Solmetric PVA-600
PV Analyzer

User's Guide

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Solmetric Corporation
www.solmetric.com
Tel: (877) 263-5026
Fax: (707) 823-4620

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1 Introduction

Overview

The PVA-600 PV Analyzer is a portable test instrument designed to measure 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 current-voltage (I-V) curve of a PV module, string, or array provides a detailed description of its energy collecting 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.

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)
- Display Resolution: 1024 X 600 (minimum)
- Processor Speed: >700 MHz
- RAM: >500 Mbytes
- 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	0 to 600 V dc
Minimum Voc	20 V dc
Minimum Isc	1 A dc
Wireless Communications Range	10 m (industrial building walls) to 75 m (open range)
Measurement Sweep Time[2]	80 ms to 240 ms
Measurement Points per Trace (typical)	100
PV Models	Sandia (>420 modules) 5-Parameter (>1760 modules) Simple Datasheet Model (user enters datasheet values)
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).

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.

PVA Sensor Kit Equipment (Optional)

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

PVA Sensor Kit Specifications (Optional)

Table 3. PVA Sensor Kit temperature specifications

Parameter	Specification
Thermocouple Type	K
Range	-100º C to 1260º C (-148º F to 2300º F)
Resolution	1º C
Accuracy (greater of)	±0.5% of rdg or ±1.0º C (1.8 º F)

Table 4. PVA Sensor Kit irradiance specifications

Parameter	Specification
Sensor Type	Silicon Solar Cell
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% or 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.

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

Compliance pending. 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

PV Connectors

PV connectors, regardless of manufacturer, are not designed for large numbers of connections/disconnections. For this reason, the PVA-600 is shipped with connector-saver jumpers attached to its primary test leads. These short jumpers are sacrificial. PV devices under test (modules, strings, or arrays), extension cables, and clip leads are always connected to the connector-saver jumpers, extending the life of the primary PV connectors. When the lifetime of the connector-saver jumper has been reached, it should be replaced, cut in half to prevent re-use, and recycled. With the use of connector-saver jumpers, the life of the primary test leads of the PVA-600 should be extended to 5,000 to 10,000 connections.

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.

- Avoid working 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 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. For this reason, modules (or strings) of high-efficiency modules 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.

The PVA-600 consists of the following:

- I-V Measurement Unit (PVA-600)
- Control/display device (computer, supplied by user)
- Optional wireless irradiance and temperature sensors (PVA Sensor Kit)

Communication between the I-V Measurement Unit and PC is wireless. A wireless transmitter/receiver is built into the I-V Measurement Unit, and a wireless USB adapter allows a 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.

I-V Measurements

When enabled, the I-V Measurement Unit measures I-V curves when the user requests it from the PC interface. 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.

Logging Mode

The PVA-600 also provides a logging mode that captures I-V curves over a period of time. I-V curves are measured at time intervals, and summary data (not entire I-V data sets) is saved. This feature is useful when the weather is intermittent and it is necessary to wait for a period of clear sky or when troubleshooting intermittent or temperature related performance problems. When operating in the logging mode, the I-V Measurement Unit transmits the data continuously to the wirelessly connected notebook or tablet computer running the PVA-600 software. The computer must be present during the logging period.

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. The parameters of many modules are stored in a database in the display/control device. 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.

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. The directory structure shown in Figure 2 is created in the Documents directory.

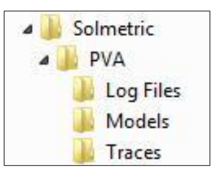

Figure 2. Directory structure of PVA-600 software

5. When the installation process is finished, start the PVA-600 software by double-clicking on the shortcut icon on your desktop as shown in Figure 3. Or, select the list of programs in the **Start** menu, then select **Solmetric>PV Analyzer>Solmetric PV Analyzer**.

Figure 3. Launching the PVA-600 software

6. The screen shown in Figure 4 should appear.

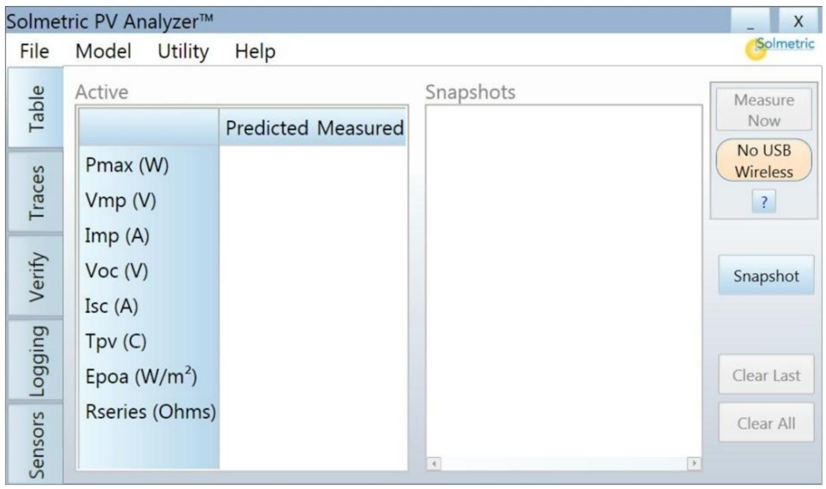

Figure 4. PVA-600 software user interface

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 PVA Sensor Kit

The PVA 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 PVA 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 5 and plugging the charger into an AC wall-plug.

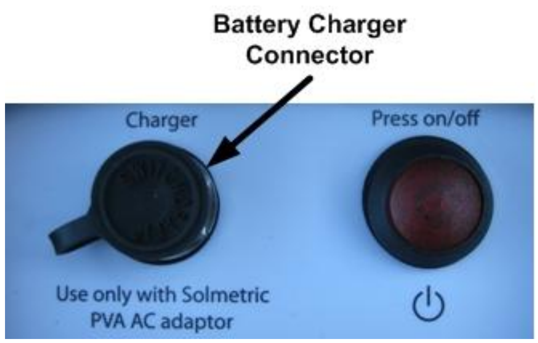

Figure 5. Battery charger connector on the PVA-600

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.

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.

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.*

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 6, 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 6. LED-illuminated button switch

PVA-600 States

The PVA-600 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.

