Solmetric PVA-600
PV Analyzer

User's Guide

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1 Introduction

Overview

The PVA-600 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 compare the results to on-board PV model predictions. Measurement results are easily saved for future reference and analysis. The PVA-600 is controlled wirelessly by the user's portable PC via a wireless USB adaptor. An optional Wireless Sensor Kit is also available. Wireless interfaces allow the user to move around in the immediate work area, and eliminate the trip hazards associated with hard-wired interconnections.

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 (Isc) at zero volts, to the open circuit voltage (Voc) at zero current. At the ‘knee’ of a normal I-V curve are the maximum power current and voltage (Imp, Vmp), the point at which the array generates 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 in the same database as the PVA-600 I-V measurement results.

Computer Minimum System Requirements

- Test and Supported Operating System: 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.

PVA-600 Equipment

- I-V Measurement Unit
- Soft Case
- Wireless USB Adapter and PVA-600 Software Application
- Battery Charger
- MC-4 to MC-4 Connector-Saver Cable (2)
- MC-4 to MC-3 Adapter Cable (2)
- User’s Guide (on Installation DVD)
- Quick Start Guide

PVA-600 Specifications

Electrical Specifications

Safety Rating: Measuring Category CATIII 600V.

Table 1. PVA-600 electrical 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	+0º°C to +50º °C
Storage Temperature	-20º°C to +60º °C
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.

[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.

Mechanical Specifications

Table 2. PVA-600 mechanical specifications

Parameter	Specification
PV Connectors[1]	MC-4
Weight	9.2 lbs (not including weight of the soft case)
Height	15 in
Width	8 in
Depth	5 in

[1] At ends of the primary test leads permanently attached to the I-V Measurement Unit.

Solmetric Wireless Sensor Kit Equipment (Optional)

- Irradiance Sensor
- Temperature Sensor
- Pack of Replacement Temperature Sensors
- Wireless USB Adapter
- Transmitter (irradiance)
- Transmitter (temperature)
- Case
- Rechargeable AAA batteries and battery charger

Solmetric Wireless Sensor Kit Specifications (Optional)

Table 3. Solmetric Wireless Sensor Kit temperature specifications

Parameter	Specification
Thermocouple Type	K
Range	-100º C to 200º C
Resolution	1º C
Accuracy	1.0º C typical

Table 4. Solmetric Wireless Sensor Kit irradiance specifications

Parameter	Specification
Sensor Type	Monocrystalline Silicon Solar Cell
Range	0 - 1500 W/m^2
Accuracy	5% typical
Angle of Incidence Effect	Typically < 1% if AOI is less than 60 degrees from normal
Temperature Effect	Typically < ±2.7% variation over -20º C to +70º C
Uncertainty Contributed by Wireless Link	±0.5% of reading
Uncertainty from Time Lead or Lag in Reading Irradiance Sensor	0.5% to > 5% depending on atmospheric conditions

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 has 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.

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2 Getting Started

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'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-600'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-600'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 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’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 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's 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.

Understanding the PVA-600

Application Overview

The PVA-600 is used during PV system installation and commissioning to ensure proper performance of PV modules, strings, and arrays. The PVA-600 is also used for maintenance and troubleshooting to assist in locating the cause of performance problems in the system and documenting the problems to support module warranty returns.

The PVA-600 consists of the following:

- I-V Measurement Unit (PVA-600)
- PC/PVA software (Windows PC, supplied by user)
- Optional wireless irradiance and temperature sensors (Solmetric Wireless Sensor Kit)

Communication between the I-V Measurement Unit and your PC is wireless. A wireless transmitter/receiver is built into the I-V Measurement Unit, and a wireless USB adapter allows your notebook or tablet computer to be the control/display device. The wireless USB adapter and PC-based software are supplied with the PVA-600.

The optional wireless irradiance and temperature sensors communicate with the PC by means of a second wireless USB adapter, supplied with the sensor kit. If you have only one USB port in your PC, you can expand that port using a notebook-style USB port expander.

I-V Measurements

The I-V Measurement Unit will measure an I-V curve when the user presses the Measure Now button on the PVA PC software. The measurement results are transmitted shortly after an I-V sweep is completed.

The measured I-V curve is displayed along with the modeled (predicted) I-V points. Key values such as Isc, Voc, and so on, are displayed in a table.

PV Models

Three PV models are used in the PVA-600: the Sandia, the 5-Parameter, and the Simple Performance Model. These models make use of parameters unique to each PV module which are stored in a database in the PC. These parameters are updated or extended when an update is done through the Solmetric web site. Some modules, particularly very old or very new ones, may not be represented in the on-board databases. In this case, the Simple Performance Model can be used with parameters entered by the user from the PV module data sheet.

Insulation Resistance Measurements

The PVA-600 PC software provides a convenient method to store and retrieve your insulation resistance measurements. Data is entered by the user manually, making the software compatible with any brand of insulation resistance tester. Measurements can be stored at the subarray (combiner box), string, or module level in the Meg Test screen of the PVA-600. The results are saved and recalled using the same database that is used to manage the I-V measurement data.

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-600 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. Alternatively, 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-600 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.

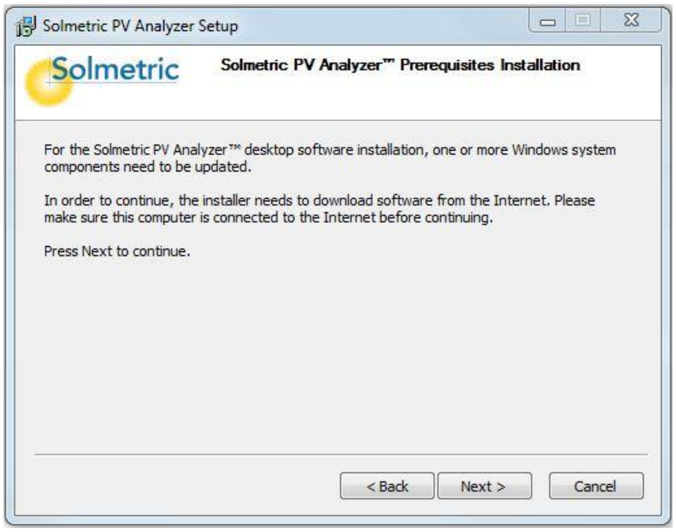

Figure 2. Prerequisites dialog

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

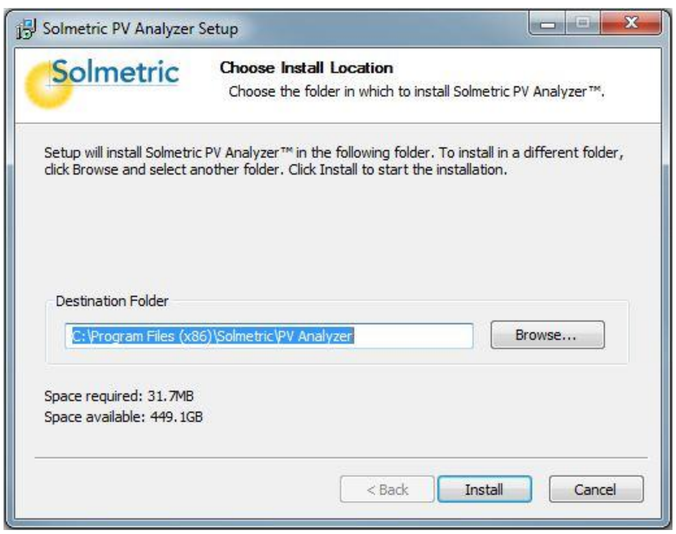

Figure 3. Installation default location dialog

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 Measurement Unit.

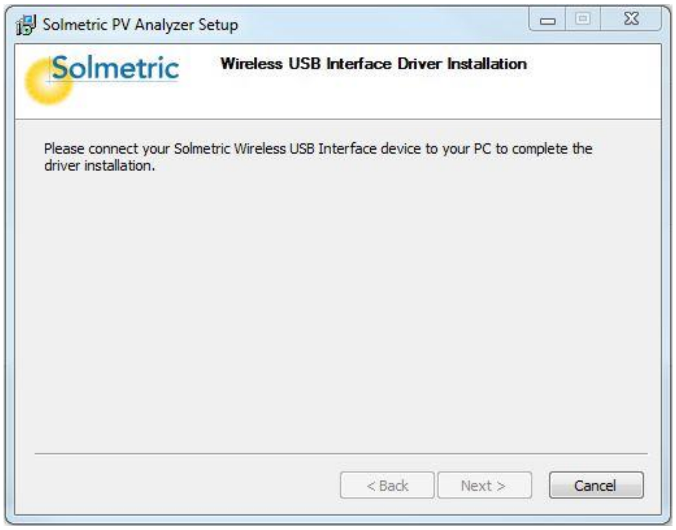

Figure 4. Insert wireless USB adapter dialog

7. Insert the wireless USB adapter shown below.

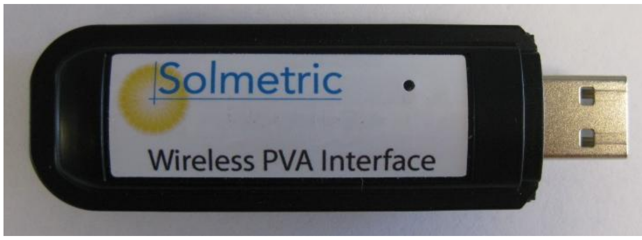

Figure 5. Insert wireless USB adapter

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

Figure 6. Installation complete dialog

9. If the Run Solmetric PV Analyzer box is checked, the PVA software will launch when you click Finish. Alternatively, you can start the PVA-600 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-600 software

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

Figure 8. Splash screen

11. When the initialization is complete, the screen shown in Figure 9 should appear.

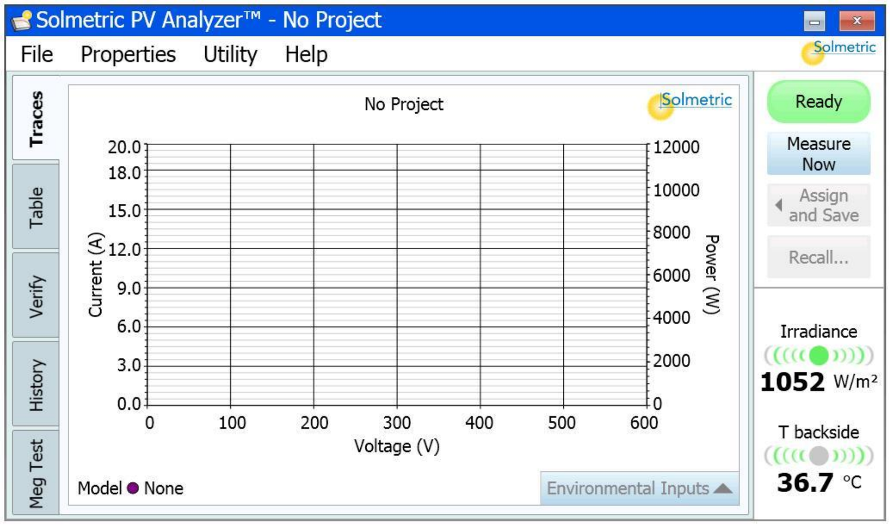

Figure 9. PVA-600 software user interface

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.

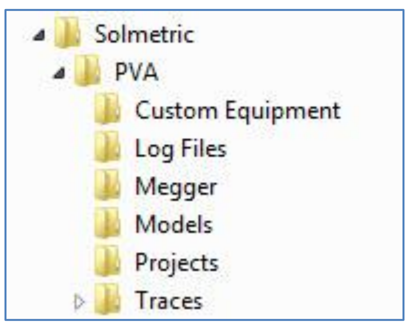

Figure 10. Directory structure of PVA-600 software

Updating the PV Equipment Databases

If your PC is connected to the internet when you start the PVA software, the software will check whether new PV module or inverter equipment databases are available to be downloaded from Solmetric.

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 re-installation 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:

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

b. 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.

Installing Drivers for the Optional Solmetric Wireless Sensor Kit

The Solmetric Wireless Sensor Kit uses the same drivers as the PVA-600. Therefore, once the PVA-600 Software has been installed, no additional installation is required for using the Solmetric Wireless Sensor Kit.

Charging the Battery

The battery in the PVA-600 is not removable. It may be recharged by attaching the battery charger to the connector on the PVA-600 shown in Figure 11 and plugging the charger into an AC wall-plug.

Figure 11. Battery charger connector on the PVA-600

Charging the battery can take up to 6 hours. Once the battery has been charged, the PVA-600 will operate for approximately 20 hours of normal operation. If you are using your PVA-600 heavily, we suggest you charge it each night.

There is no visible indication of charging on the PVA-600 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-600 Software interface. However, the PVA-600 Software interface will warn the user 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 PVA-600 should not be operated while the battery is charging.*

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3 Using the PVA-600

System Controls and Settings

The LED-illuminated button switch on the top surface of the I-V Measurement Unit, shown in Figure 12, is used to control the state of the measurement system, to enable or disable the I-V Measurement Unit, and to reset the unit.

When the I-V Measurement Unit is turned on, it searches for its wireless partner, the Wireless USB Adapter that is plugged into your notebook or tablet computer, to establish a network for control and data transfer.

Figure 12. LED-illuminated button switch

PVA-600 States

The PVA-600 I-V Measurement Unit has the following states:

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

Table 5. PVA-600 states

PVA-600 State	Description	Power Button State
Power Off	PVA-600 is turned off.	LED Off.
Network Search	Press the power button once. Communication between the I-V Measurement Unit and the Wireless USB Adapter is attempted. If a network is not established within 15 minutes, the I-V Measurement Unit will turn off automatically.	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 sweep.
Sweep Disabled (pause)	While the I-V Measurement Unit is on, press the power button once. The sweep is disabled. Disable the sweep before connecting or disconnecting the I-V Measurement Unit to/from PV modules or strings. If left in Sweep Disabled mode for more than 15 minutes, the I-V Measurement 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 PVA-600

1. Place the I-V Measurement 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 Measurement Unit. The Solmetric PVA Test Leads are recommended for this application. These heavy duty armored test leads have MC-4 connectors at one end and 4-mm sheathed banana plugs with jumbo alligator clips at the other end.
4. If long extension cables are connected to the I-V Measurement 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 Wireless Sensor Kit, refer to Setting Up the Optional Solmetric Wireless Sensor Kit for setup information.

Setting Up the Optional Solmetric Wireless Sensor Kit

Figure 13 shows the Solmetric Wireless Sensor Kit components that will be set up.

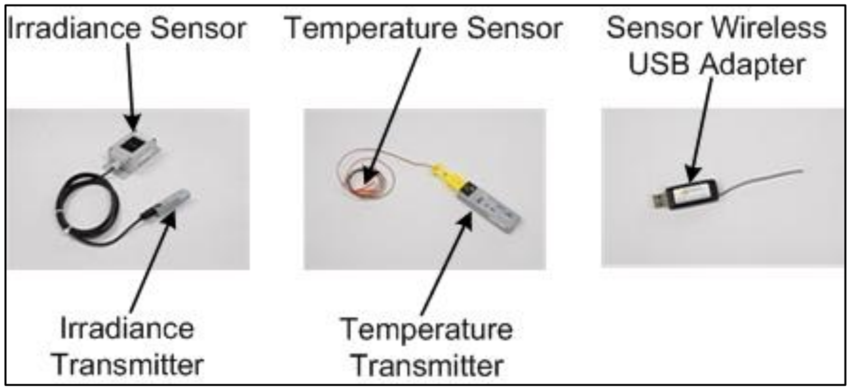


Figure 13. Components of the Solmetric Wireless Sensor Kit

The relative orientations of the sensor transmitters and the wireless USB adapter (at your PC) have a moderate effect on transmission range. Transmission range is slightly longer when the physical axes of the transmitter and wireless USB adapter are parallel to one another, and slightly shorter when the axes are perpendicular or when one is 'pointing' at the other, broadside. Refer to Figure 14.

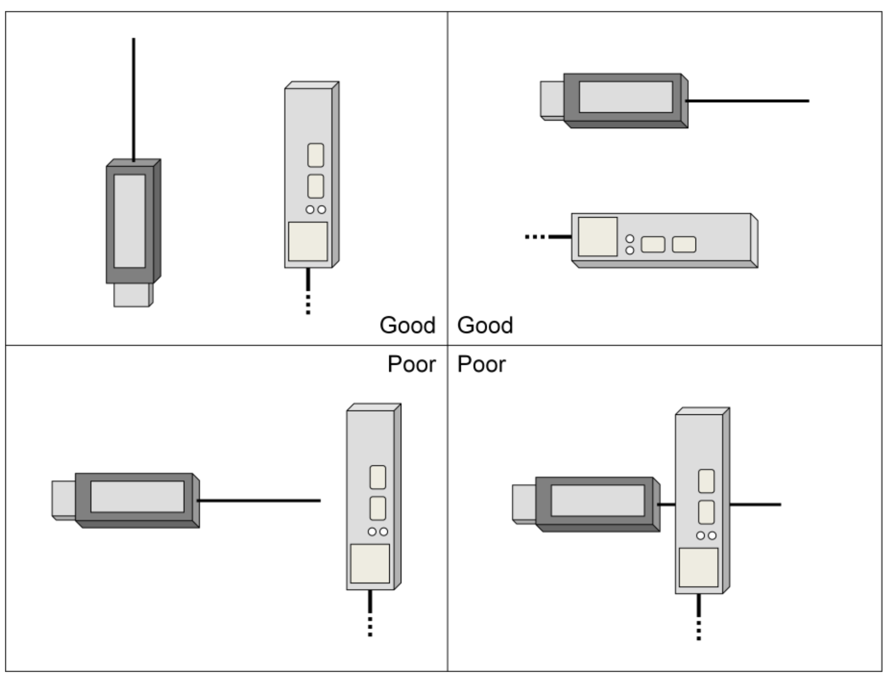


Figure 14. Orienting the sensor transmitter and wireless USB adapter for best wireless range

1. Connect the Sensor Wireless USB Adapter to a USB port in your computer.

NOTE On some PCs, the USB adapters may not fit side-by-side due to their width. If a second USB position is not available, a notebook-style USB hub may be used.

2. Ensure that the transmitter with the “I” label is connected to the irradiance sensor. Observe polarity markings.

3. Ensure that the transmitter with the “T” label is connected to the temperature sensor. Observe polarity markings.

4. Position the irradiance sensor in the same plane as the modules under test. For example, on the surface of a neighboring module that is not in the string of modules being tested. The irradiance sensor can also be mounted on a short, straight (un-warped) length of wood that is in turn clamped to the corner of a module as shown in Figure 15. Clipping the irradiance sensor to the racking system with a lanyard can avoid the risk of injury to personnel or damage to the sensor, in the event the irradiance sensor drops out of position.

