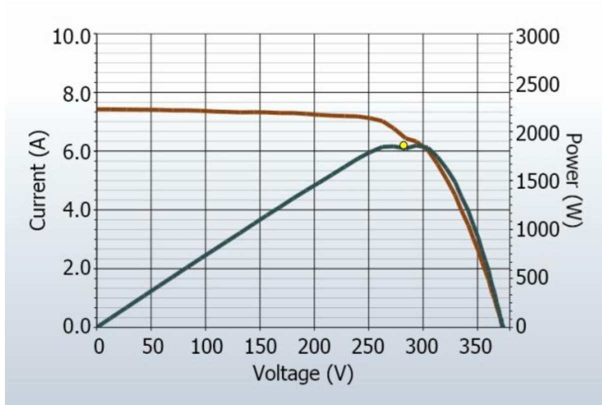

Figure 67. The shading impact of placing a business card on a single cell in a string of fifteen 180-watt modules

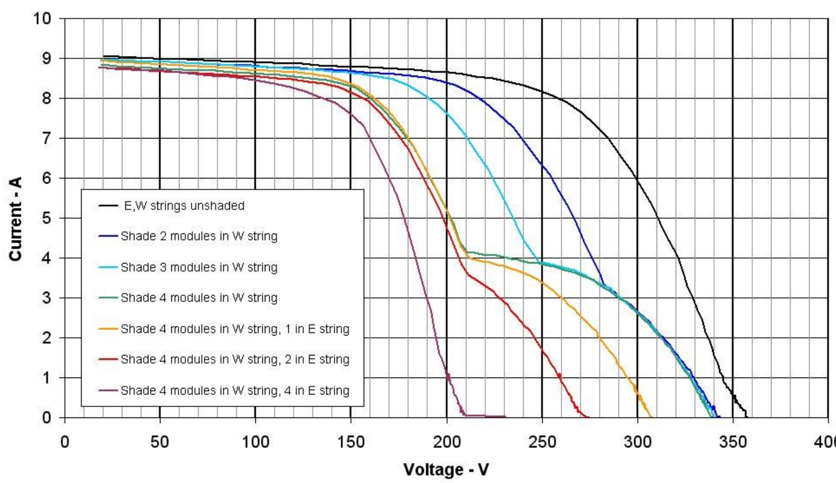

Figure 68. The effect of intentionally shading entire modules in different combinations, in two parallel-connected strings

NOTE	The graphic shown in Figure 68 is an overlay of several I-V curve measurements.

In general, these types of patterns in the I-V curve are indications of mismatch between different areas of the array or module under test. Although the figures shown above all involve shading, mismatch can have other causes. The notches in the I-V curve are indications that bypass diodes are activating and passing current around module sub-strings (internal cell strings) that are not able to pass the full current of the stronger modules.

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

Potential causes located in the array include:

- Array is partially shaded, or non-uniform soiling or debris is present
- PV cells are damaged

- Bypass diode is short-circuited

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 in turn reduces the maximum current that can be produced by other series connected cells. For example, slightly shading one cell in a 72 cell module that has 3 bypass diodes will slightly reduce the current in 24 cells. Bypass diodes prevent that cell from going into reverse bias. If the PV module is supplying a load and the current demanded by the load is above the (reduced) current provided by the partially shaded cells, the bypass diode will begin conducting and pass current around the shaded cell strings. Without the bypass diode present, the cells would be reverse biased, which can generate potentially damaging reverse breakdown voltage and hotspot failure, as discussed in *5. Steeper slope in horizontal leg*. The impact of partial shading on the I-V curve is to create a notch. In a single PV string, the vertical height or current at which the notch appears is equal to the reduced short-circuit current of the partially shaded cells. The horizontal or voltage distance from V_{oc} to the notch is related to the number of cell strings within modules that have been bypassed.

PV Cells Are Damaged

In a cracked cell, a portion of the cell may be electrically isolated. This has the same effect on the I-V curve as shading of an equivalent area of a normal cell. A notched I-V curve can result depending on the severity of the PV cell damage.

Cell String Conductor Is Short Circuited

A localized hot spot, as discussed in X. Steeper Slope in Horizontal Leg, can also cause a bypass diode to turn on, effectively removing a cell string from production.

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.