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.

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.
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 PVA Sensor Kit, refer to Setting Up the Optional PVA Sensor Kit for setup information.

Setting Up the Optional PVA Sensor Kit

Figure 7 shows the PVA Sensor Kit components that will be set up.

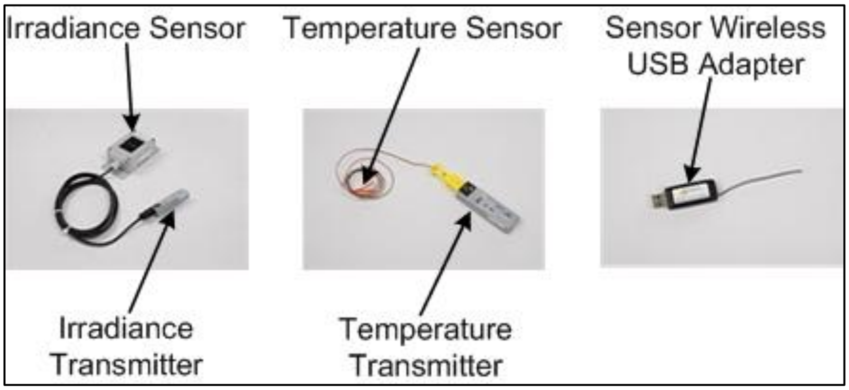

Figure 7. PVA Sensor Kit

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 USB hub with short connecting cable (<6”) 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.
5. Ensure that the irradiance transmitter is not resting on the ground or on the roof, and is not placed against a metal surface. Elevating the irradiance transmitter improves the transmission range.
6. Secure the temperature sensor close to the middle of a PV module. Temperatures toward the outside of a PV module or array are cooler.

NOTE The temperature sensor has adhesive tape on it used to secure it to a panel. When the adhesive tape will no longer hold the temperature sensor to the panel, use duct tape to hold the sensor tip and at least an inch of wire in intimate contact with the module back surface.

7. Ensure that the temperature transmitter is not resting on the ground or on the roof, and is not placed against a metal surface. Elevating the temperature transmitter improves the transmission range.

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 again 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 insulated test leads of the PVA-600 to the test string. The connection may be made at PV connectors at the ends of the test string, or by clipping to the de-energized buss bars in a DC combiner box as shown in Figure 8, using suitable test leads with MC-4 connectors at one end and insulated alligator clips at the other end.

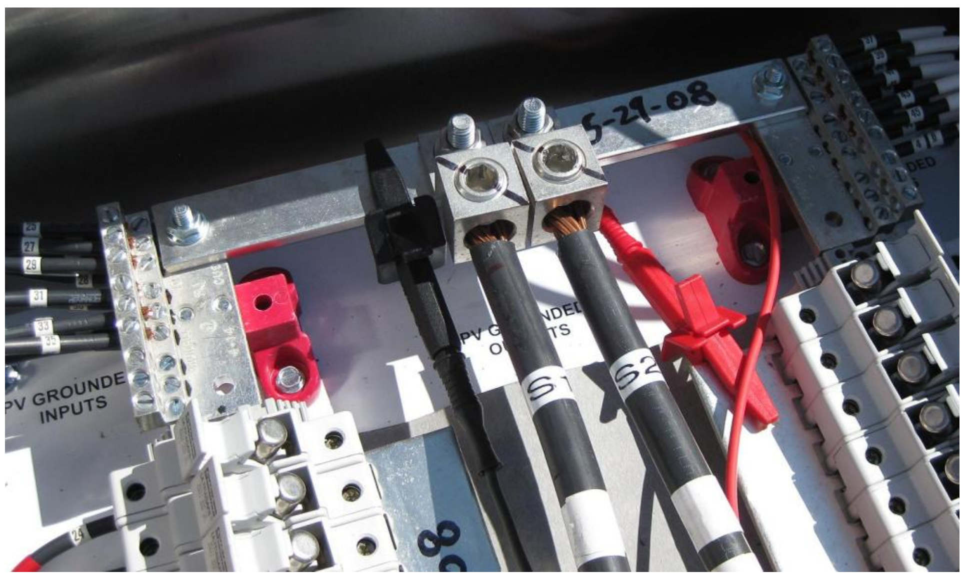

Figure 8. Example of PVA-600 test leads clipped to the buss bars of a PV combiner box

4. If one or both of the terminals of the test device must be some distance from the I-V Measurement Unit, use extension cables made of UL (or equivalent) listed PV wire, with correctly installed connectors. Select a wire gauge that will introduce minimal 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 the fuse for the string to be measured.

Powering-Up the I-V Measurement Unit

Press the power button once on the I-V Measurement Unit. Refer to Figure 9.

Figure 9. 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 I-V curves 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.

Sweep Disabled

PV current is stopped automatically at the end of each I-V measurement. However, to ensure no current is flowing, 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.

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.

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

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

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 10.

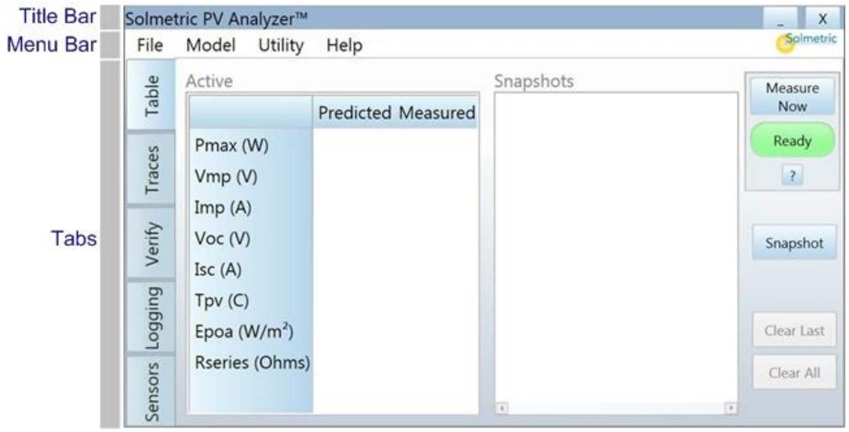

Figure 10. PVA-600 main screen

The Title Bar is located at the top of the main screen and displays the name of the product. 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 measurements.