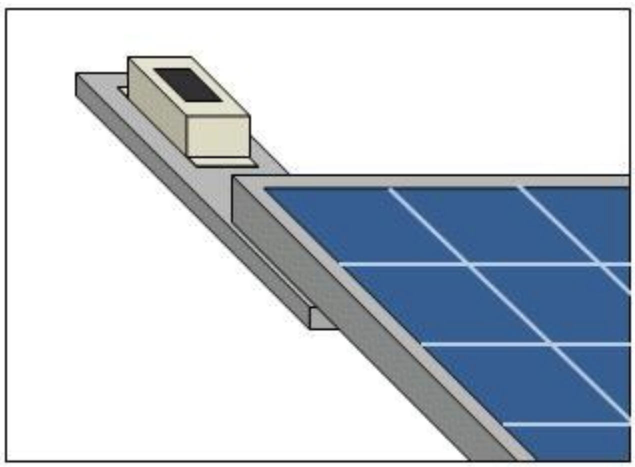


Figure 15. Positioning the irradiance transmitter

5. Position the irradiance transmitter so that it has good line of sight to your PC. Position it at least 6 inches above the module frames and at least 3 feet above the ground or roof surface.

6. Position the temperature sensor on the backside of a PV module, 2/3 of the distance from a module corner to the center of the module, as shown in Figure 16 below. Use high-temperature tape to assure that the tape does not sag during your measurement time. Kapton (polyester) tape is recommended for this purpose. Use a square or disk of tape at least 1.75 inches across. To make the tape easier to remove, fold one edge of the tape over to form a tab. Place the tip of the thermocouple at the center of the tape. Press the tape firmly against the backside of the module to ensure that the thermocouple wire - and especially the tip, where the temperature is sensed - is in good contact with the surface of the modules. If you are using stiff thermocouple wire (24 AWG or heavier), apply a second piece of tape 6 inches from the first, to

capture the thermocouple lead and prevent it from moving around and pulling the thermocouple tip loose.

NOTE The temperature of a PV array is usually cooler along its edges, due to better air circulation. To measure a more representative array temperature, reach under the module and attach the temperature sensor near the middle of a module.

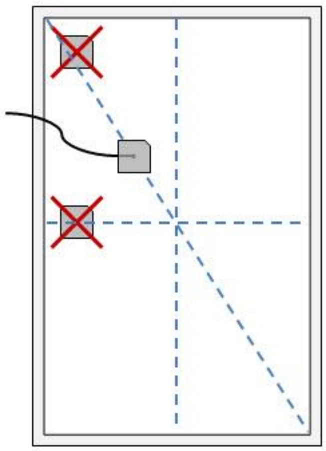


Figure 16. Mounting the temperature sensor

7. Position the temperature transmitter so that it has good line of sight to your PC. Position it at least 6 inches above the module frames and at least 3 feet above the ground or roof surface.

8. To turn on the irradiance and temperature transmitters, press the **I/0** button on each transmitter.

NOTE When turned on, each transmitter has a **TX** LED that will flash green periodically. However, it is difficult to see the green LED in direct sunlight. Pressing the **I/0** button a second time will cause the transmitter to turn off, indicated by the **TX** LED flashing red three times.

When not in use, turn the transmitter power off to conserve battery life. The lithium batteries in the transmitters are not re-chargeable. The typical battery life of the irradiance transmitter battery is 300 hours. The typical battery life of the temperature transmitter battery is 1500 hours.

9. If the **LOW BATT** LED on either the irradiance or temperature transmitter is on, replace the battery as follows:

    a. Remove the two screws securing the cover on the rear side of the transmitter.

    b. Remove the cover.

c. Replace the battery with a Lithium AAA battery.

NOTE In emergencies, you can substitute AAA Alkaline batteries. However, battery life will be very short.

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 the user 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 Measurement Unit to disable the I-V sweep.

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.**

3. Following safe operating procedures, connect the PV leads of the PVA-600 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.

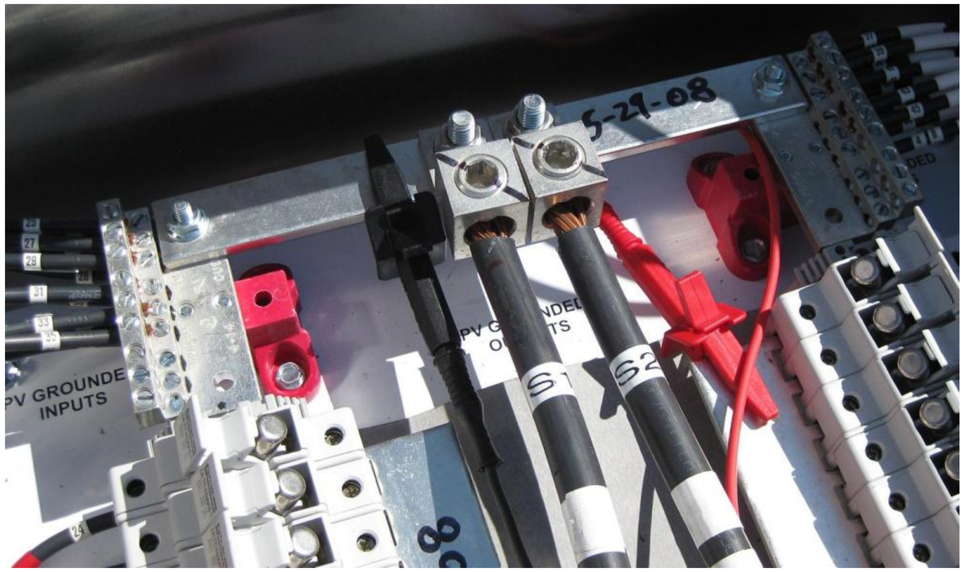


Figure 17. Example of PVA-600 test leads clipped to the buss bars of a PV combiner box

4. If the distance between the test device and the I-V Measurement 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 Measurement Unit

Press the power button once on the I-V Measurement Unit. Refer to Figure 18.

Figure 18. Powering-up the I-V Measurement Unit

The LED will begin to blink indicating that the I-V Measurement Unit is attempting to establish communication with the wireless USB adapter connected to the PC. If the wireless USB adapter is inserted into an operating PC, 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 Measurement Unit will turn off to conserve the battery.

I-V Measurements

The I-V Measurement Unit will measure an I-V curve each time the user clicks on the **Measure Now** button. I-V data is transmitted to the PC shortly after each I-V sweep is taken. Data is not stored in the I-V Measurement Unit after it is transmitted.

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

WARNING	**If the LED on the PVA-600 is illuminated (either solid on or flashing), do not connect or disconnect the PV leads.**

Over-Temperature Protection

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

NOTE The PVA-600 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 PVA-600 is placed, and exposure to direct sunlight.

CAUTION Place the PVA-600 in the shade to reduce the likelihood of thermal shutdown. Never place the PVA-600 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 Measurement 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 Measurement 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 rate at which measurements are being taken by the user. 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 Measurement Unit. Shade the measurement unit from direct sunlight, elevate it above hot surfaces, and allow more time between I-V sweeps.

Over-Voltage Protection

If a voltage in excess of 650 V is detected, the I-V Measurement Unit switches into disabled mode. Clicking on the "Disabled" message in the Status display pops up a warning that the voltage specification was exceeded and the I-V Unit may have been damaged.

When the over-voltage condition is detected, the I-V Measurement unit is immediately reprogrammed into a disabled state to prevent continued use of a damaged unit. Resetting or restarting the I-V Unit will not re-enable it. Please contact Solmetric to arrange for repairs.

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

Over-Current Protection

If greater than 20 A dc is applied to the I-V Measurement Unit, the PVA-600 detects the over-current condition and switches into disabled mode automatically and an I-V measurement does not take place.

The I-V Measurement 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 Measurement Unit is connected with the wrong polarity across a string, an internal protection diode opens the circuit, the PVA-600 switches into disabled mode, and an I-V measurement does not take place.

4 Using the PVA-600 Software

Using Projects

Version 2 of the PVA-600 PC software is organized around the concept of a Project, which contains a description of the PV system and the collection of measurements that were all made on that system. These measurements can be made at multiple different locations of the system hierarchy, and at different dates / times.

A Project will contain information about the location of the PV system, a complete electrical representation of the PV system hierarchy, and information for the PV comparison models. A Project Wizard guides you in entering the descriptive information and model choices. Within the Project Wizard, the Array Navigator guides you in creating the electrical system hierarchy and automatically generates a 'tree' description of the system that you will click on to save measurement data to a selected location in the system. The same tree is used to recall measurement data already taken.

Main Screen Overview

The PVA-600 software runs on a PC and is the main user interface for making measurements, storing data, and viewing data. The main screen is divided into three main areas as shown in Figure 19.

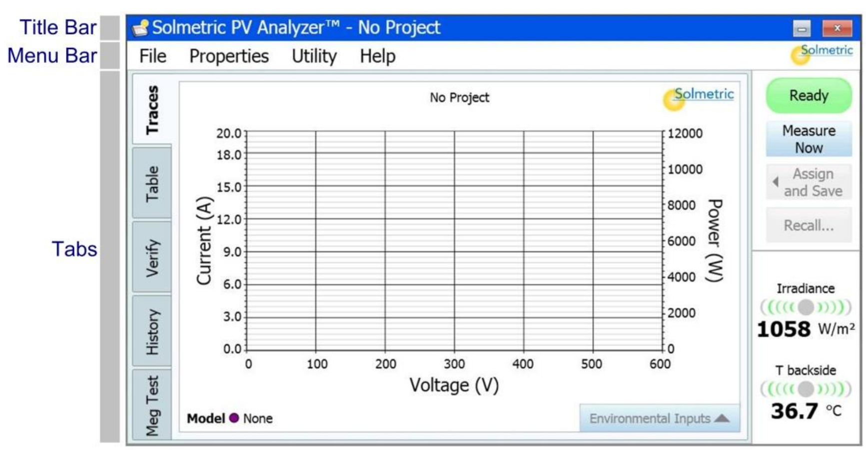


Figure 19. PVA-600 main screen

The Title Bar is located at the top of the main screen and displays the name of the product and the name of the Project that is currently loaded. The Project is a file that contains information used in modeling and archiving measurement data. Also, two of the most common Windows® software buttons (Minimize and Close) are displayed in the upper right corner.

The Menu Bar is located just below the Title Bar and is a drop down menu system for setting up PV models and measurement details.

The Tabs are located along the left side of the main screen and serve as the main interface for collecting and viewing data.

Title Bar

The product name is displayed in the Title Bar along with the name of the Project, if one has been created. In addition, the Minimize and Close buttons are displayed and function in the same way as they do in other Windows® applications.

Menu Bar

File Menu

The File Menu is used to set up new projects and access and load previously saved projects and to export measurement data.

New Project menu item

Setting up the project involves the steps that are listed as links at the far left of the New Project Wizard. The user can use the controls at the bottom of the page to move through the process, or can jump to a particular step using the links.

The New Project Wizard steps through the following screens:

- Notes/Info screen
    - Name the project
    - Specify the Project file path
    - Add descriptive notes

- Performance Model screen
    - Select a PV module
    - Select a PV performance model
    - Define the wiring properties
- Site Info screen
    - Define latitude, longitude, elevation, array azimuth, and array tilt
- Array Navigator
    - Create a hierarchical description of the PV system. This 'system tree' provides information to the measurement process and is used to archive measurement results.

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.**

Your 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. The user must choose the time zone and daylight savings setting.

The four screens of the New Project Wizard are described below.

Notes/Info Screen

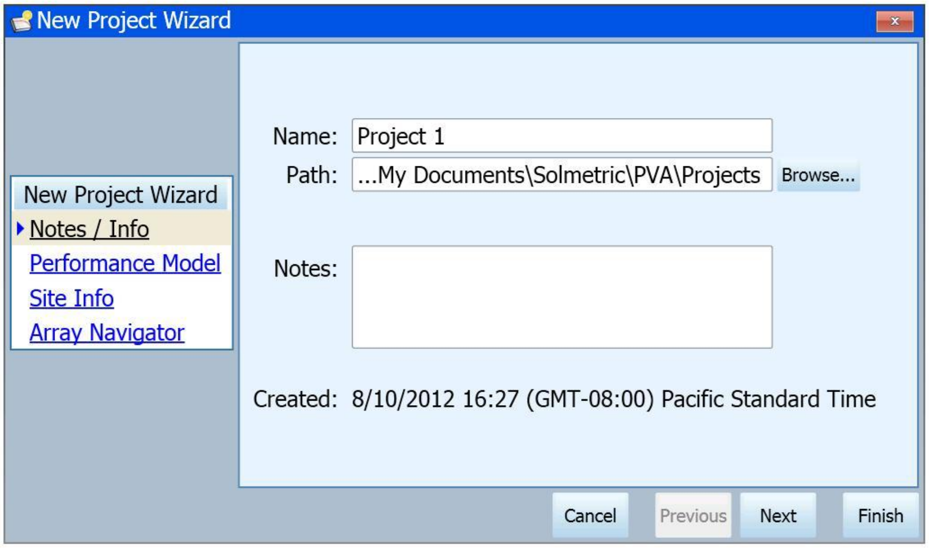


Figure 20. Notes/Info screen

Table 6. Notes/Info screen description

Name	Description
Name	Name you wish to give your project. For example, the name of a high school where a car park system has been built. This will also determine the name of the .pvap project file that is created in the Path you specified.
Path	Path name of the Project. The Project is a file that defines the details of the PV model and the hierarchy of the PV system. The software uses this information to configure measurements and to archive measurement results.
Notes	Your notes.
Created	Shows the date, time, and time zone as loaded from the computer's date/time function. Be sure that the displayed time accounts for daylight savings. This information must be correct in order for the PC software to correctly calculate the position of the sun at the instant the I-V curve is measured, and also to properly time/date stamp your I-V curve measurement results.

To move to the next step of the Wizard, click **Next** or click the **Performance Model** link.

Performance Model Screen

In the screen shown in Figure 21 you will select your PV module from a built-in database and select a PV model.

The details of the performance model do not affect the measured I-V curve.

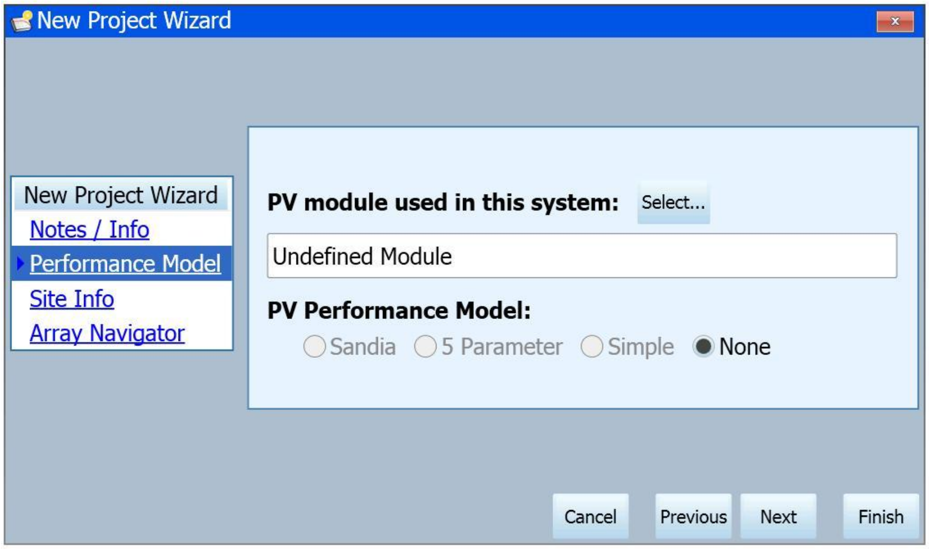


Figure 21. Performance model screen

Table 7. Performance model screen description

Name	Description
Select Module	Accesses the built-in PV module database. Later, when you use the Array Navigator to describe the electrical configuration of your PV system, the PV module you select here will be used to populate the system. The software assumes that the same PV module is used everywhere in the array. **Refer to Figure 22 and** Table 8.
Performance Model	Select your desired model. Available model choices will be shown in black font. The Sandia model is the most detailed and accurate. The 5-Parameter model is less detailed and accurate, but is available for a far larger number of modules. If neither of these models is available for your selected PV module, select Simple. This will invoke a simple performance model that uses parameters specified in the module datasheet. If these values are not in the PVA module database, enter them manually from your datasheet.

The screen shown in Figure 22 appears when the **Select…** button is selected.

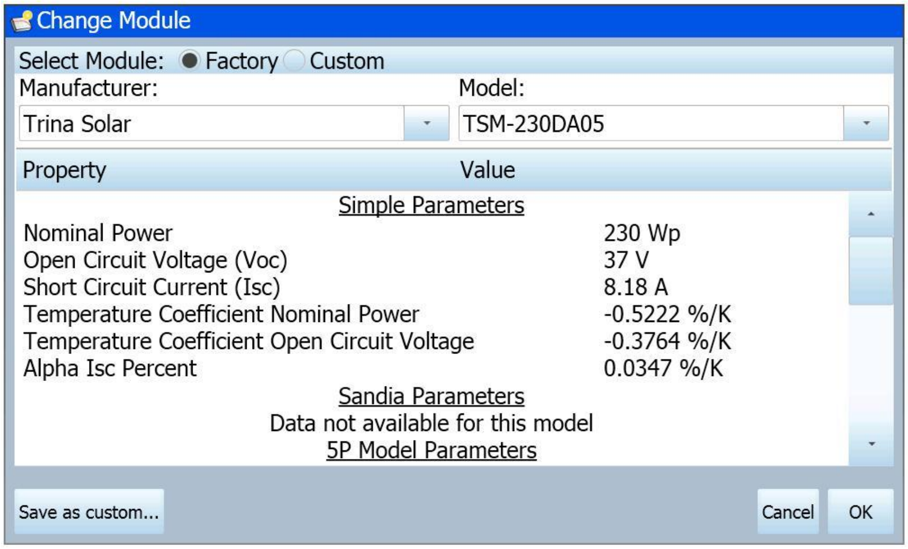


Figure 22. Select Module screen

Table 8. Select module screen description

Name	Description
Factory	Invokes model parameters from the built-in database.
Custom	Click **Custom** to access the controls for selecting or creating a custom PV model. Then click **Select...** to load an existing custom model, or click **New...** to define a new set of model parameters. Customizing PV model parameters allows you to adjust the module parameters for one PV module type to represent another PV module type of similar technology for which model parameters do not yet exist. Contact your PV module manufacturer for the parameter values.
Save as custom…	Click **Save as custom...** to edit the values of the currently selected PV module and save as a custom 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	This field 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.

Name	Description
OK	Press to accept the choices shown.
Cancel	Press to leave this form without impact to the prior settings.

Site Info screen

To move to the next step of the Wizard, click **Next** or click the **Site Info** link.

The Site Info screen shown in Figure 23 is needed by the PV model in order to predict the position of the sun at the time of measurement, to account for the relationship of the sun's position and the PV array itself, and to account for the distance sunlight travels through the atmosphere.