Potential causes located in the array include:

- Uniform soiling
- Strip shade
- Dirt dam
- Module degradation

Potential causes associated with the model settings include:

- Incorrect module is selected for the PV model
- Number of PV strings in parallel is not entered correctly in the model

Potential causes associated with irradiance or temperature measurements include:

- Irradiance changed during the short time between irradiance and I-V measurements
- Irradiance sensor is not oriented in the plane of the array
- Albedo effects (reflection) contribute additional irradiance
- Irradiance is too low, or the sun is too close to the horizon
- Manual irradiance sensor is not accurate

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

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 factors that can affect the height of the I-V curve, the operator should estimate the impact of these other 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.

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) Contribute Additional Irradiance

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.

Irradiance Is Too Low, or the Sun Is Too Close to the Horizon

Most PV modules exhibit changes in the shape of their I-V curves under low light conditions. This effect tends to set in below 600 W/m^2 and becomes quite significant below 400 W/m^2. Also, if sunlight is hitting the module surfaces at a glancing angle - early or late in the day - a much greater share of the light will be reflected by the module glass and the cells themselves. Finally, the spectrum of sunlight changes in the course of a day. For best results, measure PV arrays during the central part of the day, preferably within a two-hour interval either side of solar noon. See this web site to determine solar noon for your location: http://www.esrl.noaa.gov/gmd/grad/solcalc/.

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.

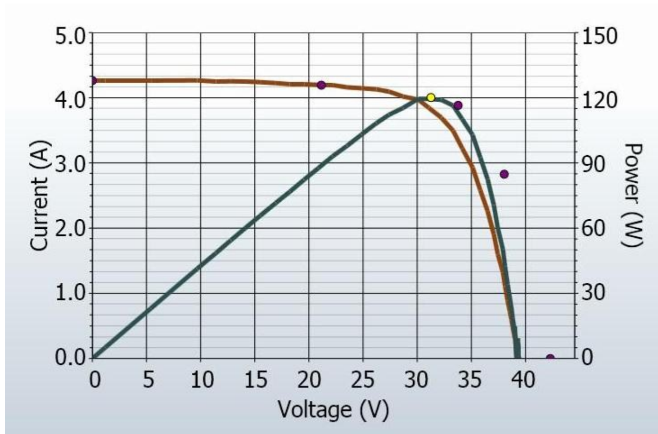

Figure 69. Measurement with less steep than predicted slope in the vertical leg of the I-V curve.

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

Potential causes located in the array include:

- PV cell temperature is hotter than the measured temperature
- One or more cells or modules are completely shaded
- One or more bypass diodes is conducting or shorted

PV Cell Temperature Is Hotter than the Measured Temperature

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 temperature measurement device and the back of the module. Also, if the temperature measurement is taken on the front side of the module, direct sunlight on the temperature sensor could result in erroneous temperature readings. It is also possible that the PV module under test has a poor thermal connection between the back of the module and the actual PV junction.

One or More Cells or Modules Are Completely Shaded

Hard shade on an entire cell causes its associated bypass diode to begin conducting a very low current, making it look like V_{oc} has shifted downward. If you are uncertain, check the value of V_{oc} that the PVA software lists in the Table tab. This value is measured under open circuit conditions, just a moment before the I-V measurement actually begins.

One or More Bypass Diodes Are Conducting or Shorted

Failure modes within individual PV modules may cause a bypass diode(s) to conduct even in the absence of shade or severe module-to-module mismatch. The I-V curve shape may look normal except that the V_{oc} value is lower than predicted. You can use selective shading to locate the module(s). This troubleshooting method involves taking I-V measurements of the string, shading a different module each time. The I-V curves taken with the normal modules shaded will all look alike.

4. Rounder knee

An example of this type of deviation is shown below.