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. 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

Table 6. File menu description

Name	**Description**
Exit	Closes the PVA-600 software application.

Model Menu

Table 7. Model menu description

Name	**Description**
New	Creates a new model file used to set up new PV modules, sensors, and related site information. The file will be saved in the **Models** folder.
	**Name**: name of model file. **Notes**: pertinent notes about the PV modules.
	**Latitude**: numeric entry in degrees. Range is -90 to +90. Default is 38.25. **Longitude**: numeric entry in degrees. Range is -180 to +180. Default is -122.80. **Time Zone**: numeric entry in hours (relative to GMT). Range is -12 to +12. Default is -7.

Name	Description
Modules / String	**Detailed Performance Model**: **Modules**: the **Change…** button is used to select the module manufacturer and module number. **Sandia**: selects the Sandia performance calculation model. This model accounts for all performance related factors of a PV module and is based on module measurements taken in independent laboratories. **5 Parameter**: selects the 5 Parameter performance calculation model. This model is derived from module data sheet specifications and independent laboratory tests where available. Once a module is selected from the dropdown list, either or both of these models will be available, depending on the data availability. **Simple Performance Model**: **Edit** button: accesses the screen for entering the manufacturer's published module specifications. This model predicts the maximum power voltage and current at the existing irradiance and temperature. Based on data sheet values, this model can be used with almost any PV module with basic specifications. **NOTE –** While default values are included in the Simple Performance Model screen, you will have to replace these values with those from your desired module. **# of Modules in String**: enter number of modules in series. **# of Strings in Parallel**: enter number of modules or strings in parallel. **CAUTION –** *Conventional PV modules and strings can be measured in parallel up to the specified current limit of the PVA-600. However, high-efficiency modules and strings should NOT be measured in parallel. The large current transient produced by these modules can electrically stress the instrument.*
Inverter	**Inverter**: the **Change…** button is used to select the inverter manufacturer and model number. The maximum power tracking voltage range of the selected inverter will be displayed as a green shaded region superimposed on the I-V curve.

Name	Description
	This is the resistance of the external wiring calculated from user entries of wire length and wire gauge: Rseries = [Resistance per Foot] * Wire Length 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 **Wire Gauge (AWG)**: selects the wire gauge of conductors between the PV string and the point at which the I-V curve is being measured. **Wire Length (Feet, one-way)**: enter the wire length in feet. For instance, if you have two 10 foot leads running between the I-V unit and the string, enter “10” (not “20”).

Name	Description
Sensor Methods	**Use wireless irradiance sensor**: irradiance is transmitted wirelessly when using the PVA Sensor Kit. **Cal Factor**: enter calibration factor of the sensor. **Enter solar irradiance manually**: irradiance is entered manually from an external sensor. This method is suitable when irradiance is relatively stable. **Irradiance (POA)**: enter irradiance manually in this text box. **NOTE** – All irradiance measurements must be made in the plane of the array (POA). This means the irradiance sensor is mounted parallel to the PV modules. Horizontal plane measurements are not supported. **Determine irradiance from IV curve**: PVA-600 extracts irradiance mathematically from measured I-V data. This method is used when the main objective is to demonstrate consistency among PV strings and to observe subtle deviations from predicted I-V curve shape. An external sensor is not required because the array itself is the sensor. Assumes functional PV module(s). **Use wireless temperature sensor**: temperature is transmitted wirelessly when using the PVA Sensor Kit. **Offset**: enter the temperature offset to be added to the module backside temperature to determine cell temperature. **NOTE** – The offset will vary typically from 0º C to 8 º C during a day depending on mounting and wind conditions. The default value of 3º C is only a typical number. **Enter module temperature manually**: temperature is entered manually from an external sensor. This method is suitable when temperature is relatively stable. Temperature readings should be taken close to the middle of a panel. Temperatures toward the outside of a panel tend to be cooler. **PV Temperature**: enter temperature manually in this text box. **Determine temperature from I-V curve**: PVA-600 extracts temperature mathematically from measured I-V data. This method is used when the main objective is to demonstrate consistency among PV strings and observe subtle deviations from predicted I-V curve shape. An external sensor is not required because the array itself is the sensor. Assumes functional PV module(s).

Name	Description
Array Plane	**Slope (degrees)**: enter the tilt of the array in degrees, which can be measured with an inclinometer or slope meter (0° is horizontal, 90° is vertical). **Azimuth (degrees from true North)**: enter the direction of the array in degrees (0° is north, 90° is east, 180° is south, and 270° is west). **NOTE** – These array plane entries are only required when using the Sandia performance model and an irradiance sensor.
Browse	Accesses previously saved Model files for retrieval.
Copy	Creates a copy of the currently loaded Model file so it can be edited.
Properties	Displays the properties of the currently loaded Model file including Name, Location, Modules/String, Inverter, Wiring, Sensor Methods, and Array Plane parameters. Properties can be changed in this view. The changes are saved.

Utility Menu

Table 8. Utility menu description

Name	Description
Settings	Used to select the I-V Measurement Unit and PVA 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 PVA Sensor Kit and the PC. Select the port with the “+” symbol.

Help Menu

Table 9. Help menu description

Name	Description
User's Guide	Accesses the PVA-600 User's Guide.
About	Accesses the software version number and software build date.

Tabs

Table Tab

The Table tab presents a summary of the I-V measurement results displayed in the Traces tab, as well as predicted values from the selected performance model. Figure 11 is an example of the Table tab screen.