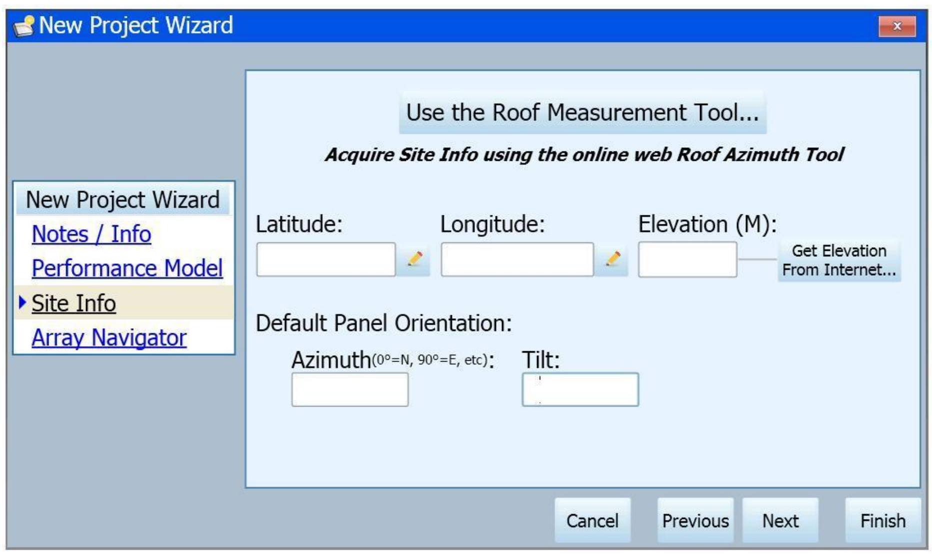
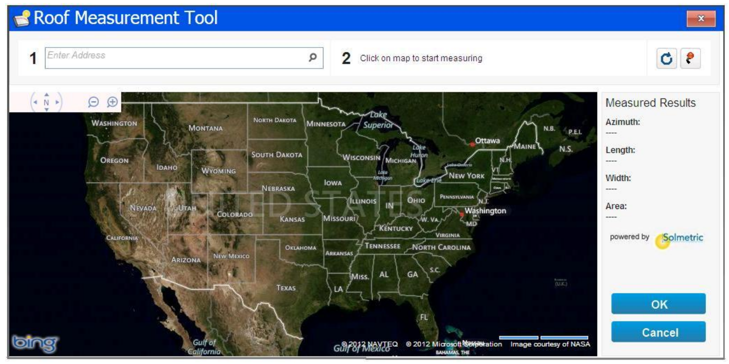


Figure 23. Site info screen

Table 9. Site info screen description

Name	Description
Use the Roof Measurement Tool button	Site information can be entered using the data entry boxes, or by using the Roof Measurement Tool. Internet access is needed to use the Roof Measurement Tool. For this reason, it is suggested that the project be created before visiting the site.  1 - Enter the address of the site. 2 - Use map controls to zoom in on the roof plane structure or roof plane of interest. 3 - Review the measured results in the right hand column. 4 - Click **OK** to transfer the results to the PVA New Project Wizard.
Latitude	Enter the value in decimal form. Click on the pencil icon to use the numeric keypad entry.
Longitude	Enter the value in decimal form. Click on the pencil icon to use the numeric keypad entry.
Elevation	Enter the physical elevation of the site. If you are connected to the internet and have already entered the lattitude and longitude, you can press the Get Elevation From Internet button to down load the site elevation.
Default Panel Orientation	Enter the azimuth and tilt angles that best characterize the PV array. Azimuth is entered in degrees (0° is north, 90° is east, 180° is south, and 270° is west). Tilt can be measured with an inclinometer or with the tilt feature of the Solmetric SunEye (0° is horizontal, 90° is vertical).

Array Navigator screen

To move to the next step, press **Next** or select the **Array Navigator** link.

The Array Navigator screen shown in Figure 24 helps you build a system tree, an electrical description of the DC side of the PV system that you'll 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 24 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 details at the level of individual strings, or for all strings in a combiner, or for all strings in an inverter field, or in the system overall.

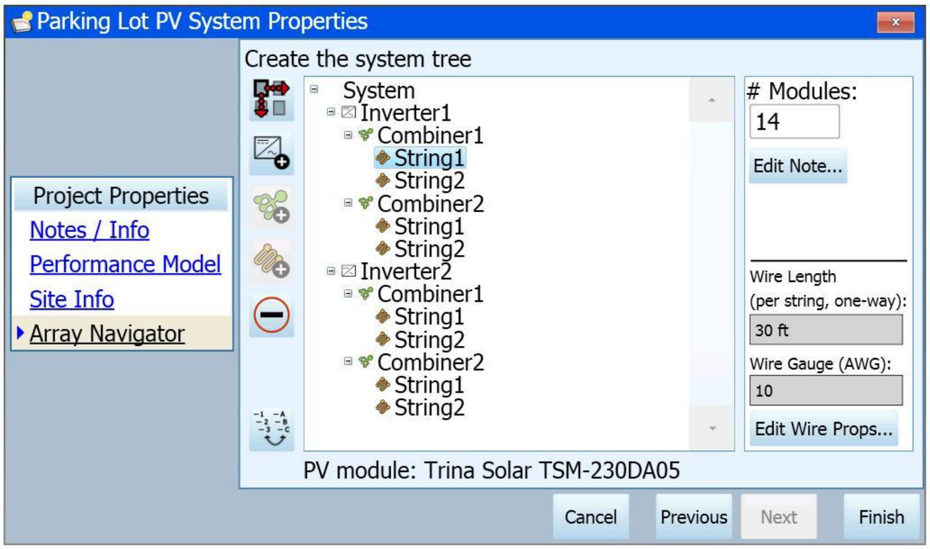
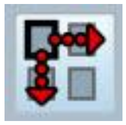
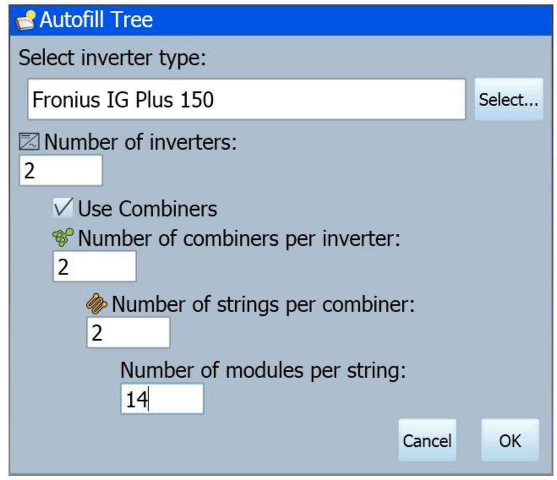
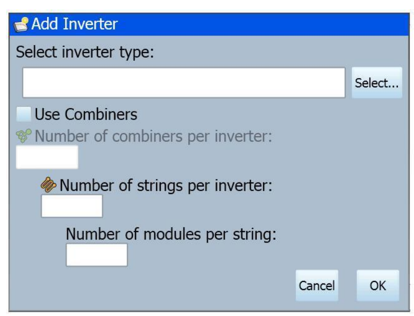
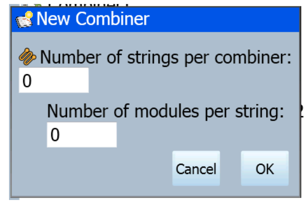
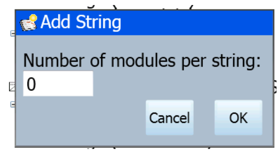


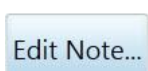
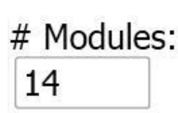
Figure 24. Array navigator screen

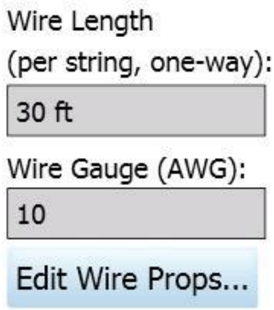
Table 10. Array navigator screen description

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 detail of their arrays are the same.  **Select Inverter** – Select your inverter from the built-in database. **Use Combiners** – Check the box 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 inverter from built in database. The selected inverter can be different from other inverters in the system. **Use Combiners** – Check box if combiners will be used. **Number of combiners, strings, modules** – Fill in these boxes with appropriate numbers

<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td></td><td>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.</td></tr>
<tr><td></td><td>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.</td></tr>
<tr><td></td><td>The Delete Selected icon deletes a selected item from the system tree.</td></tr>
<tr><td>
</td><td>The Array Navigator Naming icon is used to select between numeric or alphabetic naming convention.</td></tr>
<tr><td>
</td><td>The Edit Note… button is used to add or edit notes for a specific inverter, combiner, or string.</td></tr>
<tr><td>
</td><td>The Change Inverter button accesses the screen used to change to a different inverter. This button only appears when an inverter is selected.</td></tr>
<tr><td>
</td><td>The # Modules is used to change the number of modules for the selected string. This control appears only when a string is selected.
Normally, the number of modules per string should be the same across all the strings feeding a particular inverter.</td></tr>
</table>

Name	Description
	These controls input the wire properties of conductors between the I-V Measurement Unit and the string or module under test. These values are used in the predictive PV model and have no effect on the actual measurement of the I-V curve. PV ouput 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 do use these controls. You can change these properties at the level of individual strings, or for all strings in a combiner, for all strings feeding a given inverter, or for all strings in the system. If wire losses are low by design, you may want to enter a single wire length and single wire gauge for the entire system, inverter, or combiner. **Default Wire Length Per String (one-way)** Enter the one-way wire length between the I-V Measurement 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.

Name	Description
	Wire Gauge (AWG) Enter the wire gauge of the conductors between the I-V Measurement 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. Rseries = (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 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.
PV Module	Lists the manufacturer and model number of the PV module used in the system. This is the module that you selected when you created the PV model. The software assumes that the same module is used everywhere in the array feeding this particular inverter.

Browse Project menu item

The Browse Project menu item is used to access previously saved Projects for retrieval.

Recent Projects menu item

The Recent Projects menu item displays the path and filename of recent Projects.

Export Trace for Active Measurement menu item

This function exports the measurement results for the measurement currently displayed in the Traces screen, as a csv file.

Export Traces for Entire System menu item

This function exports the measurement results for the currently loaded Project, as a Windows folder tree 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, available as an accessory to the PVA-600.

Properties Menu

The Properties menu item accesses system properties of the currently loaded Project for viewing and editing. You can go directly to any of the Properties screens by selecting the corresponding menu item from the Properties menu. The Notes/Info screen is shown in Figure 25.

Refer to File Menu discussion above for descriptions of Notes / Info, Performance Model, Site Info, and Array Navigator screens.

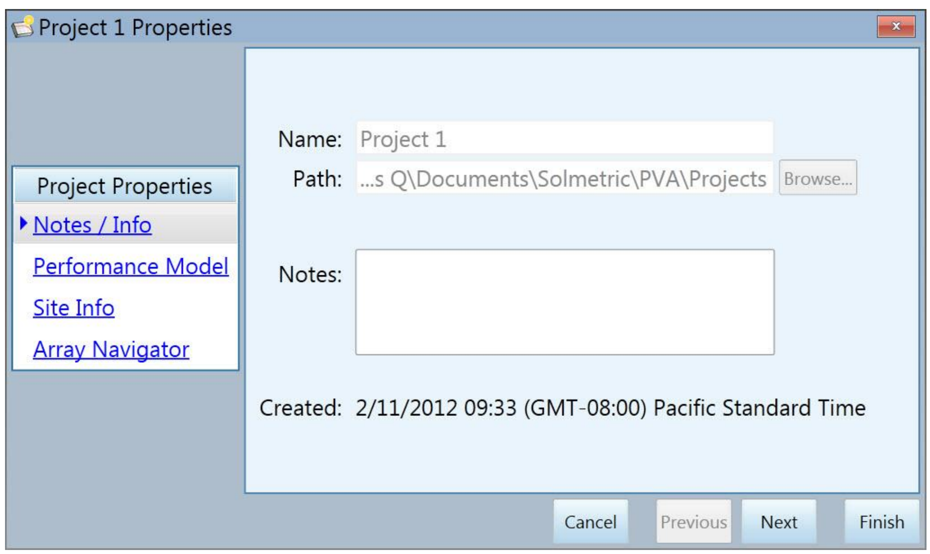


Figure 25. Project properties screen showing the Notes/Info controls

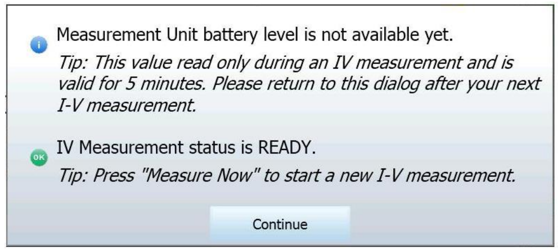
Utility Menu

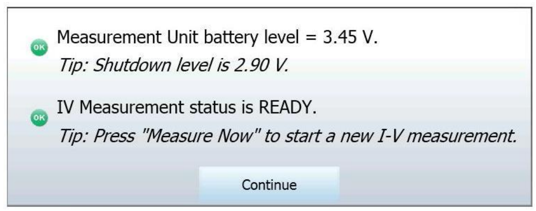
Table 11. Utility menu description

Name	Description
Settings	Used to select the I-V Measurement Unit and Solmetric Wireless Sensor Kit communication ports manually. **NOTE** – If the Wireless USB Adapters are installed into the PC before starting the PVA-600 Software, the communication ports are selected automatically. **Wireless I-V Measurement Unit USB Interface**: select communications port to use for communication between the PVA-600 and the PC. Select the port with the "+" symbol. **Wireless Sensor USB Interface**: select communications port to use for communication between the Solmetric Wireless Sensor Kit and the PC. Select the port with the "+" symbol.
Global Sensor Calibration Factors…	Enter the irradiance sensor calibration factor and the temperature sensor offset factor. **Wireless Irradiance Sensor Cal Factor:** Enter the calibration factor listed on the label attached to the irradiance sensor in the Solmetric Wireless Sensor Kit. **Module Backside to Cell Temperature Offset Factor:** The PV performance models require solar cell temperature as an input. The Wireless Sensor Kit measures the module backside temperature, and the PC software translates that value to the solar cell by adding a temperature offset. The PC software calculates this temperature offset by starting with an estimated offset value under 1000 W/m2 and then linearly adjusting (prorating) that value based on the actual irradiance at the time of the I-V measurement. In the Wireless Temperature Sensor Offset Factor entry box, enter the backside-to-cell temperature rise that you would expect at 1000 W/m2. For modules mounted 6" above the roof, a 3ºC offset is an appropriate starting point.

<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>Battery Level…</td><td>The battery level value is 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></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>Allows you to capture and save the currently displayed measurement results.</td></tr>
</table>

Help Menu

Table 12. Help menu description

Name	Description
User’s Guide	Accesses the PVA-600 User’s Guide. The PVA-600 User’s Guide can be downloaded and printed if desired. A hard copy User's Guide is not provided with the PVA-600.
About	Accesses the software version number and software build date.

Tabs Introduction

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

The Traces tab displays the most recent measurement results along with the predicted shape of the I-V curve (if an advanced PV model is selected). Figure 26 is an example of the Traces tab screen.

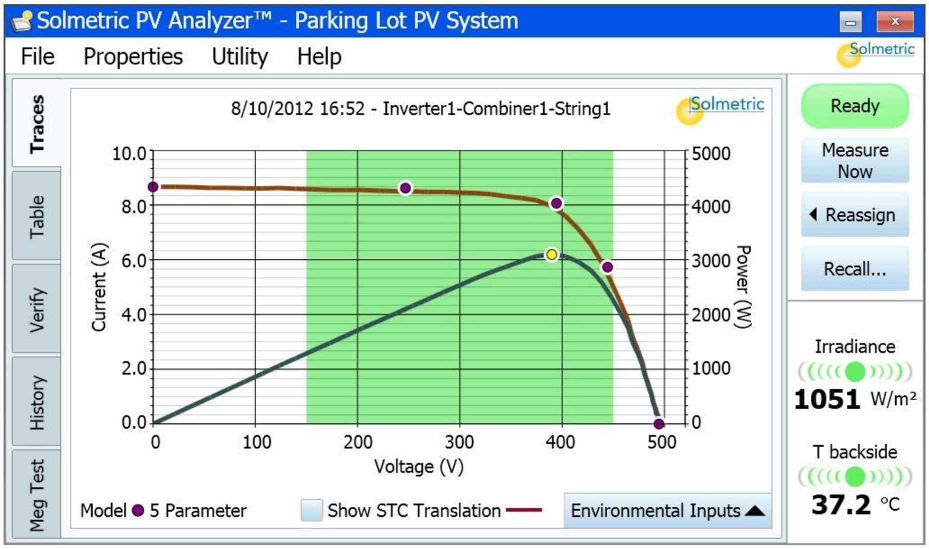


Figure 26. Traces tab

There are four main datasets displayed in the Traces screen:

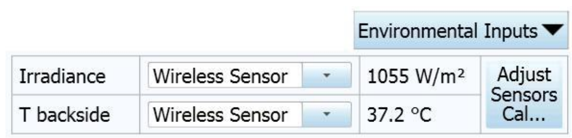
1. I-V curve. This solid red curve displays the measured I-V points transmitted from the I-V Measurement Unit. There are approximately 100 points on a typical curve. The points are connected with line segments for display. Points below 0 V are not displayed.

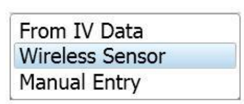
2. P-V curve. This solid blue curve displays the power available from the test device (module or string), calculated from the I-V curve simply by multiplying I x V for each I-V point. The yellow point simply indicates the maximum value of the measured P-V curve (not the predicted maximum power value derived from the PV model). It 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.

3. Model prediction points. The five red I-V points are the predicted I-V values for the five key points as defined by the Sandia or 5 Parameter performance model. If the actual I-V curve goes through or near the predicted five points, then the array is functioning as predicted.

4. The green shaded area indicates the specified DC voltage operating range for the selected inverter. The left and right edges of the green shaded area represent the lower and upper limits of the inverter’s maximum power tracking range.

Table 13. Traces tab description

<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>Measurement ID</td><td> 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. </td></tr>
<tr><td>Current (A)</td><td>Displays the current scale along the vertical axis on the left side of the graph.</td></tr>
<tr><td>Voltage (V)</td><td>Displays the voltage scale along the horizontal axis of the graph.</td></tr>
<tr><td>Power (W)</td><td>Displays the power scale along the vertical axis on the right side of the graph.</td></tr>
<tr><td>Model</td><td>If a model has been created and enabled, your selected model type is indicated in the lower left corner of the screen. This is the model that is used to locate the dots that predict the I-V curve shape.</td></tr>
<tr><td>Environmental Inputs</td><td> Click the Environmental Inputs button to access controls and displays associated with determination of irradiance and PV module temperature.