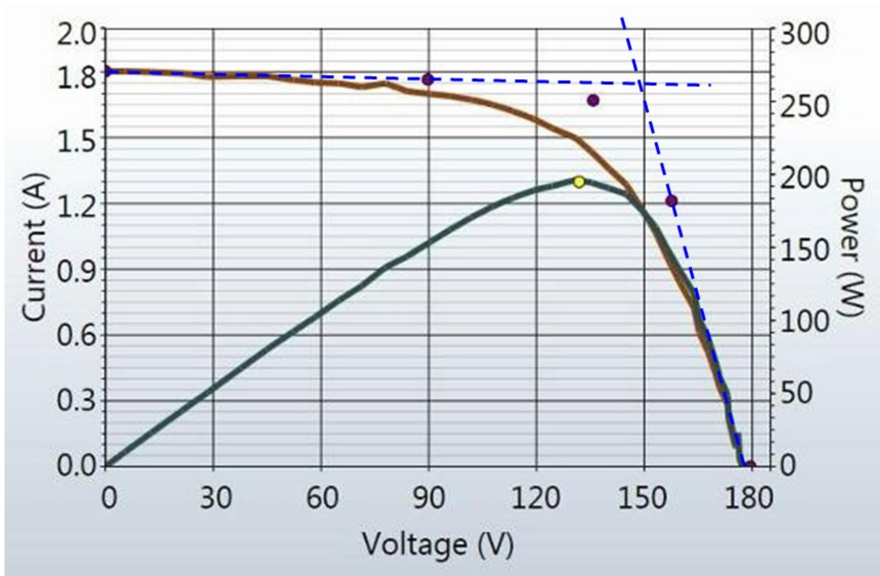

Figure 70. I-V curve measurement showing rounder knee than predicted by the PV model.

Rounding of the knee of the I-V curve can be a manifestation of the aging process. Before concluding that this is the case, check the slopes of the horizontal and vertical legs of the I-V curve. If they have changed, it can produce a visually similar effect in the shape of the knee.

5. Steeper slope in horizontal leg

An example of this deviation is shown below.

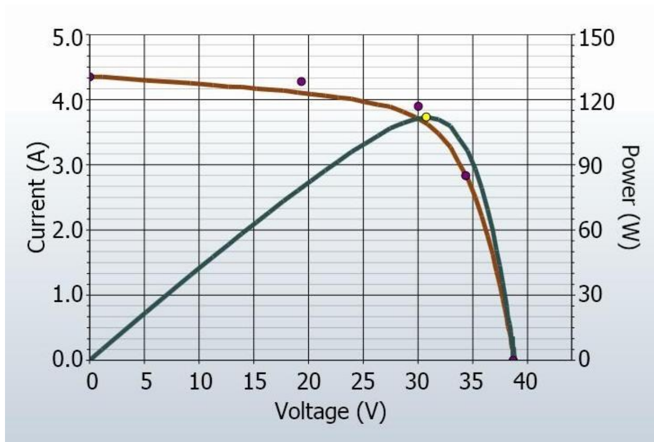

Figure 71. An I-V curve showing steeper slope in the horizontal leg of the I-V curve.

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.

Potential causes located in the array include:

- Tapered shade or dirt dams
- Module I_{sc} mismatch
- Shunt paths exist in PV cells

Shunt Paths Exist In PV Cells or Modules

Shunt current is current that bypasses the solar cell junction without producing power, short circuiting a part of a cell or module. Some amount of shunt current within a solar cell is normal, although higher quality cells will have a higher shunt resistance and hence lower shunt current. Shunt current can lead to cell heating and hotspots appearing in the module encapsulant material. Shunt current is typically associated with highly localized defects within the solar cell, or at cell interconnections. Infrared imaging of the PV module can usually identify minor shunt current hot spots since a temperature rise of 20 ºC or more is common.

A reduced shunt resistance will appear in I-V curves as a steeper (less flat) slope near I_{sc}. As the cell voltage increases from the short circuit condition, the current flowing in these shunts increases proportionally, causing the slope of the I-V curve near I_{sc} to become steeper. The shunt current in a series of modules or within a single module can be dominated by a single hotspot on a single cell, or may arise from several smaller shunt paths in several series cells.

Shunts within a module can improve over time, or can degrade until the module is damaged irreparably. Smaller shunts can self-heal if the high current through the shunt path causes the small amount of material shorting the cell to self-immolate. Larger shunts can result in localized temperature rises in the module that can reach the melting point of encapsulant material or the module backsheet. Modules that have failed in this manner will tend to show burn spots or other obvious evidence of failure. Bypass diodes in the PV module are designed to prevent damage due to hotspot, and so failure of the bypass diode may accompany hotspot damage.

If the I-V measurement of a PV string shows a substantial slope, you can localize the problem by successively breaking the string into smaller segments and measuring the segments individually. Be sure to update the model with the reduced number of modules in series.