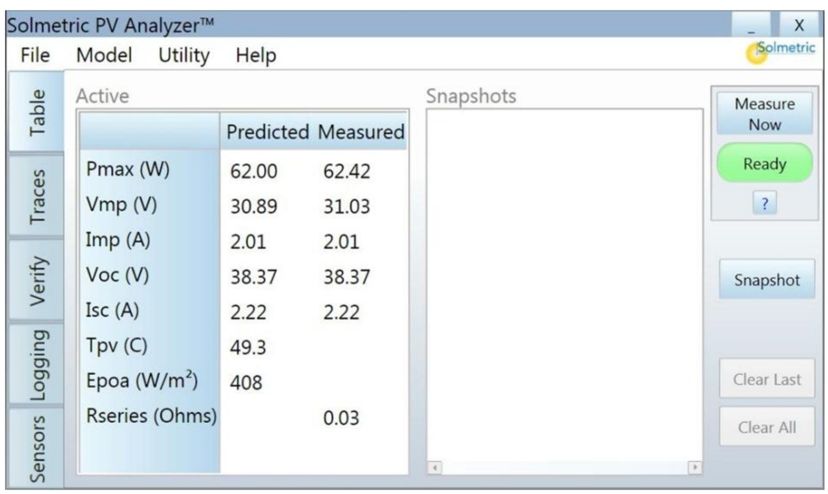

Figure 11. Table tab

Table 10. Table tab description

Name	Description
Active	Indicates the table containing the latest measurement data.
Predicted	Displays the predicted values from the selected performance model.
Measured	Displays actual measured values most recently measured.
Pmax (W)	Displays the predicted and measured maximum power values in Watts.
Vmp (V)	Displays the predicted and measured values of the voltage at the maximum power point.
Imp (A)	Displays the predicted and measured values of the current at the maximum power point.
Voc (V)	Displays the predicted and measured values of the open circuit voltage.
Isc (A)	Displays the predicted and measured values of the short circuit current.
Tpv (C)	Displays the predicted and measured PV temperature 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.
Epoa (W/m^2)	Displays the predicted and measured 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.
Rseries (Ohms)	Displays the series resistance calculated from the user entered wire gauge and wire length.
Snapshots	Each time you click on the Snapshot button, the currently measured values of the data populate one of the columns in the right hand table. This allows comparing successive measurement results There 25 columns available. Data is not permanently saved.

Name	Description
No USB Wireless (indicator)	Displayed when the USB Wireless Adapter is not found. When displayed, clicking on this indicator accesses information to aid in troubleshooting the problem.
No I-V Unit (indicator)	Displayed when communication between the I-V Measurement Unit and PC is not established. When displayed, clicking on this indicator accesses 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.
Ready (indicator)	Displayed when the system is ready to start a new I-V measurement.
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 (indicator)	During a measurement, the **Measuring** label blinks.
Paused (indicator)	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 (indicator)	Displayed when a problem exists other than communication between the PC and I-V Measurement Unit. Problems could be related to low battery, over current, over voltage, over temperature, reversed polarity, etc. No measurements can be taken while in this state. When displayed, clicking on this button accesses information to aid in troubleshooting the problem.
? button	Clicking on this button accesses information specific to the current state of the PVA-600.
Snapshot button	Takes the current measured values of the data and populates one of the columns in the right hand table.
Clear Last button	Clears just the most recent section of data from the Snap Shots table.
Clear All button	Clears all columns of data from the Snapshots table.

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 12 is an example of the Traces tab screen.

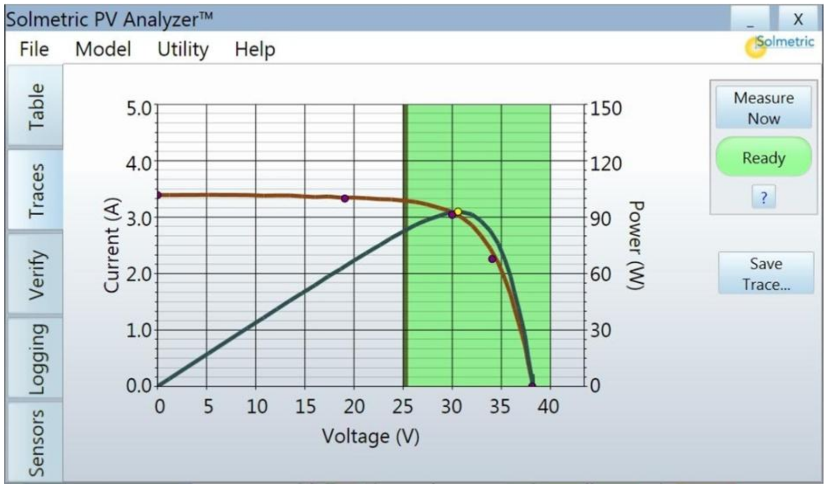

Figure 12. Traces tab

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 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. It is not the predicted maximum power value.

3. Model prediction points. The five purple 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. The left black line is the inverter starting voltage and the right black line is the maximum input voltage.

Table 11. Traces tab description

Name	Description
Current (A)	Displays the current scale along the vertical axis on the left side of the graph.
Voltage (V)	Displays the voltage scale along the horizontal axis of the graph.
Power (W)	Displays the power scale along the vertical axis on the right side of the graph.
Save Trace button	Saves all of the I-V and P-V graph data points and other descriptive information in a csv file in the **Traces** folder.
Save a Screen Image ...	Click on the camera icon at the lower right corner of any screen to save the screen.

Verify Tab

The Verify tab is a display of predicted and measured maximum power for a quick check of the system. The height of the gray bar is the maximum power actually measured for the system. This value corresponds to the single yellow point on the P-V curve. The black target line is the maximum power predicted by the performance model. The numeric Performance Factor value is the ratio of actual to predicted maximum power, as a percentage.

NOTE Typically, if a string is operating correctly, the Performance Factor will be between 95% and 105% when using the Sandia model. The range 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 range for TF modules is likely to be still higher.

The dotted STC line is the predicted power under Standard Test Conditions. Figure 13 is an example of the Verify tab screen.

NOTE STC conditions (typically found on module datasheets) occur infrequently in real world measurements as they combine bright sun with low temperatures.