A drop-down list provides three methods by which irradiance can be determined. The same three methods are available for temperature. You can choose different methods for irradiance and temperature. The methods are:
From I-V data
Irradiance and/or temperature are calculated automatically from the measured I-V curve.
Wireless sensor
Irradiance and/or temperature is transmitted by the Wireless Sensor Kit.</td></tr>
</table>

Name	Description
	• Manual entry You manually enter irradiance and/or temperature values that were measured using other equipment. The Wireless Sensor option appears in the list only if the Wireless Sensor Kit is in operation. If the Wireless Sensor Kit is in operation when the first PVA measurement is taken, the Wireless Sensor Kit option is selected by default. Number boxes display the irradiance and temperature values associated with the currently displayed trace. The number boxes are numeric displays in the case of the Wireless Sensor, or From I-V Data options. If Manual Entry is selected, a numeric entry box appears for entering your irradiance value. When you save I-V measurement data, irradiance and temperature are saved along with it. If the wireless sensors are operating, the wireless irradiance and/or temperature will be saved, even if you used the From I-V Data or Manual method for that particular measurement. This allows you to change the method later, during analysis of the measurement data. See Chapter 6, Measuring Environmental Conditions, for guidance on selecting environmental input methods and deploying sensors. The **Adjust Sensors Cal...** button brings up a screen showing two controls that allow you to adjust the irradiance and temperature calibrations for the presently displayed trace. If you edit either of these values, you will be asked whether you would like to make them the new global calibration values, such that they will be applied to successive measurements.
Show STC Translation	When this box is checked, 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 button)	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 for details.
Measure Now button	Highlighted when the system is ready to start a new I-V measurement. Each time this button is clicked, a single I-V measurement sweep is started.
Measuring (in Status button)	During a measurement, the **Measuring** label blinks.

Name	Description
Assign and Save button **Reassign** button	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. After a fresh measurement is taken, the Assign and Save button is highlighted. When you click this control, the measurement results area shrinks to the left and the System Tree appears. Click the location in the System Tree at which the measurement was taken. Then use the buttons at the bottom of the screen to Assign the measurement to that location, or the Assign and Save button to assign and save the data. After a measurement has been saved, the Assign and Save button becomes the Reassign button. The Reassign button in the Traces screen allows the user to change the location in the array with which this measurement is associated.
Recall Measurement… button	Accesses the Recall Measurement screen for recalling measurement data. To select the data to be recalled, select the location in the System Tree and then select the Date/Time of the measurement you want to recall. The Date/Time tab allows you to select a measurement from a time-sorted list.
Paused (in Status button)	Displayed when the I-V measurement process is paused by pressing the button on the I-V Measurement Unit. 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 button)	Displayed when a problem exists other than communication between the PC and I-V Measurement Unit. Problems could be related to low battery, over current, over voltage, over temperature, reversed polarity, etc. No measurements can be taken while in this state. When "Disabled" is displayed, click on the question mark icon for information to aid in troubleshooting the problem.
No USB Wireless **(indicator)**	When displayed, click on the question mark icon for information to aid in troubleshooting the problem.

Name	Description
No I-V Unit (in Status button)	Displayed when communication between the I-V Measurement 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 out-of-range, or the I-V Measurement Unit is turned off.
Wireless Sensor Displays	If the wireless sensors are selected and are within range, their values are displayed in the lower right corner of this screen.  The 'wireless' icon blinks each time a transmission is received from the corresponding sensor. The 'wireless' icon also indicates the relative signal strength for each sensor. If a wireless sensor link is lost due to low signal level, the corresponding wireless sensor display (in the lower right corner of the measurent screens) will show "-----" instead of a numerical value. Improve the signal level by moving the transmitter closer to the PC or providing better line-of-sight, until the link is re-established.

Table Tab

The Table tab presents summaries of the predicted and measured I-V data and a translation of the measurement results to Standard Test Conditions. Figure 27 is an example of the Table tab screen.

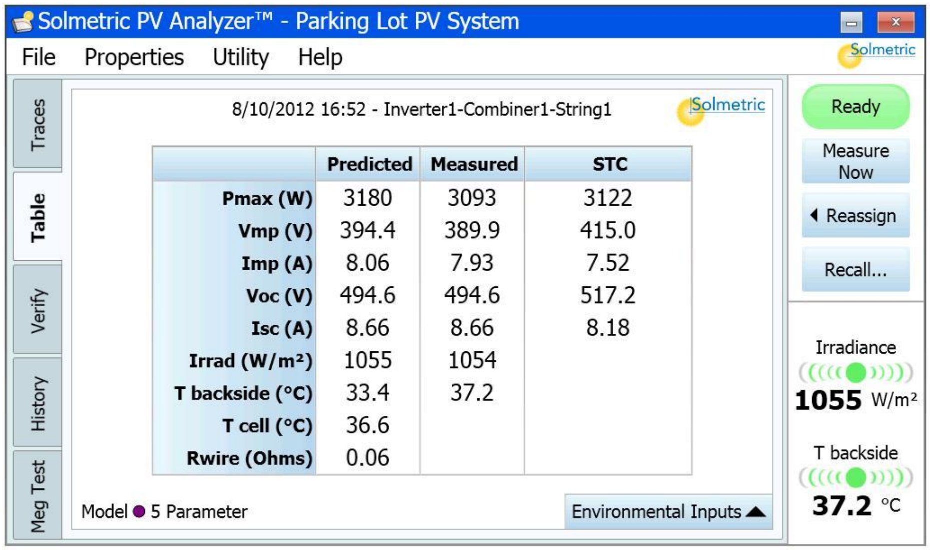


Figure 27. Table tab

Table 14. Table tab description

Name	Description
Predicted	Displays the predicted values from the selected performance model.
Measured	Displays actual measured values most recently measured.
STC	Displays a translation of the measured parameters to Standard Test Conditions, 1000W/m2 and 25 C.
Pmax (W)	Measured maximum power values in Watts.
Vmp (V)	Voltage at the maximum power point.
Imp (A)	Current at the maximum power point.
Voc (V)	Open circuit voltage.
Isc (A)	Short circuit current.

Name	Description
Irrad (W/m^2)	Irradiance in the plane of the array. The irradiance value in the **Predicted** column is derived from the selected PV model. If no model is selected, the predicted irradiance is left blank. The irradiance value in the **Measured** column is either the manually entered value or the wireless sensor value, depending on which method is in effect. If neither of these methods is selected, no value is displayed.
T backside (C)	Surface temperature of the backside of the PV module in Celsius. The temperature value in the **Predicted** column is derived from the selected PV model. If no model is selected, predicted temperature is left blank. The temperature value in the **Measured** column is either the manually entered value or the wireless sensor value depending on which option is in effect. If neither of these methods is selected, no value is displayed.
Tcell (C)	Predicted temperature of the PV cells. The way this value is calculated depends on how you elect to determine temperature in the Environmental Inputs controls. If you choose to determine the backside temperature using the wireless sensor or from manual entry, then Tcell is calculated from those values, also using the value of the Module Backside Temperature to Cell Temperature Offset Factor. Click on Adjust Sensors Cal... to adjust that factor. If temperature is being obtained from the measured I-V data, Tcell is calculated directly and an offset factor is not used.
Rwire (Ohms)	Displays the estimated series resistance of the wiring between the I-V Measurement Unit and the device (module or string) under test based on the user-entered wire length and gauge, assuming room temperature. Refer to Table 7 for the table of values versus wire gauge.

Verify Tab

The Verify tab graphically compares the measured power with the target (predicted) value and also displays the Performance Factor, the ratio of these two values as a percentage. Figure 28 is an example of the Verify tab screen.

NOTE Typically, if a string is operating correctly, and is not shaded or age-degraded, the Performance Factor will be in the mid-90’s or higher when using the Sandia model. The uncertainty will typically be higher when using the 5 Parameter and Simple Performance models. The industry has relatively little experience using the 5 Parameter model with thin film modules; the uncertainty for TF modules is likely to be still higher.

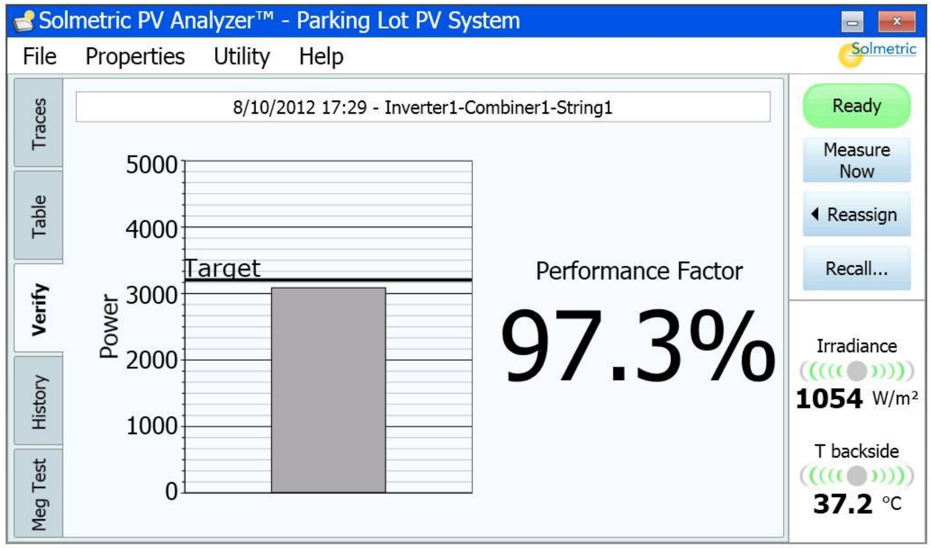


Figure 28. Verify tab

Table 15. Verify tab description

Name	Description
Power	Displays the power scale along the vertical axis on the left side of the graph.
Target	Displays the maximum power predicted by the performance model and the selected sensor method.
Performance Factor	Displays the ratio of actual to predicted maximum power as a percentage.

History Tab

The History tab automatically displays the tabular results of your most recent measurements. This information helps you check the consistency of your measurement results, as when measuring strings at a combiner box, and view the effects of your troubleshooting process.

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.

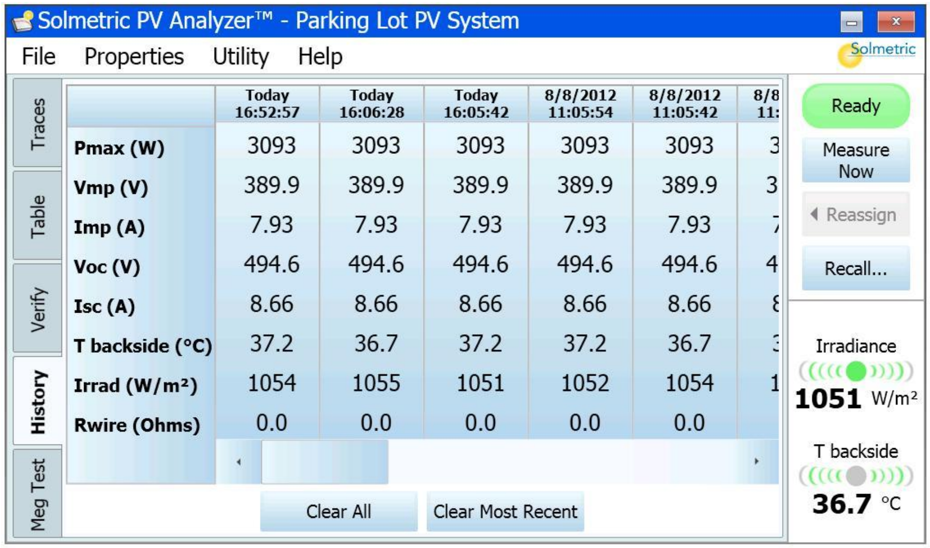


Figure 29. History tab

Meg Test Tab

The Meg Test tab is used to collect insulation resistance measurement results obtained from a separate instrument such as the Megger® MIT430 Insulation Resistance Tester. Data is entered manually. The measurement results are saved in the same database used to save I-V curve measurement data.

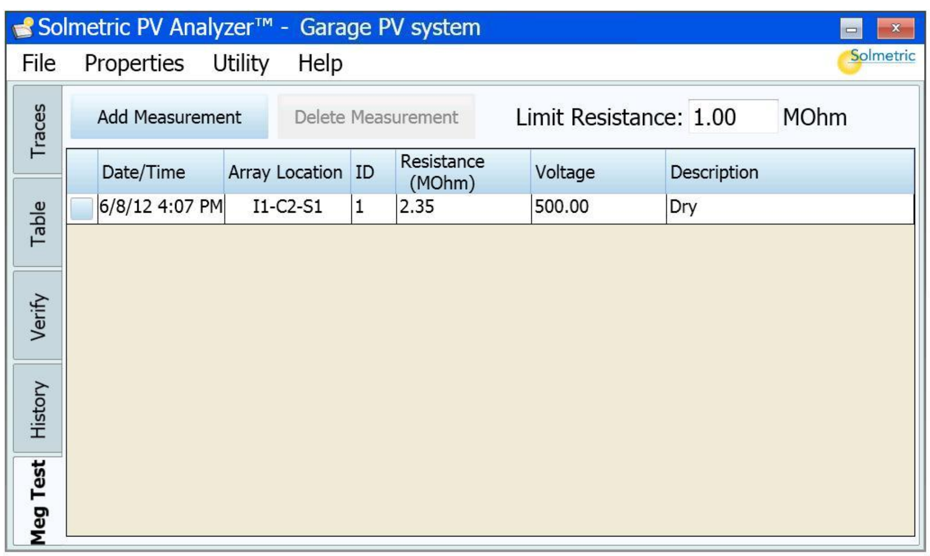


Figure 30. Meg Test tab

Table 16. Meg Test tab description

Name	Description
Add Measurement button	Adds a new line to the table. The current date and time is listed, and the line is assigned an ID number.
Delete Measurement button	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/deselects the measurement of interest.
Date/Time	Displays the date and time each measurement was added to the table.
Array Location	Clicking in this field accesses the Array Navigator used to select at which level the measurement was made.
ID	An identification number that is automatically assigned by the software. 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.

Creating a New Project

The following procedure shows how to set up the PVA-600 for particular PV modules/strings, inverters, and related site information using the New Project wizard.

Start the PVA-600 Software

1. On the PC, double-click on the **Solmetric PV Analyzer** icon to start the PVA-600 application. The Traces screen appears as shown in Figure 31.

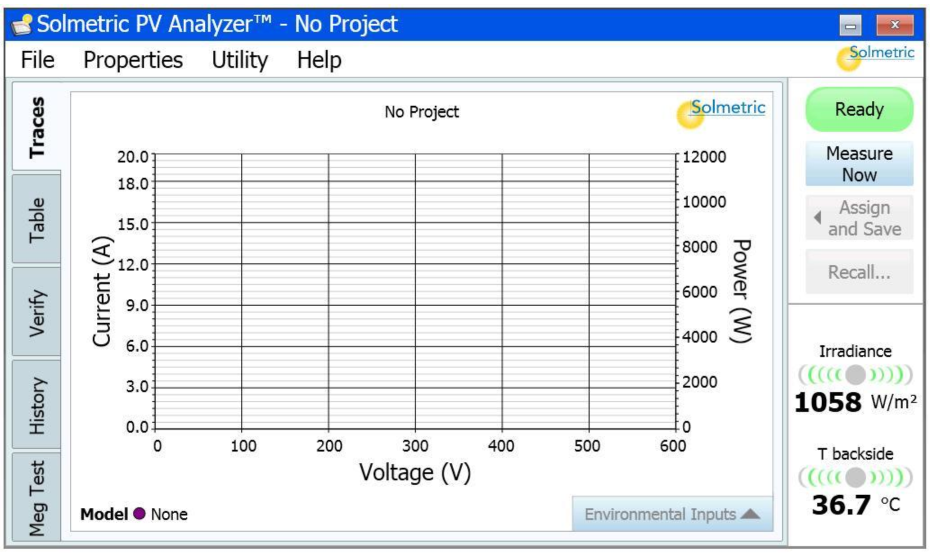


Figure 31. Traces screen

Select New Project

1. In the **File** menu, select **New Project…** to launch the New Project Wizard. The Notes/Info screen of the New Project Wizard appears as shown in Figure 32.

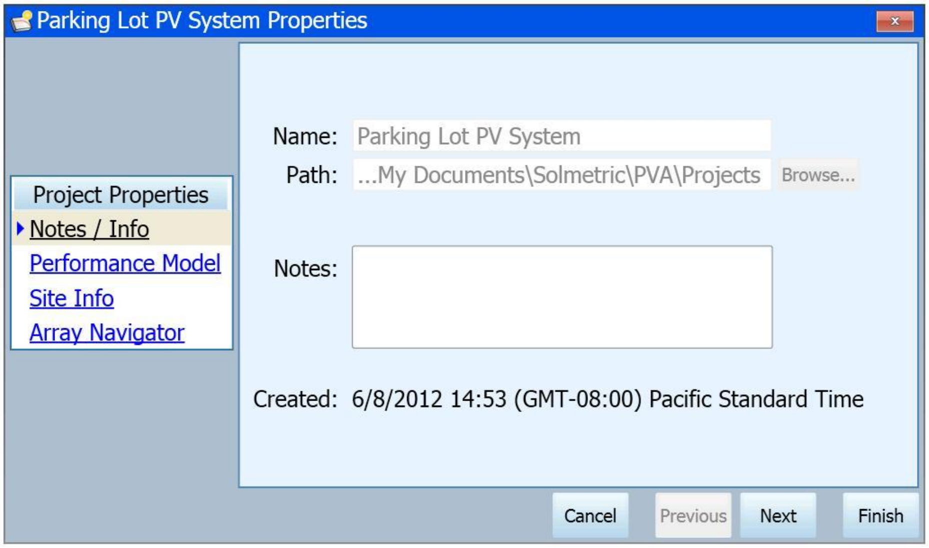


Figure 32. Notes/Info screen

Enter the Project Name, Path and Notes

1. Click in the **Name** text box and enter the desired name for this project.

Click on the **Browse…** button to select the path to the location where all of the relevant PV model and PV system description information will be stored. The default location is in Solmetric\PVA\Projects, the folder that was automatically created when the PVA software was installed.

2. Click in the **Notes** text box to enter notes for this project.

3. Ensure that the date, time, and time zone are correct.

4. Click the **Next** button or click on the **Performance Model** link.

Select PV Module, Performance Model

1. The Performance Model screen should be displayed as shown in Figure 33.

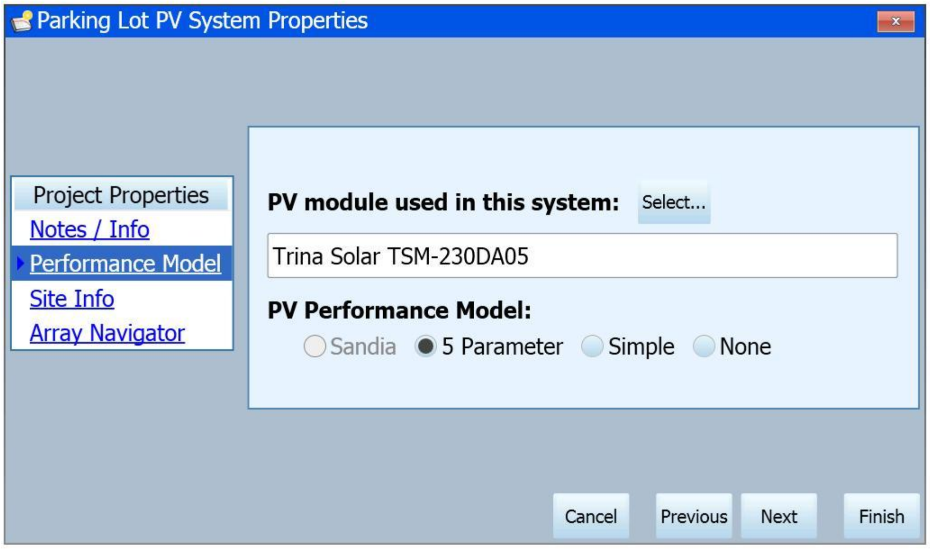


Figure 33. Performance model screen

2. Click on the **Select Module…** button to access the screen used to set up a new module. The screen shown in Figure 34 appears.