Module I_{sc} Mismatch

Increased slope along the upper leg of the I-V curve may have less to do with shunt resistance, and more to do with small mismatches between the I_{sc} values of each module. I_{sc} values in a real PV system will have some mismatch, due to slight manufacturing variations, slightly different installation angles, or special cases of shading and non-uniform soiling.

Special cases of shading can also cause more slope in the upper leg of the I-V curve. The most common case takes place in multi-row tip-up arrays in which the upper edge of one row of modules casts a sliver of shadow across the lower edge of another string of modules. If the sliver of shade varies in height from one end of the shaded string to the other, the result is an effective change in module I_{sc} from one module to another. This can cause the upper leg of the I-V curve to tilt more steeply.

Special cases of module soiling can also cause more slope in the upper leg of the I-V curve. The most common case appears in shallow-tilt arrays that encourage soiling to build up along the lower edge of modules. If a string of modules is mounted in a row and the lower edge of the string is not horizontal, the height of the dirt band may vary from one end of the string to the other. This has the same effect as a slight reduction in module I_{sc} from one end of the string to the other. The result is an increase in slope of the upper leg of the I-V curve.

Tapered shade or dirt dam

When a string of modules is mounted in portrait orientation, a band of shade or dirt across the entire string can cause the steeper slope in the horizontal leg of the curve, but only if the band is tapered from one end to the other (or if there is a randomized slight variation in the extent of the dirt band across the modules in the string).

6. Less steep slope in vertical leg

An example of this type of deviation is shown below.

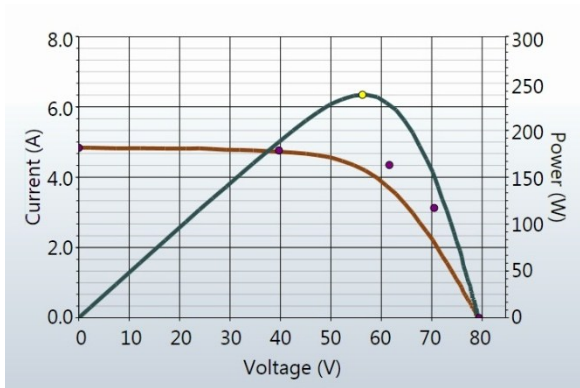

Figure 72. Measurement with less steep slope in the vertical leg of the I-V curve.

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.

Potential causes located in the array include:

- 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 or Is Insufficiently Sized

The electrical resistance of the PV modules and their connecting cords are accounted for in the models stored in the PV analyzer module database. If the PV output conductors (for example, from string to combiner box) are very long, or the wire gauge unusually small, or both, the PV model can be adjusted to account for that extra resistance.

To see the effect of wire resistance on the predicted I-V curve, enter 500 feet (1-way) of #10 wire. This will add approximately 1 ohm of series resistance. Notice the change of slope in the I-V curve near V_{oc}.

The resistance of the primary test leads of the PV analyzer is extremely low and can be neglected. The resistance of the Solmetric Test Lead kit can also be neglected. Using smaller-gauge test leads can add significant resistance and corresponding measurement error.

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. Corrosion damage is more common in aged modules in humid or coastal environments. Manufacturing defects within the module can also result in poorly interconnected solar cells. If you see a burn mark along one of the module's internal ribbon conductors, it may be an indication that an interconnection is becoming more resistive. These burn marks tend to be located at the connection of two spans of internal ribbon conductors, or at the interconnection between these ribbons and the PV module cords. Before deciding that excess resistance comes from these sources, be sure to properly account for PV wiring resistance in the model, and check the electrical connections external to the PV modules for signs of damage, corrosion, or heating.

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/m^2 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 I_{mp}, (%/°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)

Definition of the translation process

The basic translation model used here makes the following approximations:

1. P_{mp} is proportional to E, the irradiance
2. I_{mp} does not depend on temperature
3. V_{mp} is independent of E
4. P_{mp} varies with temperature according to γ_{mpp}. (taken from the datasheet)
5. 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:

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

$I_{sctrans} = I_{scm} * [E_{trans} / E_m] / \{1+\alpha_{Isc}/100*(T_m-T_{trans})\}$

$I_{mptrans} = I_{mp} * E_{trans} / E_m$

$V_{mptrans} = V_{mpm} * [\ln(E_{trans}) / \ln(E_m)] / \{1+ \gamma_{mpp} /100*(T_m-T_{trans})\}$

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