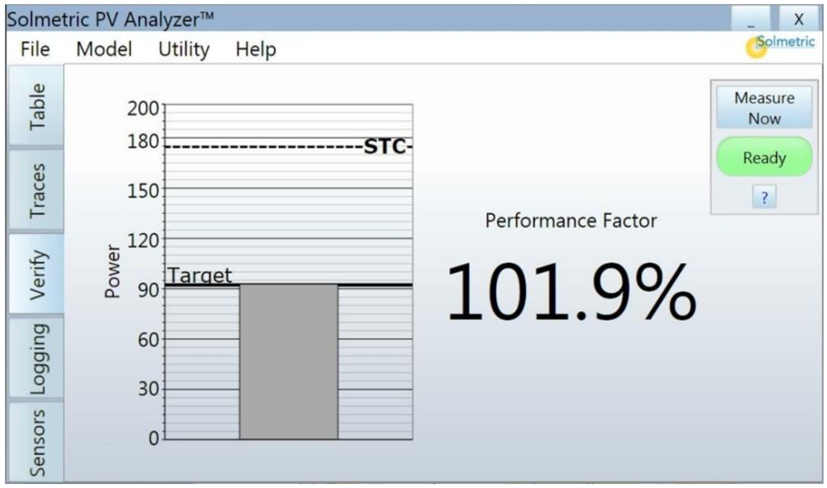

Figure 13. Verify tab

Table 12. Verify tab description

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

Logging Tab

The Logging tab displays maximum power values (equivalent to those shown in the Verify tab) which have been accumulated (or logged) over a time period. Figure 14 is an example of the Logging tab screen. You can clearly see when the modules entered a late afternoon shade condition.

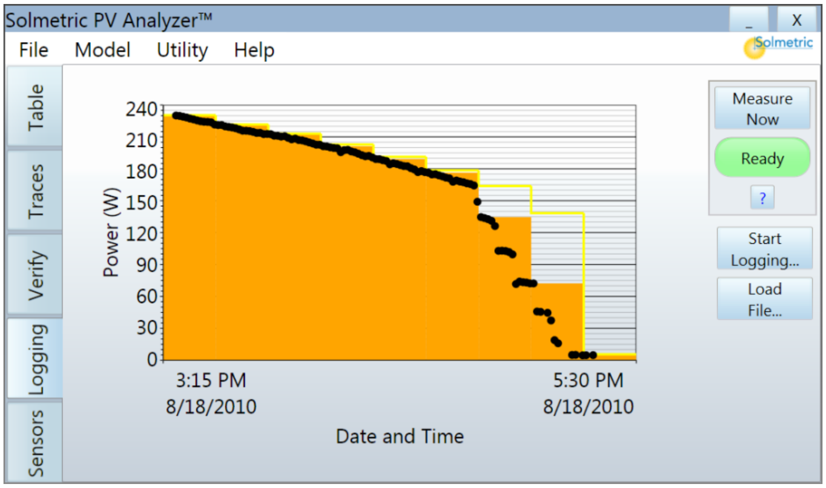

Figure 14. Logging tab

There are three values displayed on the graph:

1. The small black dots are measured maximum power.
2. The orange steps represent the maximum value measured during each 15-minute interval.
3. The yellow line is the target (predicted) maximum power in each 15-minute interval.

The time axis autoscales to display all the available data taken over the measurement period.

As each value is acquired by the PVA-600 it is stored in a csv file in the **Log Files** folder. The intent is to show the performance of the array over a time period. This time period may be from a few minutes to an entire day. The I-V curve data is not saved.

Table 13. Logging tab description

Name	Description
Power (W)	Displays the power scale along the vertical axis on the left side of the graph.
Date and Time	Displays the start date/time and end date/time along the horizontal axis. The date and time are taken from the PC's internal clock when the first measurement is started.
Start Logging button	**Sample Rate (minutes)**: sets time interval between actual measurements. **Log File**: sets name for csv data file. The log file is stored in the **Log Files** folder. **Change File** button: allows you to change to a different file name.
Load File button	Allows you to select and load an existing csv file for viewing on the graph.

Sensors Tab

The Sensors tab displays irradiance and temperature measurement values when using the PVA Wireless Sensor Kit, as shown in Figure 15. This screen also monitors the communication status between the PVA-600 and the wireless irradiance and temperature sensors.

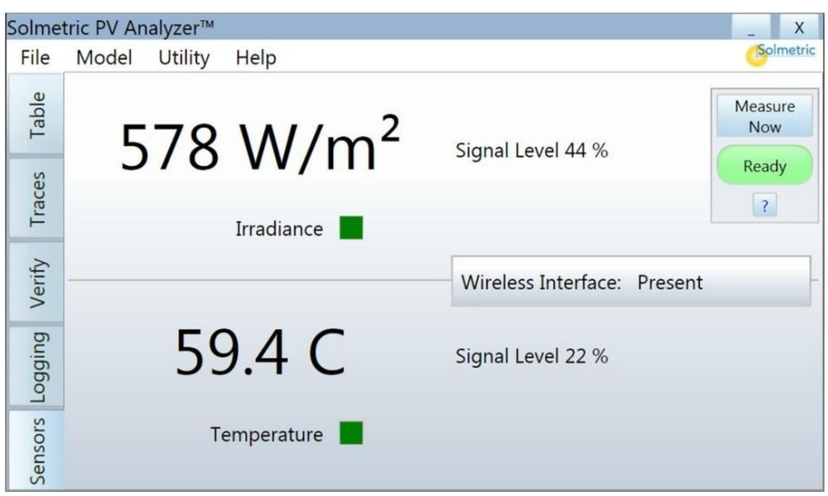

Figure 15. Sensors tab

Table 14. Sensors tab description

Name	Description
Irradiance	Blinks (green) when data arrives from the wireless irradiance sensor (approximately every two seconds).
Temperature	Blinks (green) when data arrives from the wireless temperature sensor (approximately every ten seconds).
Signal Level	Displays the signal level of the irradiance and temperature sensors (as a percentage). The greater the distance between the PVA-600 and the sensors, the lower the signal level.
Wireless Interface	Displays whether the sensor's wireless sensor USB interface adapter was found or not. The **Help** button accesses information to aid in troubleshooting the problem.

Setting Up a New Model

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

Start the PVA-600 Software

1. On the PC, double-click on the **Solmetric PV Analyzer** icon to start the PVA-600 application. The Table screen appears as shown in Figure 16.