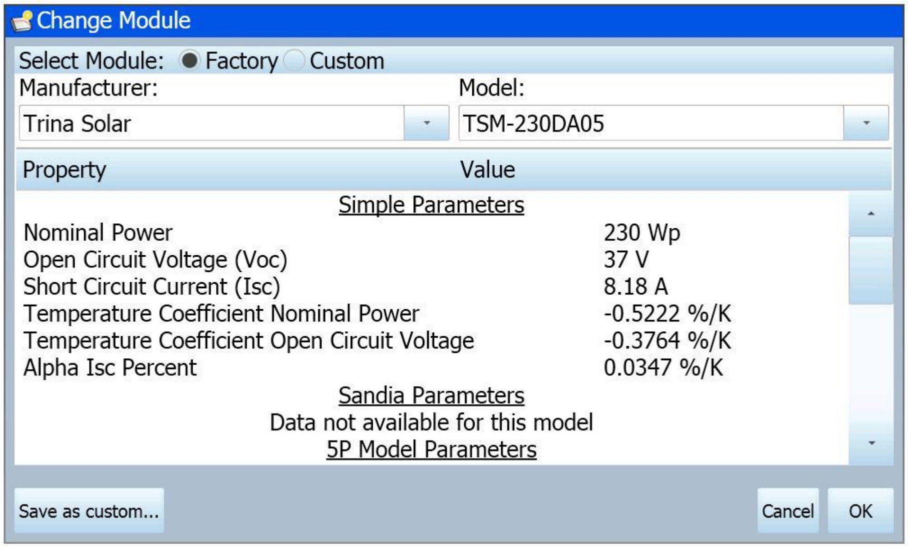


Figure 34. Change module screen

3. Select the **Factory** option to invoke model parameters from the built-in database. Select the Custom option if you wish to load a previously created custom module, or to create a new custom module.

4. Click on the **Manufacturer** dropdown menu and select the manufacturer.

5. Click on the **Module** dropdown menu and select the module number. Parameter values for the available PV models appear in the Property and Value columns as shown in Figure 34.

6. Click on the **OK** button.

7. Select the desired performance model. Available model choices are shown in black font. The Sandia model is the most detailed and accurate. The 5-Parameter model is less detailed and accurate, but is available for a larger number of modules.

8. The Simple model is the most basic. If none of these models are available for your PV module, click the **Select...** button, click the **Custom** radio button, then click **New...**

9. When the New Custom Module screen opens, enter the model number of your module. Then expand the Simple Parameter section of the Module Definition table, and enter the required PV parameters from your module datasheet.

10. When the New Custom Module screen opens, enter the model number of your module. Then expand the Simple Parameter section of the Module Definition table, and enter the required PV parameters from your module datasheet.

11. Click the **Next** button or click on the **Site Info** link.

Enter Site Information

1. The Site Info screen should be displayed as shown in Figure 35.

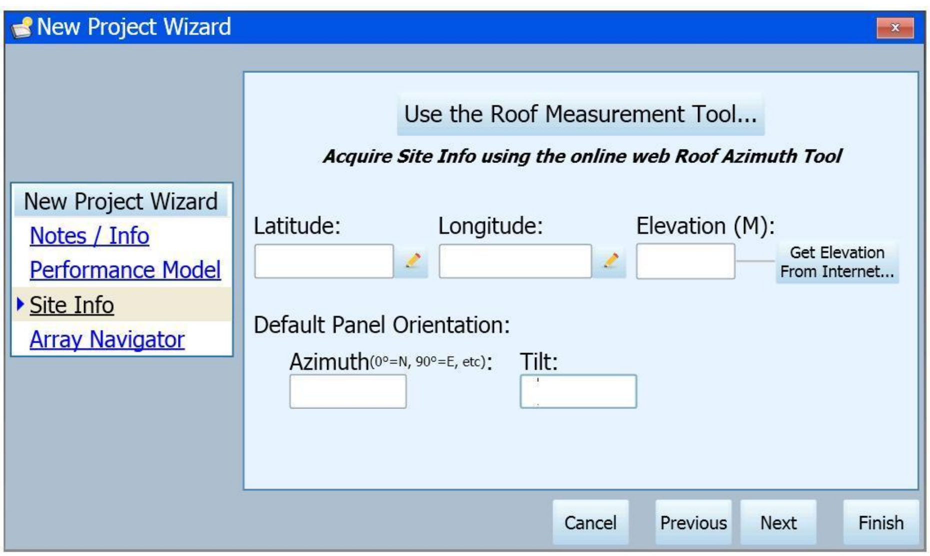


Figure 35. Site info screen

2. Enter the site information values manually, or you can obtain most of the data from the web by clicking on the **Use the Roof Measurement Tool…** button. See Figure 36.

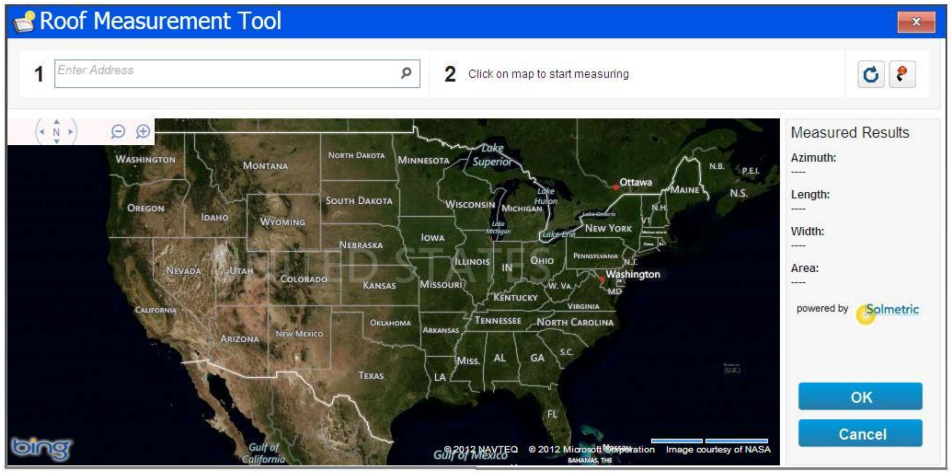


Figure 36. Roof azimuth and tilt

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. Click at one end of the lower or southern-most eve to establish a base point, and drag to the other end of the eve to create a line along the eve.

d. Drag the line up along the roof plane. This forms a rectangular outline on the roof as shown in Figure 37.

Figure 37. Map controls to zoom in on roof plane

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

f. If necessary, adjust the size of the rectangle by moving the edges in or out.

g. The white arrow indicates the orientation of the roof plane.

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

The length, width and area values may be of interest, although they are not used by the software. These values represent the projection of the roof onto the horizontal plane. If the roof is tilted, these numbers require correction.

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

Perform the following steps to enter values manually:

a. Click in the **Latitude** text box and enter the latitude for this model in decimal form.

b. Click in the **Longitude** text box and enter the longitude for this model in decimal form.

c. Click in the **Elevation (M)** text box and enter the physical elevation of the site or click on **Get Elevation From Internet**. This feature requires that the latitude and longitude already be entered.

d. In the **Default Panel Orientation** enter the azimuth and tilt angles that best characterize the PV array.

3. Click the **Next** button or click on the **Array Navigator** link.

Create the System Tree

1. The Array navigator screen should be displayed as shown in Figure 38.

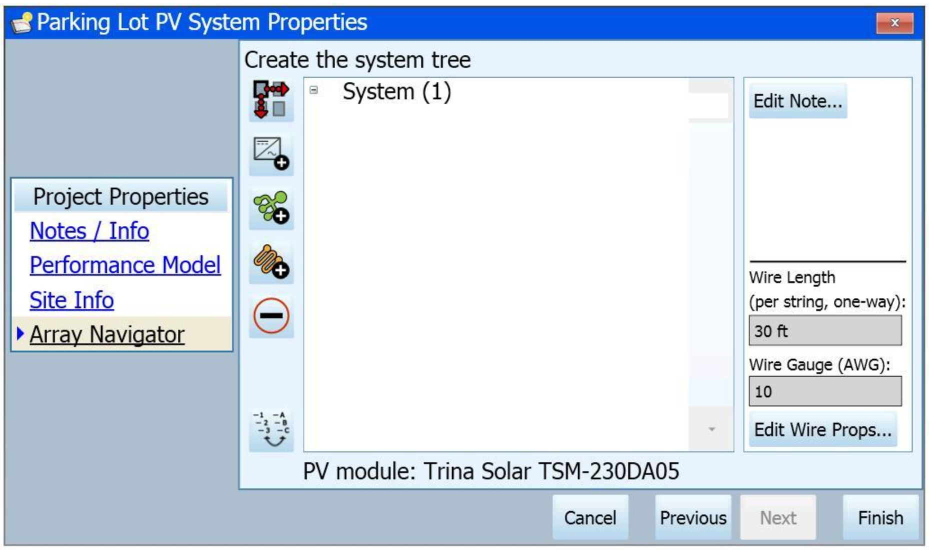


Figure 38. Array navigator screen

2. If your PV system is very uniform in its design (identical inverters, numbers of combiners, number of strings per combiner), click on the Autofill Tree icon (the icon at the top of the column) to access the screen shown in Figure 39.

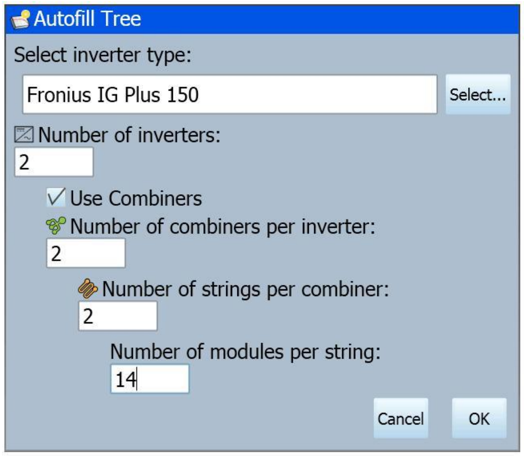


Figure 39. Autofill tree screen

3. Click on the **Select Inverter** button to select the inverter from the built-in database.

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

5. Click in the **Number of inverters** field and enter the appropriate value.

6. Click in the **Number of combiners per inverter** field and enter the appropriate value.

7. Click in the **Number of strings per combiner** field and enter the appropriate value.

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

9. Click on the **OK** button. Figure 40 is an example of what you will see.

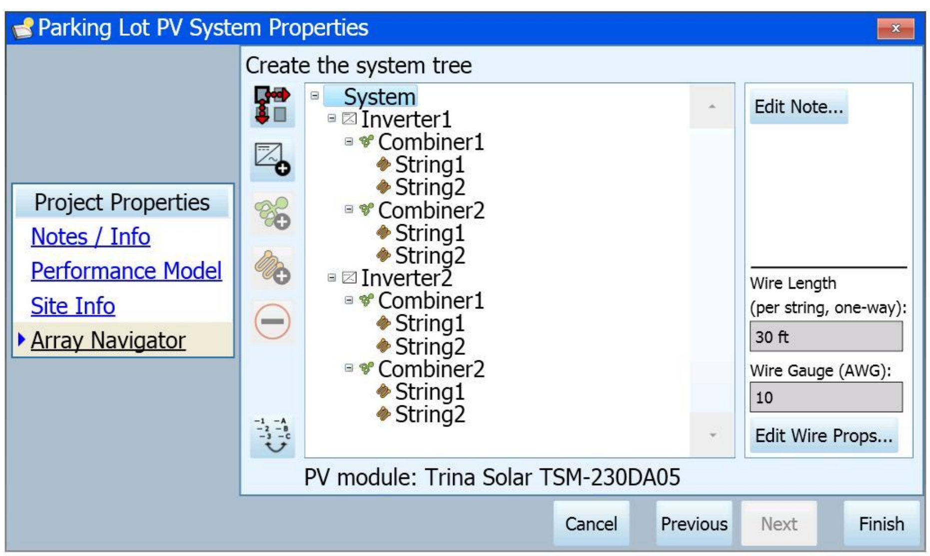


Figure 40. Populated Array Navigator screen

Add a New Inverter

If your PV system is not uniform in its elements, use the individual icons to create your system tree as described in the following procedure.

1. Click on the Add Inverter icon to access the Add Inverter screen shown in Figure 41.

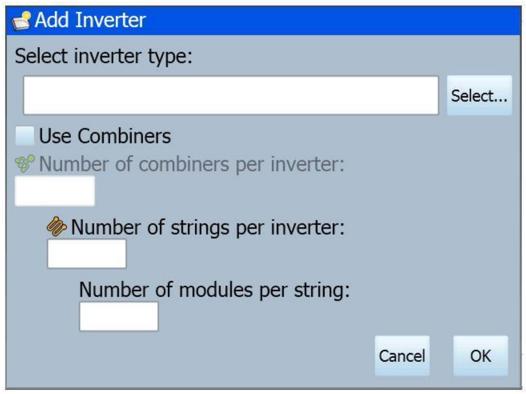


Figure 41. Add inverter screen

2. Click on the **Select Inverter** button 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** 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.

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 in Figure 42.

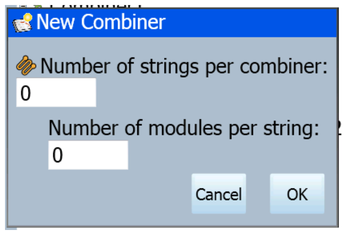


Figure 42. New combiner screen

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 on the **OK** button.

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 Figure 43.

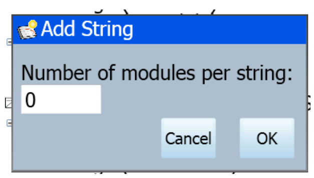


Figure 43. Add string screen

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

Creating a New Project that is Similar to an Existing Project

Setting up a new Project is faster if you can re-use an existing Project with little or no modification.

1. Navigate to the Project files on your PC.
2. Locate the existing Project that you wish to re-use.
3. Copy and Paste that project file within the Projects folder, and rename the copy with the name of your new project.
4. Using the Browse Project... item in the File menu, navigate to the new Project file.
5. Use the tools in the Properties menu to edit the Project as needed.

Making Measurements

The following procedure shows how to make typical measurements.

1. Ensure that the PVA-600 is connected properly.
2. Boot the PC.
3. On the PC, insert the Wireless USB Adapter into a USB port.

NOTE If the Wireless USB Adapter used for PVA-600 or wireless sensor communication is installed before starting the software, the USB port will be found automatically. If you install the Wireless USB Adapter(s) after starting the software, you must select the proper USB ports on your PC manually using the **Utility/Settings** menu. Instructions are provided in the Settings screen.

4. If you are using the Solmetric Wireless Sensor Kit, perform the following:
    a. Insert the Wireless Sensor USB Adapter into a second USB port on your PC.

NOTE On some PCs, the USB adapters may not fit side-by-side due to their width. You can use a USB port extender to accommodate both USB adaptors.

b. Ensure that the Solmetric Wireless Sensor Kit components are connected properly. Refer to Setting Up the Optional Solmetric Wireless Sensor Kit.

5. On the PC, double-click on the **Solmetric PV Analyzer** icon to start the PVA-600 application.

6. After the PVA-600 software opens, turn on the irradiance and temperature transmitters by pressing the **I/0** button once.

7. To open an existing Project file, select **Browse Project…** in the **File** menu then open a file using the **Open** dialog box.

8. If you need to set up a new Project, refer to Creating a New Project or Creating a New Project that is Similar to an Existing Project.

9. Turn on the I-V Measurement Unit by pressing the red power button shown in Figure 44. The LED will begin to blink indicating that the PVA-600 is attempting to establish communication with the wireless USB adapter connected to the PC. Once communication is established, typically in less than 20 seconds, the **Measure Now** button will become active and the red LED on the I-V Measurement Unit will glow steadily.

NOTE If communication is not established within one minute:

a. Check that the COM ports are selected correctly, using **Settings...** in the **Utility** menu.
b. Move the PC closer to the I-V Measurement Unit.
b. Reset the I-V Measurement Unit using the LED-illuminated button switch on the top surface of the I-V Measurement Unit.
c. Remove and replace the Wireless USB Adapter.

Figure 44. Turn on the I-V Measurement Unit

10. If you are using the Solmetric Wireless Sensor Kit to transmit the irradiance and temperature wirelessly, refer to Setting Up the Optional Solmetric Wireless Sensor Kit for setup information then perform the following:

a. If you do not see wireless sensor readings in the displays at the lower right corner of the measurement screens, select **Settings** from the **Utility** menu and set up the wireless sensor USB interface manually. Select the communications ports with the "+" sign.

b. Ensure that the **Irradiance** indicator blinks green every two seconds. The status is shown in the lower right corner of the screen as shown in Figure 45. If the dot is not blinking, you may need to move the PC closer to the sensor transmitter location or reposition the sensor transmitter. Ensure that the signal level increases, as indicated by the number of bars. Refer to Setting Up the Optional Solmetric Wireless Sensor Kit for setup information.

Figure 45. Irradiance and temperature communication status

c. Ensure that the **T backside** indicator blinks green every ten seconds. The status is shown in the lower right corner of the screen as shown in Figure 45. If the dot is not blinking, you may need to move the PC closer to the sensor transmitter location or reposition the sensor transmitter. Ensure that the signal level increases, as shown by the number of bars. Refer to Setting Up the Optional Solmetric Wireless Sensor Kit for setup information.

11. Click on the **Measure Now** button to start a measurement. The **Ready** button will change to **Measuring** and blink during the measurement. The red pushbutton on the I-V Measurement Unit will blink once.

    If a Project was loaded before the measurement was taken, at completion of a fresh measurement the data display area (in this case the I-V curve graph) will shrink to the left and the System Tree will appear as shown in Figure 46. Click on the string that was tested, and click **Assign and Save**. A screen similar to Figure 47 appears. You can also Assign the measurement to a string without saving it. These behaviors are the same for all of the measurement results tabs (screens).

    If no model was loaded prior to the measurement, the measurement results will be displayed without the predictions of the PV model and you will not be able to save the data to the System Tree.