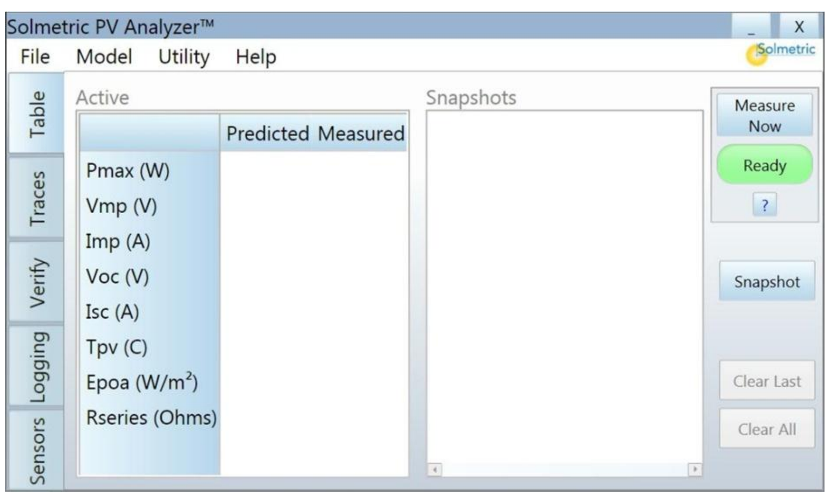

Figure 16. Table screen

Enter the Name and Notes

1. In the **Model** menu, select **New…** to access the screen used to set up a new model as shown in Figure 17.

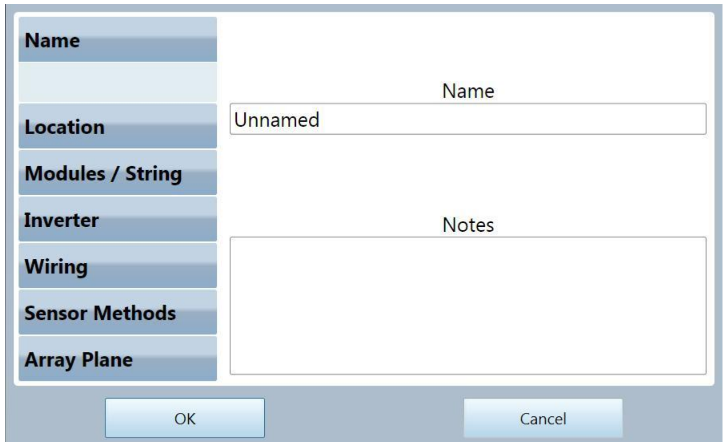

Figure 17. Model screen

2. Click in the **Name** text box and enter the desired name for this model. The model file will be saved in the **Models** folder.

3. Click in the **Notes** text box to enter notes for this model.

Enter Latitude, Longitude, and Time Zone

1. Click on the **Location** button to access the screen used to set up location information as shown in Figure 18.

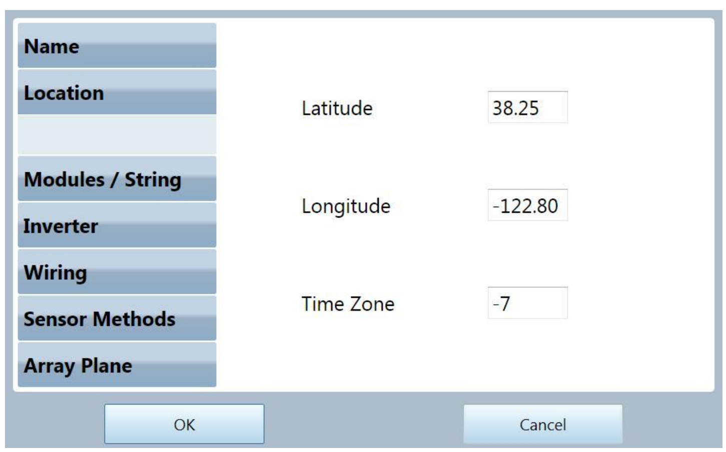

Figure 18. Location screen

2. Click in the **Latitude** text box and enter the latitude for this model.

3. Click in the **Longitude** text box and enter the longitude for this model.

4. Click in the **Time Zone** text box and enter the time zone for this model. The numeric entry is in hours relative to GMT as shown in Table 15.

Table 15. Time zones

GMT	Time Zone
GMT – 1	WAT: West Africa
GMT – 2	AT: Azores
GMT – 3	Brasilia, Brazil, Buenos Aires, Argentina, Georgetown, Guyana
GMT – 4	AST: Atlantic Standard
GMT – 5	EST: Eastern Standard
GMT – 6	CST: Central Standard
GMT – 7	MST: Mountain Standard
GMT – 8	PST: Pacific Standard
GMT – 9	YST: Yukon Standard
GMT – 10	AHST: Alaska-Hawaii Standard CAT: Central Alaska HST: Hawaii Standard
GMT – 11	NT: Nome
GMT – 12	IDLW: International Date Line West

Select the Modules and Enter String Information

1. Click on the **Modules/String** button to access the screen used to set up new module and string information as shown in Figure 19.

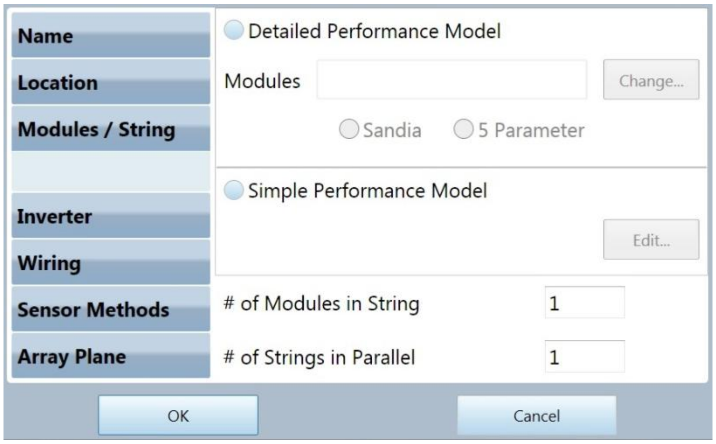

Figure 19. Modules/String screen

2. If you will be using a Sandia or 5 Parameter performance model, select **Detailed Performance Model** and perform the following steps:

   a. Click on the **Change…** button to access the screen used to select the PV module manufacturer and module number as shown in Figure 20.