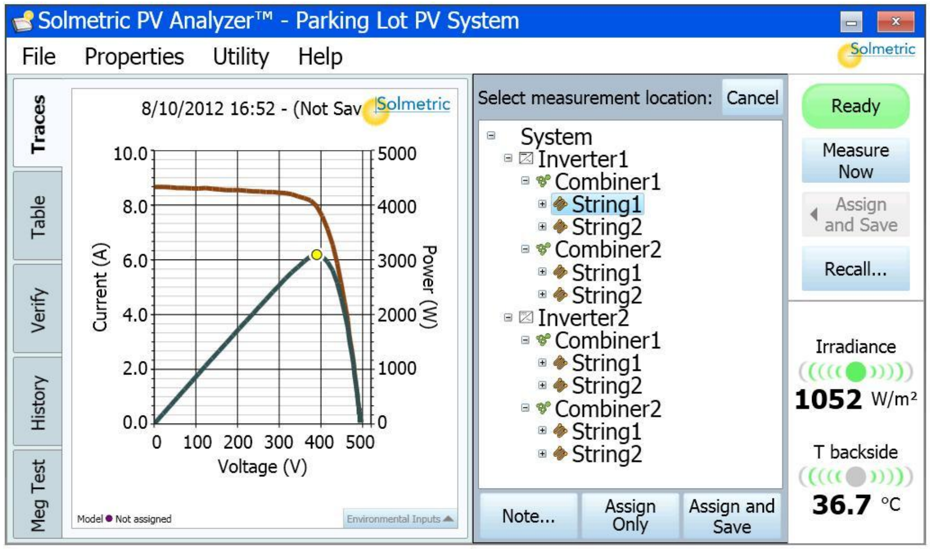


Figure 46. Split screen

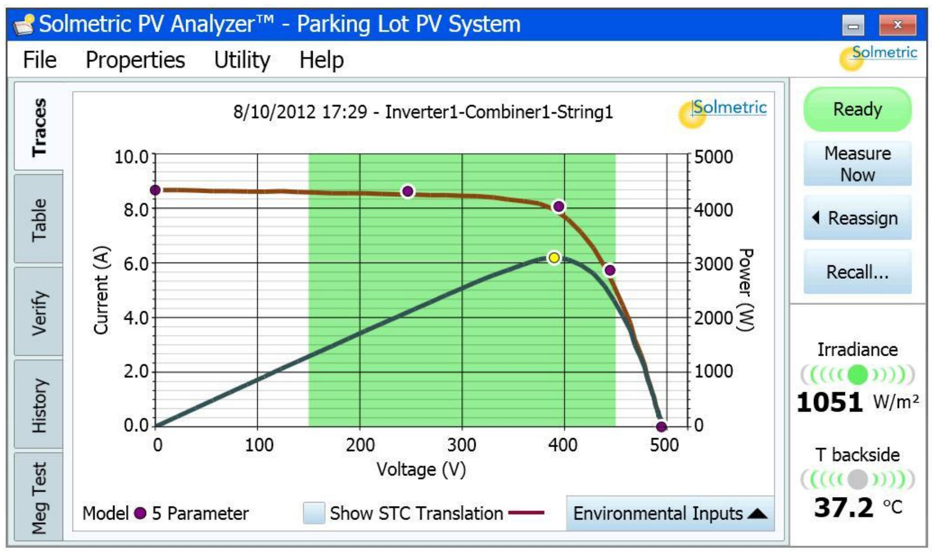


Figure 47. I-V and P-V graphs

12. Click on the Environmental Inputs button to view the irradiance and temperature saved with this measurement, and the methods by which these values were determined.

NOTE	
	After assigning and saving an I-V measurement, if you change any of the settings or values in the Environmental Input controls, including the **Adjust Sensor Cal...** settings, the changes are made in the saved measurement (in the project file) and the displayed PV model predictions change accordingly. If you wish to change any of the Environmental Input controls for subsequent measurements but not for the measurement you just made, then take a new measurement, save it, and changed the Environmental Input control settings as desired. The changes will be made to that saved trace and will be in effect for subsequent traces.

13. Click on the **Table** tab to view the **Predicted, Measured**, and **STC** columns as shown in Figure 48.

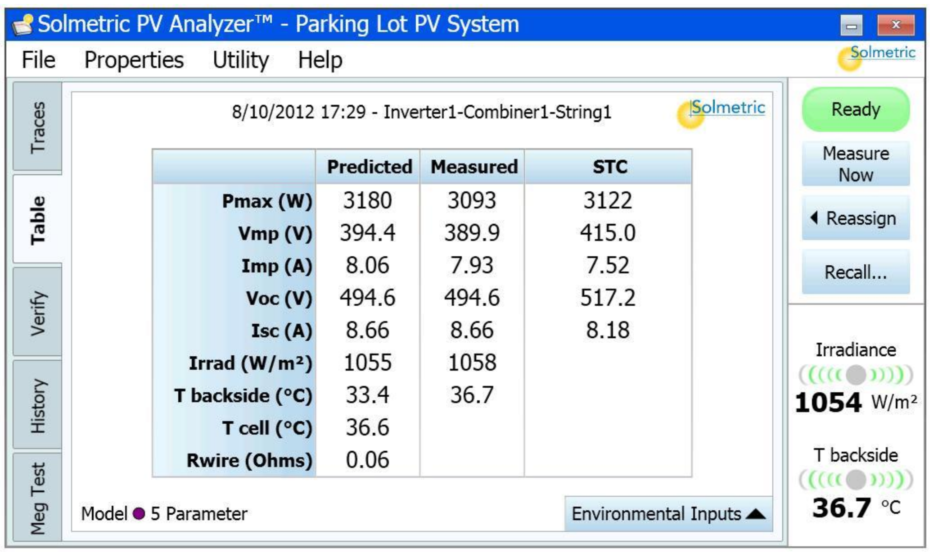


Figure 48. Table tab showing predicted, measured, and STC (translated) values

14. Click on the **Verify** tab to view the numeric **Performance Factor** value as shown in Figure 49. The **Performance Factor** is the ratio of actual to predicted maximum power as a percentage.

Figure 49. Verify tab with maximum power indicator and Performance Factor

15. Pause the measurement sequence of the PVA-600 by pressing the power button shown in Figure 44.

WARNING **Do not disconnect from the tested string unless the red power button is turned off.**

16. Disconnect from the tested string and connect to the next string to be measured.

17. Repeat the process for each string to be measured.

Using History

Each time a measurement is made, the most recent measurement results appear in the left-most column of the History tab screen for comparison with previous measurements. Up to 20 measurement results can be temporarily displayed in the History tab.

1. Click on the **History** tab.

2. Click on the **Measure Now** button. The data appears in the left-most column with a date/time stamp as shown in Figure 50.

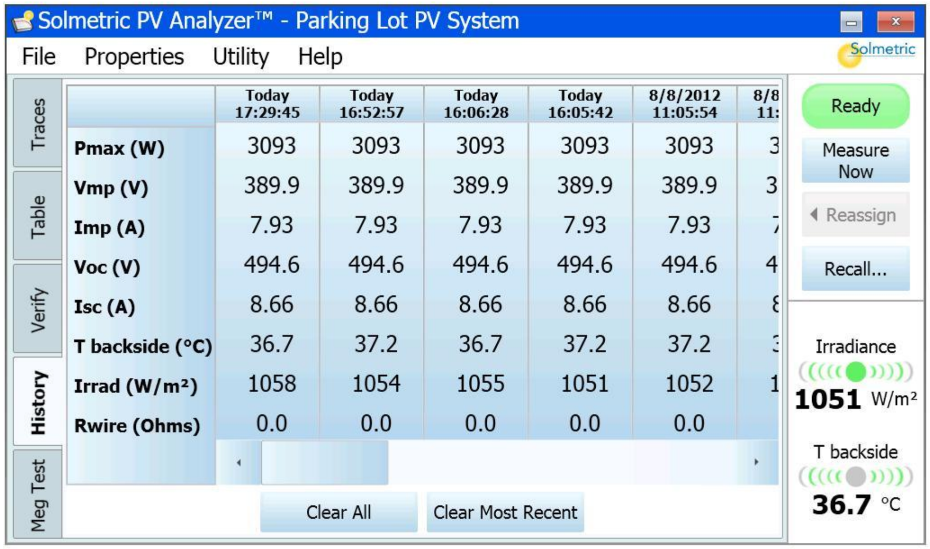


Figure 50. History table

3. To clear the most recent column of data, click on the **Clear Most Recent** button.

4. To clear all data columns, click on the **Clear All** button.

Saving a Screen Image

To save an image of the current screen, go to the **Utility** menu and click on **Capture Application Screen**. A Save dialog box will appear.

This feature does not work for capturing modal dialog boxes (for example, forms, prompts and error messages). For these situations, use the Print Screen function on your computer's keyboard.

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, select **Export Traces for Entire System...** from the **File** menu. When the dialog box appears, choose the location to save your results. To save only the currently active measurement, be sure it has been saved, then select **Export Trace for Active Measurement** from the **File** menu. 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.

Viewing and Analyzing Your Data

After saving trace data, the information can be viewed and analyzed using a program that can read a csv file, such as Microsoft Excel®. You may also use the optional Solmetric Data Analysis Tool to automatically analyze your data. Visit www. solmetric.com for details.

Figure 51 is an example of the Measurements, Model Predictions, and Manual Entries section of a csv file.

	A	B	C	D
1	SOLMETRIC PVA IV DATA	1.2		
2				
3	Report Date	3/11/2012		
4	Report Time	3:33:29 PM		
5				
6		MEASUREMENTS	MODEL PREDICTIONS	MANUAL ENTRIES
7	Voc	32.61383587	31.34196897	
8	Isc	7.812417637	7.903338015	
9	Vmpp	25.21477845	24.22769945	
10	Impp	7.154337161	7.238017032	
11	Pmax	180.3950265	175.3605013	
12	PV Temp (deg C)	61.11111069	56.06738365	45
13	Irradiance (W/m^2)	947.4659883	935.9055747	1000
14	User Series R (Ohms)	0.009989		
15				
16	Performance Factor (%)	102.9		

Figure 51. Measurements, Model Predictions, and Manual Entries section

Table 17. Descriptions of the data displayed in the Measurements, Model Predictions, and Manual Entries section of the exported csv file

Parameter	Measurements	Model Predictions	Manual Entries
Voc	Measured separately, immediately before IV curve (not extracted from IV data)	Calculated from the performance model (if one is selected)	
Isc	Extracted from IV curve data points (the current value of the first IV point)	Calculated from the performance model (if one is selected).	
Vmpp Imp, Pmax	These three values are calculated from a curve fitted to the measured IV data points	Calculated from the performance model (if one is selected).	
PV Temp (deg C) Cell temperature, not backside. All three columns for PV Temp may have entries, but only one is used to make model predictions (see "Temperature Method" below)	If wireless sensors were selected, this displays the PV cell temperature at location of the backside thermocouple, accounting for for the user-entered Module Backside Temperature to Cell Temperature Offset Factor.	If a PV model was in use, this shows the cell temperature (averaged over all modules in the string) as predicted from the measured IV curve.	This cell always shows a temperature value. The default value is 45C. It can be edited by the user to reflect their manual measurements. It will always retain the last value entered, even if this method is not in use.
Irradiance (W/m^2) Irradiance in POA All three columns for Irradiance may have entries, but only one is used to make model predictions (see "Irradiance Method" below)	If wireless sensor was in use, this displays the wireless irradiance in the plane of array.	If a model was in use, this shows the irradiance calculated from the measured IV curve.	This cell always shows an irradiance value. The default value is 100 W/m^2. It can be edited by the user to reflect their manual measurements. It will always retain the last value entered, even if this method is not in use.
Use Series R (Ohms)	Calculated from wire length and gauge entered into the model by the user. Assumes room temperature. Not manually editable. This value should not be interpreted as the measured series resistance of the PV module or string under test.		
Performance Factor (%)	Shows a value only if a PV model was in place.		

If the Sandia or 5 Parameter Performance Model is used, Lines 19 through 23 display the five predicted current and voltage points of the selected model (the Simple Performance Model has no predicted points) as shown in Figure 52.

18	MODEL IV POINTS	VOLTS	AMPS
19	Isc	0	7.903338015
20	Ix	15.67098448	7.849576172
21	Impp	24.22769945	7.238017032
22	Ixx	27.78483421	5.046416067
23	Voc	31.34196897	0

Figure 52. Model IV Points section of the exported csv file

The model points are defined in this way:

- Isc – First point, at short circuit current Isc
- Ix – Second point, at one-half of the open circuit voltage
- Impp – Third point, the maximum power point Imp, Vmp
- Ixx – Fourth point, midway between Vmp and Voc
- Voc – Fifth point, at open circuit voltage Voc

Figure 53 shows the five predicted points displayed along with a measured I-V trace.

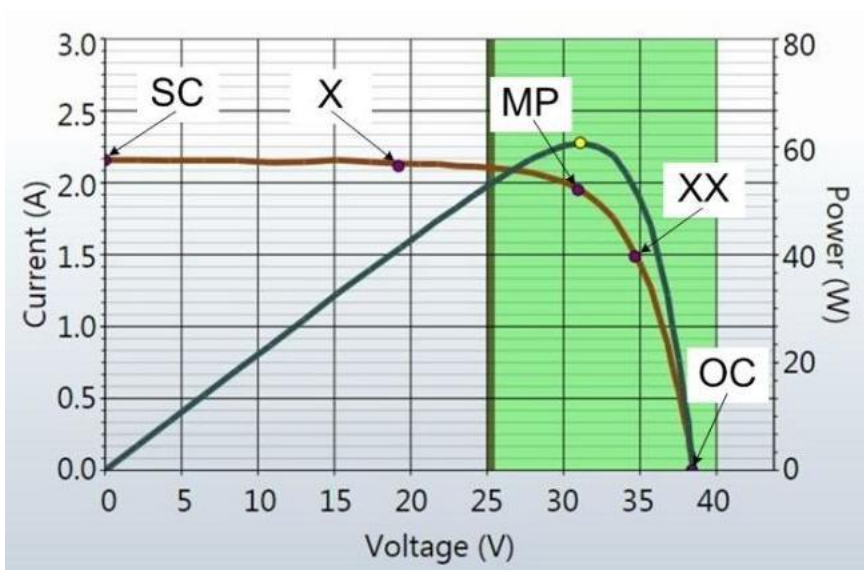


Figure 53. An example of the five predicted (I, V) points generated by the advanced PV models

NOTE	If the Sandia Model is selected and the array itself is being used as the sensor, the end points of the measured I-V trace will typically match the predicted points. If the 5 Parameter Model is selected and the array itself is being used as the sensor, the end points may not match the predicted points. When using the wireless Solmetric Wireless Sensor Kit, the end points may not match the predicted points when using the Sandia or 5 Parameter Performance Models. The five model points are not displayed when using the Simple Performance Model.

Figure 54 is an example of the Model Details section of the exported csv file.

25	MODEL DETAILS	
26	Name	Single Trina-230PAO module
27	Notes	
28	Latitude	29.6
29	Longitude	-98.5
30	Time Zone	-6
31	Model Type	5 Param
32	Module Mfr	Trina Solar
33	Module Model	Trina Solar TSM-230PA05
34	# of Modules in String	1
35	# of Strings in Parallel	1
36	Inverter Mfr	SMA America
37	Inverter Model	SB7000US (277V)
38	Irradiance Method	Sensor
39	Temperature Method	Sensor
40	Wire AWG	10
41	Wire Length (ft; one way)	5
42	Array Slope (Deg)	33
43	Array Azimuth (Deg)	180

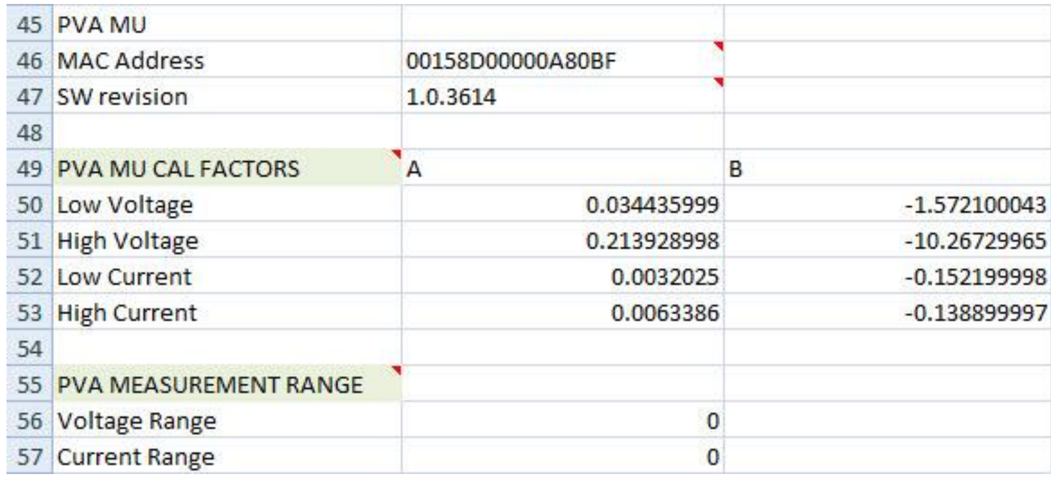
Figure 54. Model Details section of the exported csv file

Parameters displayed in the Model Details section of the csv file are explained in Table 18

Table 18. Model Details

Parameter	Description
Name	User-assigned name of the PV model or PV system.
Notes	Shows any notes entered by user.
Latitude	Positive values in the northern hemisphere. Zero at the equator.
Longitude	Longitude relative to the prime (Greenwich) meridian. Value ranges from 0 to 180 degrees. Negative values are westward, positive values are eastward.
Time Zone	The time zone value is loaded from PC's time and date function.
Model Type	Identifies the PV model that was in use when the measurement was taken.
Module Mfr	This cell identifies the PV module manufacturer.
Module Model	This cell identifies the PV module model.
# of Modules in String	Number of modules in the string.
# of Strings in Parallel	Number of strings in parallel.
Inverter Mfr	This cell identifies the inverter manufacturer.
Inverter Model	This cell identifies the inverter model.
Irradiance Method	Shows which of the three options provided this environmental value to the PV model. Choices are Sensor (wireless sensor), Manual, or Predicted (array as sensor).
Temperature Method	Shows which of the three options provided this environmental value to the PV model. Choices are Sensor (wireless sensor), Manual, or Predicted (array as sensor).
Wire AWG	Wire gauge of the conductors from the point where the PV Analyzer is connected to the module or string under test.
Wire Length (ft; one way)	One-way wire length from point where the PV Analyzer is connected to the module or string under test.
Array Slope (Deg)	Array slope entered in degrees.
Array Azimuth (Deg)	Azimuth of the array entered in degrees (0° is north, 90° is east, 180° is south, and 270° is west).

The exported csv file also contains data related to the configuration characteristics of the I-V Measurement Unit, shown in Figure 55 and Table 19. This data is included for product support purposes and does not contain PV performance-related information.



45	PVA MU		
46	MAC Address	00158D00000A80BF	
47	SW revision	1.0.3614	
48			
49	PVA MU CAL FACTORS	A	B
50	Low Voltage	0.034435999	-1.572100043
51	High Voltage	0.213928998	-10.26729965
52	Low Current	0.0032025	-0.152199998
53	High Current	0.0063386	-0.138899997
54			
55	PVA MEASUREMENT RANGE		
56	Voltage Range	0	
57	Current Range	0	

Figure 55. Configuration characteristics of the I-V Measurement Unit

Table 19. Configuration characteristics of the I-V Measurement Unit

Parameter	Description
MAC Address	Media Access Control address, the burned-in network address of the I-V Measurement Unit.
SW revision	Version number of the I-V Measurement Unit internal software, not the PC software.
PVA MU CAL FACTORS	Factory cal coefficients stored in the IV measurement unit. Not user settable.
PVA MEASUREMENT RANGE	Gain ranges automatically selected in the IV measurement unit. 0 = low range 1 = high range

Figure 56 is an example of the measured I-V data, and power values calculated from the I-V pairs. Actual I-V measurement sweeps may start at slightly negative voltages, but measurement points having negative voltages are not saved and displayed.

59	IV Measurements:		
60	VOLTS	AMPS	WATTS
61	3.579978338	7.812417637	27.96828591
62	4.957418284	7.812417637	38.72942204
63	6.264641183	7.802810137	48.88180573
64	7.538324783	7.799607637	58.79597555
65	8.777572384	7.796405137	68.43351043
66	10.08524363	7.790000137	78.56404928
67	11.35937558	7.790000137	88.48953734
68	12.56418719	7.786797637	97.83478308
69	13.87230678	7.783595137	107.9764196

Figure 56. IV Measurements

Figure 57 is an example of the raw ADC data. This data is product support for debug purposes only. Values do not necessarily represent the IV values in the same line.

ADC Counts (V)	ADC Counts (I)
65	2487
105	2487
143	2484
180	2483
216	2482
254	2480
291	2480
326	2479
364	2478
399	2476
435	2475
472	2471
508	2467

Figure 57. ADC Counts

Recalling Measurement Data

NOTE	If you wish to save a new measurement result, do so before recalling a saved result.

To recall a saved measurement result, click on the **Recall...** button in any of the measurement result tabs (Traces, Table, Verify, or History).

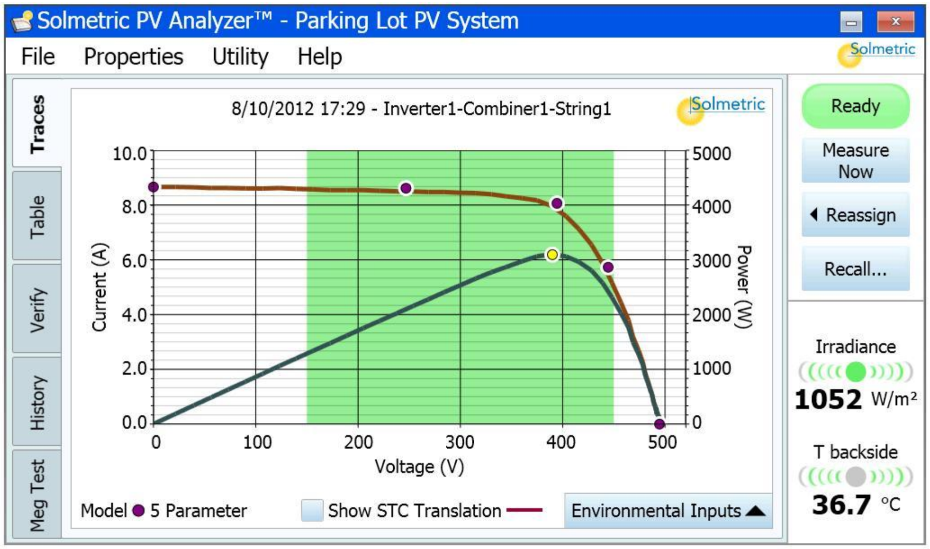


Figure 58. Recall measurement screen

The Recall Measurement screen will appear, as shown in Figure 58. To recall a measurement result, select the System tab and click on the array location of the desired measurement. If more than one measurement exists for that location, click on the measurement result with the desired date and time, then click **Recall**.

Alternatively, you can select the Date/Time tab to see all measurements saved in the Project, sorted by date and time. Select the desired entry and click **Recall**.

The Environmental Inputs controls are available when viewing a recalled trace. Any changes you make in these control settings will affect the display of the recalled trace.

Troubleshooting PVA-600 Operation

This section describes steps to troubleshoot the operation of the PVA-600. Troubleshooting of actual PV systems is not included in this discussion.

Troubleshooting Using Status Messages

Your main tool for troubleshooting PVA-600 and its wireless link to your PC is the Status button, shown in Figure 59. It appears in each of the measurement screens. The Status button indicates the state of the measurement system, and in some conditions clicking on the Status button will open a popup with additional information. The Status button labels and their meanings, as well as the contents of the popup messages, are listed below.

Figure 59. Status button

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

"Ready" message

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

Clicking on the Status button 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 button, the link to the I-V unit is established, but the PC software is waiting to receive calibration factors from it. This typically occurs when the link is first established.

"Optimizing" message

When "Optimizing" appears in the Status button, 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 Measurement Unit is established. This operation involves taking an initial trial I-V curve measurement and then optimizing the I-V Unit's internal settings. 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 button, the PVA-600 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 650 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.

  When the over-voltage condition was detected, the I-V Measurement Unit was immediately reprogrammed to a disabled state to prevent continued use of a damaged unit. Resetting or restarting the I-V Measurement Unit will not re-enable it. Please contact Solmetric to arrange for repairs.

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

When the message “Paused” appears in the indicator, this means that the I-V Unit is temporarily disabled by the user by pressing the LED pushbutton on the I-V Unit. 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. The I-V Unit can be brought back to the enabled state simply by pressing the LED pushbutton.

Clicking on the Status button 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 adaptor used to communicate with the I-V Measurement Unit. Plug the USB adaptor into an open USB port. You may need to go to the Utilities menu, select Settings, and follow the instructions to locate the USB adaptor. Be aware that each I-V Measurement Unit is matched with the USB adapter it was shipped with; mixing them up will make communications impossible. Matching USB adapters to I-V Measurement 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 adaptor, but cannot communicate with the I-V Measurement 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

I-V Measurement Unit wireless range

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.

Wireless Sensor Kit wireless range

Check that the sensor kit's wireless USB adaptor is plugged into the PC, and that the wireless transmitters attached to the sensor cables are turned on and within range. Raise the transmitters above rooftops and metal surfaces, and improve the line-of-sight to the PC.

Trace is noisy or made up of long, straight line segments

If on or more traces are noisy, check for low light conditions. This may be caused by cloud cover, by low sun angles, or, when testing un-mounted PV modules, by having the modules pointed away from the sun. For best results, perform PV measurements of fixed arrays within a few hours of solar noon.

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.

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

5 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-600 PC software
- Number of PV modules in series
- Number of PV modules or strings in parallel
- Length and gauge of wire between the string and the PV Analyzer
- Irradiance
- PV cell temperature
- For some PV models it is also necessary to provide: latitude, longitude, time zone, and array orientation.

Inverter characteristics provided in the PVA PC software are provided only to allow the user 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:

- Isc Short circuit current
- Imp Max power current
- Vmp Max power voltage
- Voc Open circuit voltage
- Vx Voltage at one half Voc
- Ix Current at Vx
- Vxx Voltage midway between Vmp and Voc
- Ixx Current at Vxx
- FF Fill Factor = Imp * Vmp / (Isc * Voc)

The fill factor (FF) of a PV module or string is a measure of the square-ness of the curve as shown in Figure 60. PV modules of a given manufacturer and model will have very similar fill factor values if they are performing normally and are no impaired by shade or soiling.

The fill factor is the ratio of two areas defined by the I-V curve as shown in Figure 60. These areas represent electrical power (watts) because each area is the product of a voltage and a current. Fill factor is the area defined by the max power point, divided by the area defined by Isc and Voc. In an ideal (but unrealizable) PV module, the two areas would be identical and a fill factor of 1.0 would result.

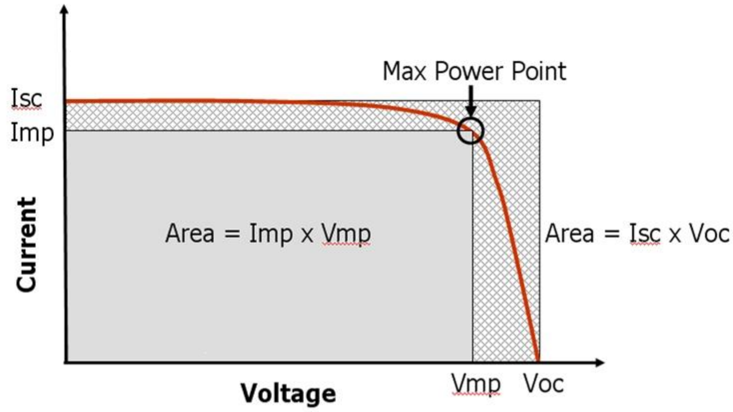


Figure 60. The Fill Factor is defined as Imp x Vmp (the gray area) divided by Isc x Voc (the cross-hatched area).

The Shape of a Normal I-V Curve

Figure 61 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's built-in PV model, is shown by the five 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.

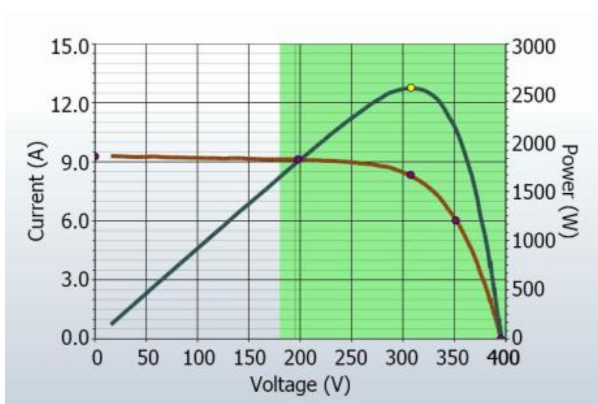


Figure 61. A normal I-V curve for the parallel combination of two strings of eight 175-watt modules, showing conformance with five points predicted by the PV model.

A normal I-V curve has a smooth shape with three distinct voltage regions as shown in Figure 61:

1. A slightly sloped region above 0 V (the horizontal leg of the curve)
2. A steeply sloped region below Voc (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 five PV model points are defined, from left to right, as follows:

- SC – First point, at short circuit current Isc
- X – Second point, at one-half of the open circuit voltage
- MP – Third point, the maximum power point Imp, Vmp
- XX – Fourth point, midway between Vmp and Voc
- OC – Fifth point, at open circuit voltage Voc

Interpreting I-V Curves

Most array problems show deviations between measured and predicted I-V curves that fall into one of these categories:

1. The measured I-V curve has higher or lower Isc value than predicted
2. The slope of the I-V curve near Isc does not match the prediction
3. The slope of the I-V curve near Voc does not match the prediction
4. The I-V curve has notches or steps
5. The I-V curve has a higher or lower Voc value than predicted

These five classes of I-V curve deviation are illustrated in Figure 62.

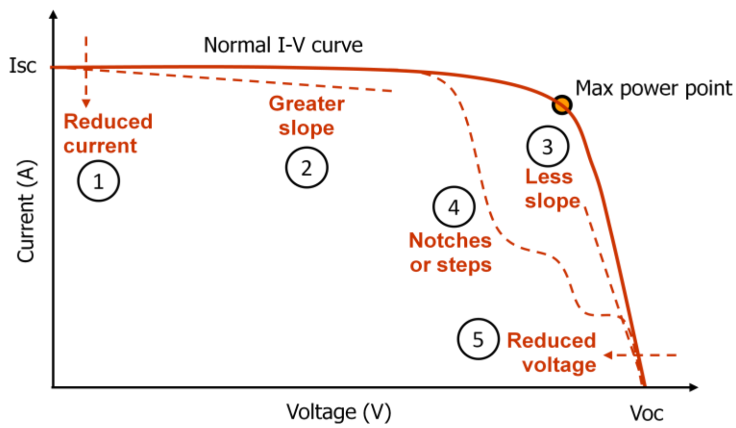


Figure 62. Deviations in the shape of the I-V curve fall into one (or a combination) of these five categories

It would be convenient if each of the I-V curve deviations illustrated in figure x 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 up to the moment temperature and irradiance values are used.

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

1. The measured I-V Curve has Higher or Lower Isc than Predicted

An example of this type of deviation is shown in Figure 63.

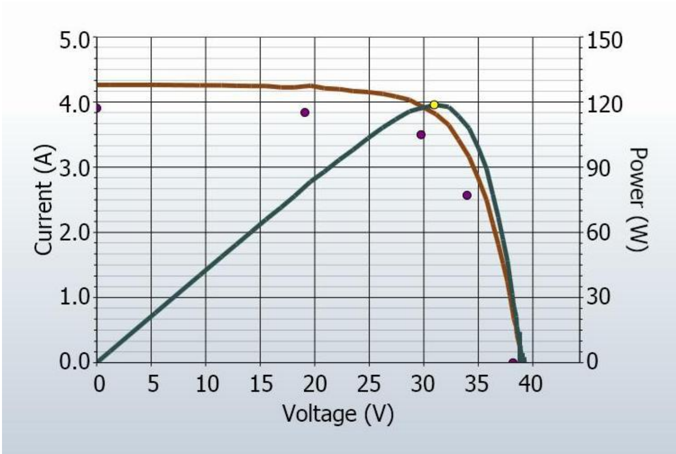


Figure 63. Example of a measured I-V curve that shows higher current than predicted

Potential causes for the measured Isc being higher or lower than predicted are summarized below, and then discussed in more detail.

Potential causes located in the array include:

- PV array is soiled (especially uniformly)
- PV modules are degraded

Potential causes associated with the model settings include:

- 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
- Irradiance sensor calibration factor is entered incorrectly
- Albedo effects contribute additional irradiance
- Irradiance is too low, or the sun is too close to the horizon
- Manual irradiance sensor is not accurate

PV Array Is Soiled

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. Under special circumstances, non-uniform soiling can also have this effect. The most common example is a low-tilt array with modules in portrait mode. Over time, a band of dirt grows upward from the lower edge of each module. When the band of dirt reaches the bottom row of cells, the height of the I-V curve is reduced. If the dirt bands are similar enough from module to module, the effect is like uniform soiling.

PV Modules Are Degraded

Degradation of PV module performance with time and environmental stress is normally a very slow process. Given the number of factors – for instance, soiling or irradiance measurement accuracy – 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 Isc 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 Isc. 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 Isc 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 (eg 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 is required by the automated process using the Wireless Sensor Kit.

Irradiance Sensor Is Oriented Incorrectly

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.

Irradiance Sensor Calibration Factor Is Entered Incorrectly

The irradiance sensor in the optional wireless sensor kit has a calibration sticker. For accurate measurements, the calibration factor value on the sticker must be entered into the PV Analyzer software.

Albedo Effects 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 Isc 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. 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

Irradiance sensors vary widely in their basic calibration accuracy, response to diffuse light, and spectral match to the array being measured. Choose a well-calibrated sensor of a technology similar to that of the array under test. The irradiance sensor provided in the PVA-600's Wireless Sensor Kit is of high quality and is well calibrated, with a spectral response similar to crystalline and multi-crystalline solar cells.

2. The Slope of the Curve near Isc Does Not Match the Prediction

An example of this deviation is shown in Figure 64.

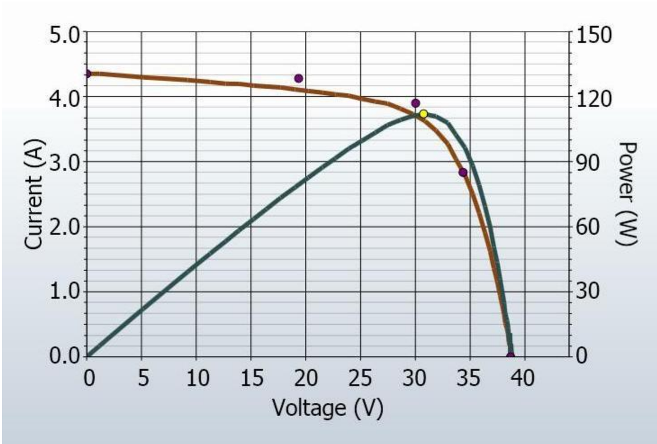


Figure 64. An I-V curve showing more slope than expected in the region above Isc

The upper 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:

- Shunt paths exist in PV cells
- Module Isc mismatch

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's 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° C or more is common.

A reduced shunt resistance will appear in I-V curves as a steeper (less flat) slope near Isc. 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 Isc 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 Isc 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 Isc values of each module. Isc 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 Isc 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 Isc 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.

3. The Slope of the Curve near Voc Does Not Match the Prediction

An example of this type of deviation is shown in Figure 65.

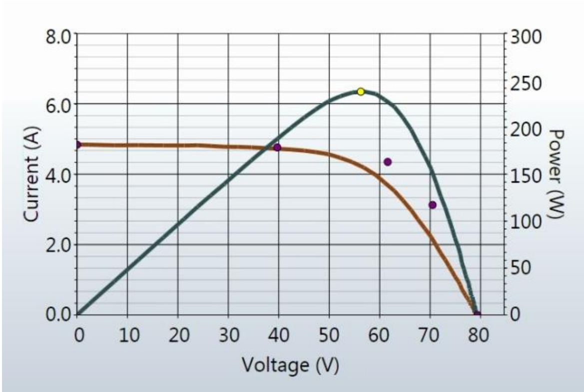


Figure 65. An I-V curve in which the slope of the measured I-V curve near Voc does not match the predicted slope

The slope of the I-V curve between Vmp and Voc 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 (eg 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 Voc.

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.

4. The I-V Curve Has Notches or Steps

Examples of this type of deviation are shown in Figure 66, Figure 67, and Figure 68.

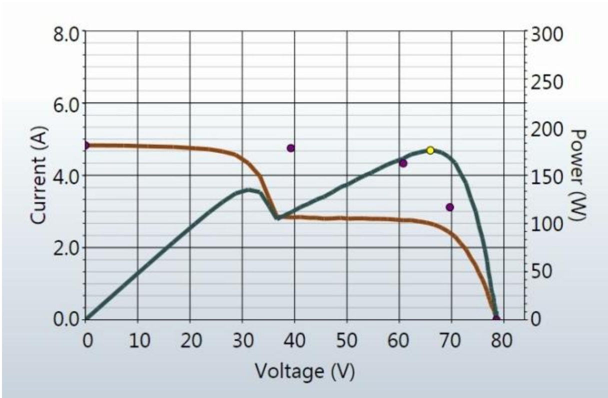


Figure 66. The effect of partial shading on two paralleled strings of eight 175-watt modules

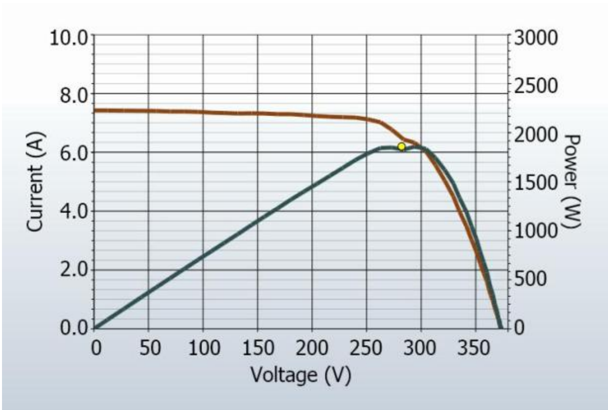


Figure 67. The shading impact of placing a business card on a single cell in a string of fifteen 180-watt modules

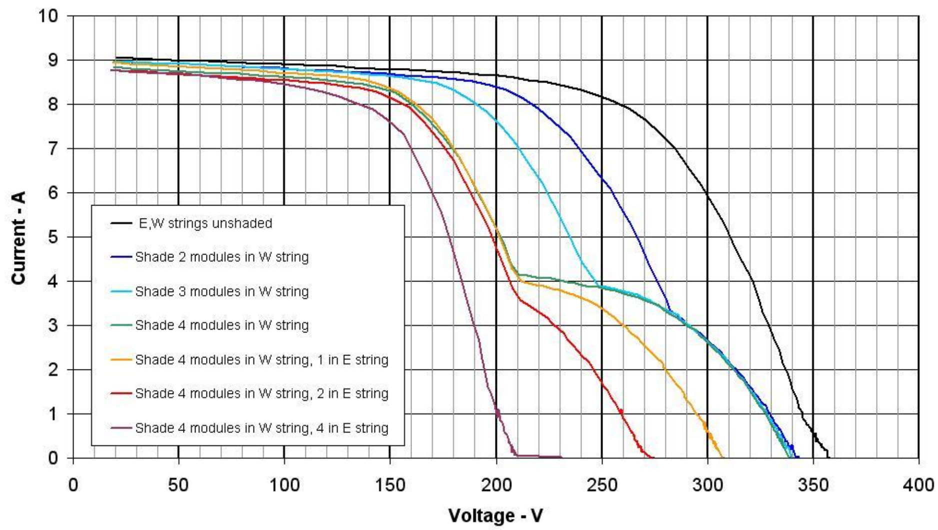


Figure 68. The effect of intentionally shading entire modules in different combinations, in two parallel-connected strings

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
- PV cells are damaged
- Bypass diode is short-circuited

Array Is Partially Shaded

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 Section 2. The Slope of the Curve near Isc Does Not Match the Prediction. The impact of partial shading on the I-V curve is to create a notch, as shown in Figure 68. 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 Voc 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

As described in Section 2. The Slope of the Curve near Isc Does Not Match the Prediction, a localized hot-spot can also effectively short out a particular cell. When this happens, the bypass diode spanning that cell string can turn on, causing a notched I-V profile. This I-V profile would be similar to a completely shaded PV module, but with a lesser voltage reduction corresponding to the loss of a single cell string.