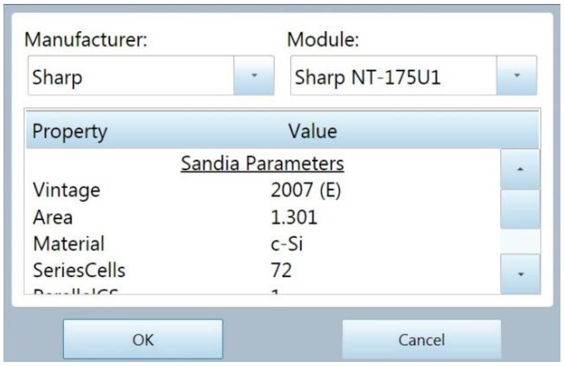

Figure 20. Change… module screen

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

   c. Click on the **Module** dropdown menu and select the module number. Data for the specific module appears in the Property and Value columns. Figure 21 is an example showing the data for the Sharp NT-175U1 module.

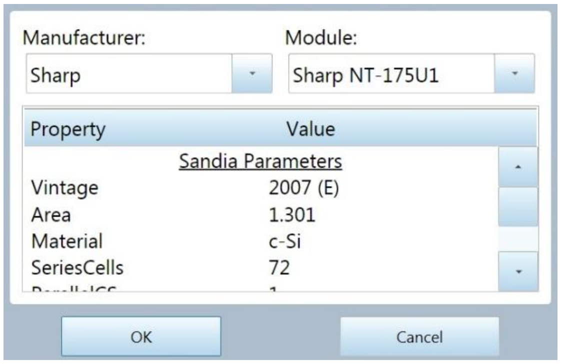

Figure 21. Module Property and Value columns

d. Click on the **OK** button.

3. If you will be entering performance model parameters from the manufacturer's published specifications, select **Simple Performance Model** and perform the following steps:

   a. Click on the **Edit…** button to access the screen used to enter the manufacturer's published specifications as shown in Figure 22.

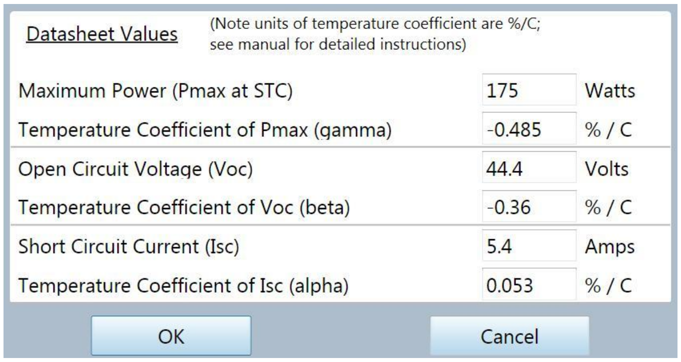

Figure 22. Simple performance model

   b. Enter the parameters from the manufacturer's published specifications.

NOTE There are multiple formats in which manufacturers supply their module's temperature coefficients. Be careful to enter values in the temperature coefficient text box in units of % / C for accurate results. If the manufacturer, for instance, supplies coefficients for Voc (STC) in V/C, this value can be converted to % / C by dividing the supplied number by Voc and multiplying by 100.

   c. Click on the **OK** button.

4. Click in the **# of Modules in String** text box and enter the number of modules in series.

5. Click in the **# of Strings in Parallel** text box and enter the number of modules or strings in parallel.

Select an Inverter

1. Click on the **Inverter** button to access the screen used to select the manufacturer and model number of the inverter as shown in Figure 23 and perform the following steps:

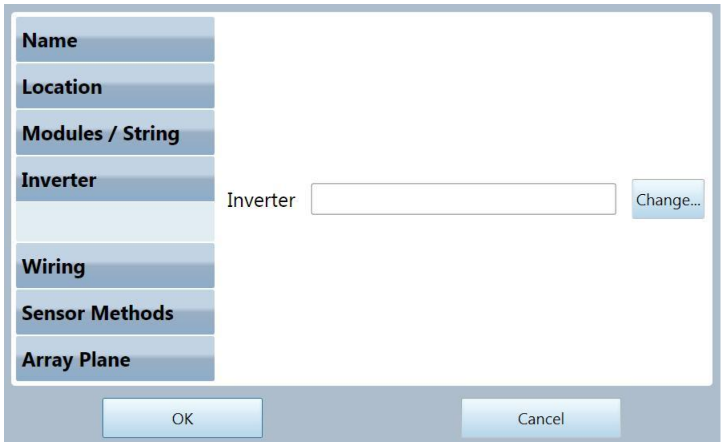

Figure 23. Inverter screen

2. Click on the **Change…** button to access the screen used to select the inverter manufacturer and model number as shown in Figure 24.

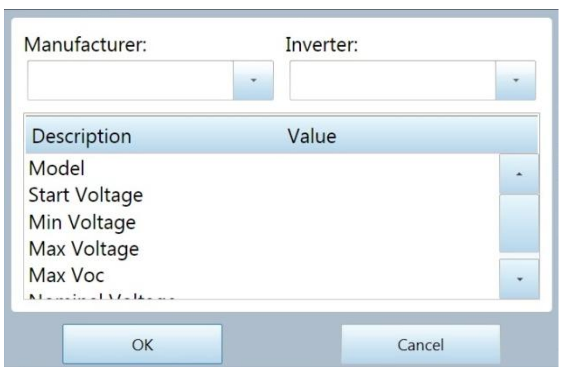

Figure 24. Change… inverter screen

3. Click on the **Manufacturer** dropdown menu and select the inverter manufacturer.

4. Click on the **Inverter** dropdown menu and select the model number. Data for the specific inverter appears in the **Description** and **Value** columns. Figure 25 is an example showing the data for the PV Powered PVP5200 inverter model.