5. The I-V Curve Has a Higher or Lower Voc Value than Predicted

An example of this type of deviation is shown in Figure 69.

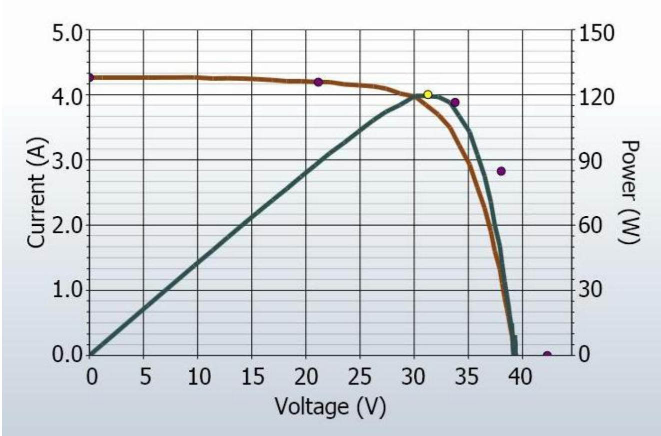


Figure 69. Example of an I-V curve with lower Voc value than predicted

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

Potential causes located in the array include:

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

PV Cell Temperature Is Different than the Modeled Temperature

The module Voc is dependent on the temperature of the solar cells, with higher temperatures resulting in a lower Voc. 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 itself 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 Voc has shifted downward. If you are uncertain, check the value of Voc that the PVA-600 lists in the table display. 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 Voc 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.

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6 Measuring Environmental Conditions

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.

The PVA-600 provides three different methods for measuring the environmental parameters:

- Measure the values with the Solmetric wireless sensor kit
- Calculate the values from the measured I-V curve
- Manually enter values measured with other instruments (eg irradiance or temperature meters)

The choices for irradiance and temperature are independent, so you can choose different methods for each if you prefer.

The Solmetric Wireless Sensor Kit is recommended for commissioning type applications, capacity studies, and for any other applications that require independent and efficient measurement of the environmental conditions.

Calculating the environmental values from the measured I-V curves is very useful when the array is not accessible for deploying sensors or you do not have the time to deploy them. This method is also useful when irradiance and temperature are varying rapidly, because there is no time delay between the I-V curve and the sensor 'reading'. This method has a limitation in that the accuracy of the irradiance and temperature determinations is dependent on the health of the module or string under test. A damaged PV system will produce unreliable estimate of the environmental parameters. This risk can be mitigated by comparing the measured I-V curves to one string to another. If one curve is very different from the others, the irradiance and temperature values calculated from that curve may be in error.

Manual entry of environmental values is helpful for small jobs where you may not wish to deploy the sensor kit, or one is not available. It also can be used when a specific sensor must be used to meet contractual obligations.

One of the considerations in selecting a sensor method is the degree to which the I-V curve and the environmental conditions are measured simultaneously, that being the ideal. Time delays introduce scatter in the correlation between sensor values and I-V data, which in turn causes more error when in modeling the expected performance. From the standpoint of minimal time delay between I-V and sensor measurements, the three methods rank in this order:

1. Calculate the values from the measured I-V curve (no delay)

2. Wireless sensor kit (< 2 seconds delay for irradiance, <10 seconds for temperature)

3. Manual entry of values measured with other instruments (eg irradiance or temperature meters) (delay is user dependent)

The following chart will help you choose the method that is best suited to your application.

Table 20. Choosing the sensor method

	Irradiance	Temperature
Solmetric Wireless Sensor Kit is recommended	• Rigorous, quantitative testing (system commissioning or capacity measurement) • Modules may be degraded or damaged. • Relatively stable irradiance	• Uniform temperature across array • Low wind speeds
Array-as-sensor method is recommended	• Screening applications • Modules are not degraded or damaged • Rapidly varying irradiance	• Substantial temperature variation across array • High wind speeds • Array is not accessible
Manual entry is recommended	• Specialized sensor is required • Small jobs where high throughput is not essential	• Specialized sensor is required • Small jobs where high throughput is not essential

Following are detailed discussions of irradiance and temperature measurement methods.

Measuring Irradiance

Introduction

The PV performance models used in the PVA-600 software are designed to take into account the irradiance and the PV cell temperature. 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 varies with time of day and often more rapidly with sky conditions
- Irradiance sensors may have different spectral responses than the PV modules themselves
- The shape of the PV module I-V curve changes at low irradiance levels
- The solar spectrum is shifted significantly early and late in the day

The most common method for irradiance measurement is to deploy a reference cell in the plane of the array, using a reference cell of similar technology to the modules under test.

Irradiance can also be calculated from the measured I-V curve, with certain caveats relating to the health of the PV modules being measured.

Solmetric Wireless Sensor Kit

The irradiance sensor provided in the Solmetric Wireless Sensor Kit is a mono-crystalline silicon solar cell. The irradiance is determined from the short circuit current, which is measured using a small shunt resistor. A label on the irradiance sensor housing provides a calibration factor, which the user enters once into the PC software.

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.

Mounting the irradiance sensor in the plane of the array can be as easy as placing the sensor on the surface of a neighboring PV module. Just be sure that the module is not in the string being measured, or you will see a shading effect.

If the sensor is being mounted at some height, consider attaching a short tether or lanyard between the sensor and the module or racking to protect the sensor and personnel should the sensor come loose.

Another mounting approach is to place the irradiance sensor on a tripod and orient the sensor to the correct azimuth and tilt. Chose a location that sees the same irradiance as the array (see the sections on albedo effects and diffuse light). For this application, select a sturdy tripod. Attach to it a leveling head, and to this a tilt and pan mount. Take these steps to deploy the sensor:

- Select the location that has representative irradiance and is well positioned for maximum wireless range
- Extend the tripod legs as needed
- Adjust the leveling base to provide a level surface for the tilt and pan mount
- Adjust the tilt control for horizontal
- Using a compass, adjust the pan control so that the sensor’s azimuth matches that of the array
- Using a tilt indicator, adjust the tilt control so that the sensor is at the same tilt as the array

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, ie clear days and pointed directly at the sun. Using a similar-technology reference cell will reduce this error, but not eliminate it.

Estimating irradiance from the measured I-V curve

The PVA-600's PV models predict the shape of the I-V curve based on the existing irradiance and cell temperature. Elements of the models can be used in reverse, to calculate the equivalent irradiance and cell temperature from the measured I-V curve (specifically, from the measured values of Isc and Voc). The method the PV Analyzer uses for this calculation uses elements of the Sandia model and the IEC standard on equivalent cell temperature.

When the irradiance and temperature are calculated from measured values of Isc and Voc and you are using one of the PV models (the five dots that predict the I-V curve shape), you will notice that the first and last of the PV model points align very well with the measured Isc and Voc (particularly when using the advanced Sandia model). In other words, when using this method, the first dot of the model will generally agree well with the measured Isc, and the last dot of the model will agree with the measured Voc. This close agreement is a result of the inherent circularity of the array-as-sensor method; the model used to predict the I-V curve shape is no longer independent from the I-V curve measurement itself. Given this limitation, certain deviations in PV performance are not detected. For example, a uniformly soiled array produces a lower output current, which in turn leads to under-estimation of the irradiance. The measured and modeled I-V curve will be well aligned with the five PV model dots, giving no indication of the effects of the uniform soiling.

Even given these limitations, the 'array as sensor' method can be very useful in many applications.. One of the valuable aspects of the array as sensor method is that since the first and last points of the model are forced to match the measured I-V curve, it is very easy to visually detect any deviations of the measured I-V curve from the three remaining model points. This allows the user to quite sensitively detect anomalies in I-V curve shape of the type that are caused by shunt loss, series loss, diffuse partial shading and various other mismatch effects.

Another benefit of the array as sensor method is that since irradiance and temperature sensors are not needed, it's not necessary to access the array to mount them. This is helpful in a variety of situations:

- Wet or icy roof surfaces
- Steep roofs or lack of fall protection equipment
- Staff lacks fall safety training
- Building Integrated PV systems in which arrays may be very difficult to access
- Any situation in which the module backside is not accessible (including some BIPV)

The user can choose to estimate the irradiance, the temperature, or both from the measured I-V curve, depending on the application. For instance, if access to the array is difficult and you'd like to use the array as sensor method but require independent irradiance measurement, you can mount an irradiance sensor remotely at the proper orientation, and determine just the temperature from the measured I-V curve. This method is also useful under windy or partially cloudy situations in which the temperature of the array is changing rapidly. Since the temperature is calculated from the measured I-V curve, the average cell temperature is determined simultaneously.

Using the array as sensor method to estimate irradiance

This method is selected in the environmental parameters control area in the PVA-600 software.

As mentioned earlier, to be useful, this method requires that the PV module or array be fully functional. Here are the factors to consider:

- Does the number of modules entered in the PV model match the number in the actual string?
- Is the PV model set to the correct PV module manufacturer and model number?

When screening the performance of a number of PV strings, compare the measured Voc values with one another. They should be very similar if all the strings are healthy. If Voc of a string deviates sharply from the rest, that string should be checked out. The array-as-sensor based comparison of the modeled and measured curves will be less reliable for that string.

If the sky is clear and the irradiance is fairly stable, also compare the heights of the I-V curves. They should be quite closely packed. If one curve is substantially lower, the environmental values calculated from that I-V curve may be in error.

Getting comfortable with the array-as-sensor method

You can develop more confidence in the array-as-sensor method by comparing its predicted irradiance values with the readings from the wireless sensor kit for identical irradiance conditions (clear sky, close to solar noon). If the readings are very close, you may decide to save time by relying on the array-as-sensor method.

Measuring PV module temperature

Introduction

The PV performance models used in the PVA-600 software are designed to take into account the irradiance and the PV cell temperature. Measuring the temperature of PV modules presents a number of requirements and challenges:

- The PV cell is embedded in other materials, so contacting the cell is not possible
- The materials in which the PV cell is embedded have poor thermal conductivity
- Temperature offset between PV cell and module backsheet depends on racking configuration
- Temperature is not uniform across a PV module or array
- Temperature at a given location may vary with time, even at constant irradiance
- Characteristics of the front and back faces make infrared temperature measurement difficult

The most common method of module temperature measurement involves attaching a thermocouple or resistive temperature device (RTD) to the backside of the PV module. This approach is widely used in commissioning new PV arrays.

Temperature (and irradiance) can also be calculated from the measured I-V curve, effectively using the predictive PV model in reverse. Because this calculation is based on the model, any deviations between modeled and actual PV array (eg degraded or damaged modules) will detract from measurement accuracy. Some of these limitations can be mitigated, and this method has several important applications.

Making backside temperature measurements

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 too delicate for this application.

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 degrees C

A good choice for this application is high-temperature polyester tape (eg 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 in spools of 1.75 inch disks for added convenience.

Do not use cheap duct tape, as it does not perform well at high temperature.

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.

Estimating the temperature offset from the backside to the PV cell

The PVA-600’s PV model requires the PV cell temperature, which is typically higher than the backside temperature. If you are using the Wireless Sensor Kit, when you set up your PV model you will be asked to estimate this temperature offset. Experience has shown that although this offset depends on the module mounting configuration, an offset of 3 degrees C is fairly typical.

The difference between the PV cell temperature and the module backside can be estimated by subtracting the measured backside temperature from the temperature that was calculated from the measured I-V curve. The two measurements must be performed as simultaneously as possible. The accuracy of this comparison is limited by the fact that the temperature is not uniform across a module or array, so the measured backside temperature may not be representative. This factor can be mitigated by measuring backside temperature at several locations simultaneously and averaging the results, but this is not practical for non-research applications. Another limitation of this method is that calculating the temperature from the measured I-V curve also assumes that all of the modules in the array are in good working order and have not degraded significantly.

For the reasons explained above, we suggest setting 3 degrees C as the offset value.

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 2/3 of the way in along the diagonal, as discussed above, but choose a module that is well away from the end of the array.

It is possible to experimentally determine the approximate temperature distribution across the module or array by making multiple backside temperature measurements around solar noon on a cloudless, windless day. However, this type of day may be rare, and the results obtained will apply only under those conditions.

If you are measuring multiple modules or strings and plan to compare predicted vs measured performance for all of them, your comparison will be more reliable if you mount the thermocouple in the same relative position for each module or string being tested. 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 backside temperature with an infrared thermometer

Infrared temperature measurement devices fall into two categories, IR thermometers and IR imagers or cameras. IR imagers are very useful for finding hot spots in switchgear and PV arrays. The images can be analyzed to produce temperature contours, though this may require companion software. IR digital thermometers are inexpensive and easy to use, so the rest of this section focuses on their use.

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 the user 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.

Estimating cell temperature from the measured I-V curve

The PVA-600's PV models predict the shape of the I-V curve based for the existing irradiance and cell temperature. Elements of the models can be used in reverse, to calculate the equivalent irradiance and cell temperature from the measured I-V curve (specifically, from the measured values of Isc and Voc). The method the PV Analyzer uses for this calculation uses elements of the Sandia model and the IEC standard on equivalent cell temperature.

When the irradiance and temperature are calculated from measured values of Isc and Voc and you are using one of the PV models (the five dots that predict the I-V curve shape), you will notice that the first and last of the PV model points align very well with the measured Isc and Voc, particularly when using the Sandia PV model. In other words, when using this method, the first dot of the model will agree with the measured Isc, and the last dot of the model will agree with the measured Voc. This close agreement is a result of the inherent circularity of the array-as-sensor method; the model used to predict the I-V curve shape is no longer independent from the I-V curve measurement itself. Because of this dependency, certain deviations in PV performance are not detected. For instance, a shorted bypass diode will drop the value of Voc by about 12 volts, and the array as sensor method interprets this an an increase in temperature.

Even given these limitations, the 'array as sensor' method can be very useful in some applications. Since the first and last points of the model are forced to match the measured I-V curve, it is very easy to visually detect any deviations of the measured I-V curve from the three remaining model points. This allows the user to quite sensitively detect anomalies in I-V curve shape of the type that are caused by shunt loss, series loss, diffuse partial shading and various other mismatch effects.

Another benefit of the array as sensor method is that since irradiance and temperature sensors are not needed, it's not necessary to access the array to mount them. This is helpful in a variety of situations:

- Wet or icy roof surfaces
- Steep roofs or lack of fall protection equipment
- Staff lacks fall safety training
- Building Integrated PV systems in which arrays may be very difficult to access
- Any situation in which the module backside is not accessible (including some BIPV)

The user can choose to estimate the irradiance, the temperature, or both from the measured I-V curve, depending on the application. For instance, if access to the array is difficult and you'd like to use the array as sensor method but require independent irradiance measurement, you can mount an irradiance sensor remotely at the proper orientation, and determine just the temperature from the measured I-V curve. This method is also useful under windy or partially cloudy situations in which the temperature of the array is changing rapidly. Since the temperature is calculated from the measured I-V curve, the average cell temperature is determined simultaneously.

Using the array as sensor method to estimate average PV cell temperature

This method is selected in the environmental parameters control area in the PVA-600 software.

As mentioned earlier, to be useful, this method requires that the PV module or array be fully functional. Here are the factors to consider:

- Does the number of modules entered in the PV model match the number in the actual string?
- Is the PV model set to the correct PV module manufacturer and model number?

When screening the performance of a number of PV strings, compare the measured Voc values with one another. They should be very similar if all the strings are healthy. If Voc of a string deviates sharply from the rest, that string should be checked out. The array-as-sensor based comparison of the modeled and measured curves will be less reliable for that string.

If the sky is clear and the irradiance is fairly stable, also compare the heights of the I-V curves. They should be quite closely packed. If one curve is substantially lower, the environmental values calculated from that I-V curve may be in error.

Getting comfortable with the array-as-sensor method

You can develop more confidence in the array-as-sensor method by comparing its predicted temperature with the average of a number of backside temperature samples (at different locations). All of these temperatures must be captured as close to simultaneously as possible. If the offset between the array-as-sensor temperature and the average backside temperature is believable, then you can be more confident about relying on the array-as-sensor method to supply the temperature values for IV curve testing of that array.

Calibrating the array as sensor temperature against the backside temperature

It's tempting to measure the temperature with both the backside and array-as-sensor methods and assume that the difference between them represents temperature offset between backside and PV cell. However, since the backside temperature is not uniform across the module or string, we can't have much confidence in the comparison. This method is not recommended for general use, although it may be applicable to special situations in which the array is at a relatively uniform temperature, or in cases where it's practical to sample backside temperature at multiple points (simultaneously) and average these values.

A slight variation on this calibration concept is to adjust the temperature offset to make the modeled Voc match the measured Voc. This approach to measuring the temperature offset also suffers from the above limitation that the backside temperature is not uniform across the PV string; we don't know if we have located our thermocouple at a point with representative temperature. Taking backside temperature measurements at a number of locations (simultaneously) can improve the result, but this is time consuming and probably only suited for research applications.

Note that the offset between backside and PV cell temperature is a sensitive function of wind speed. Since higher wind speed means cooler modules (assuming constant irradiance), any calibration we perform will become less useful as the wind speed changes. In general, the comparison method has its best chance of being useful in low to no wind situations.

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7 Translation of I-V Data to Standard Test Conditions

The PVA-600 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 $\gamma_{mpp.}$ (taken from the datasheet)
5. Voc is independent of E

In light of these approximations we make these assumptions:

Isc scales directly with E and with temperature.

Voc 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:

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

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

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

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

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