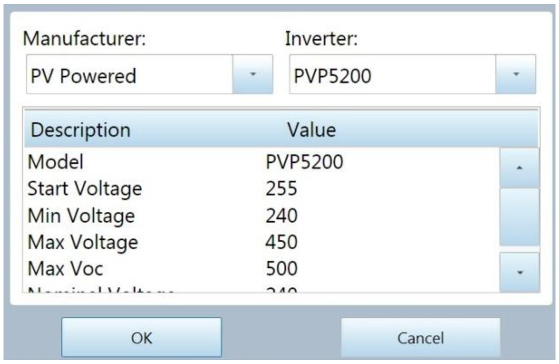

Figure 25. Inverter Description and Value columns

5. Click on the **OK** button.

Select Wire Gauge and Enter Wire Length

1. Click on the **Wiring** button to access the screen used to select the wire gauge and enter the one-way wire length (in feet) as shown in Figure 26. The gauge and length are used to calculate the series resistance per foot.

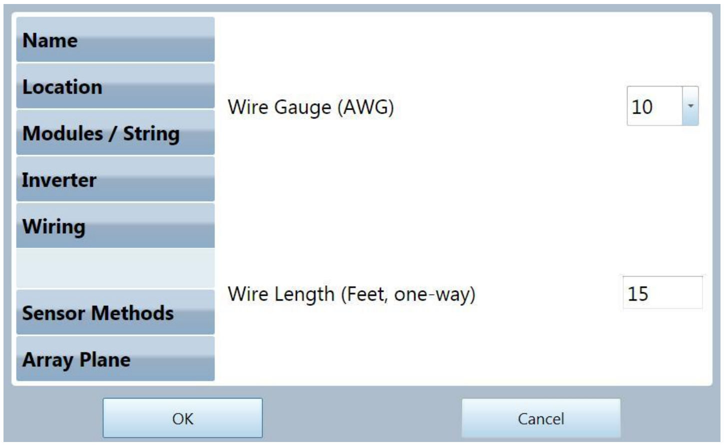

Figure 26. Wiring screen

2. Click on the **Wire Gauge (AWG)** dropdown menu and select the external wiring gauge.

3. Click in the **Wire Length (Feet)** text box and enter the one-way length of the PV output conductors from the ends of the strings/module under test to the point where the PVA-600 is connected. For instance, if you have two 10 foot leads running between the I-V unit and the string, enter “10” (not “20”).

Select the Sensor Methods

1. Click on the Sensor Methods button to access the screen used to set up irradiance and temperature methods as shown in Figure 27.

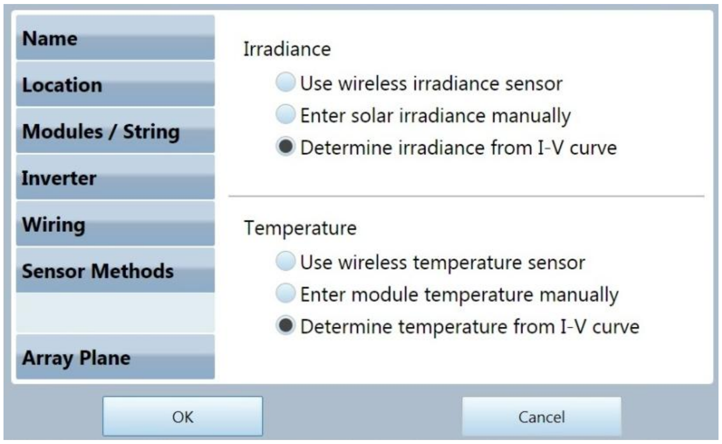

Figure 27. Controls for deriving the irradiance and/or temperature from measured I-V curve (array-as-sensor method)

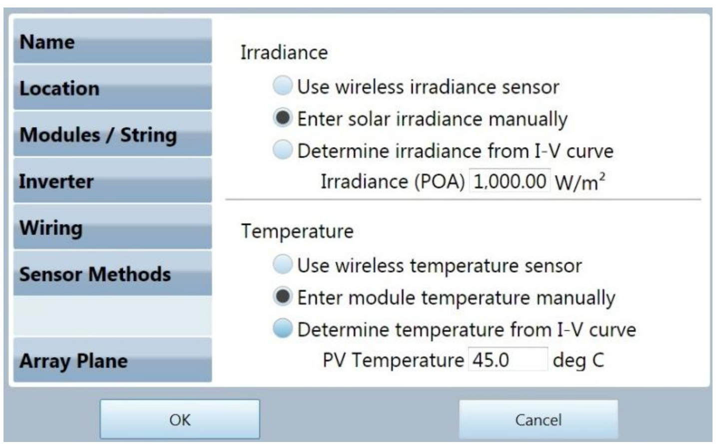

Figure 28. Controls for entering irradiance and/or temperature manually

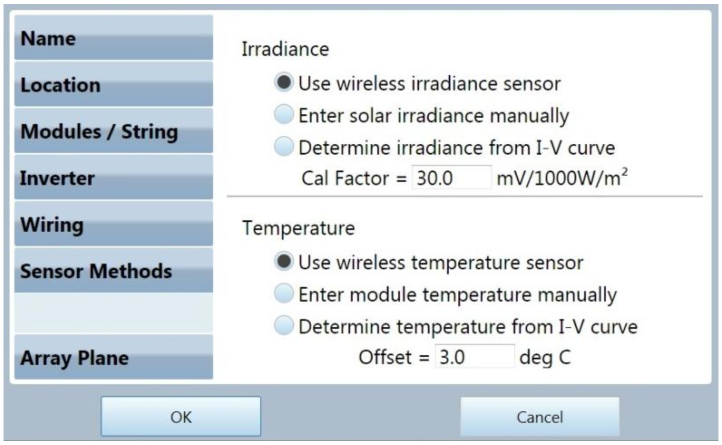

Figure 29. Controls for measuring irradiance and/or temperature automatically using wireless sensors

2. If you want the PVA-600 to extract the temperature mathematically from the measured I-V data, select **Determine temperature from I-V curve**. This feature determines the effective cell temperature.

3. If you are using external sensors to monitor temperature, select **Enter module temperature manually** and enter the temperature in the **PV Temperature** text box. The value you enter is an estimated cell temperature. Be sure to adjust your measured value by an appropriate offset to refer it to the PV cells themselves.

4. If you are using the PVA Sensor Kit to transmit the temperature wirelessly, select **Use wireless temperature sensor**. The **Offset** number is a temperature offset added to the module backside temperature to get an approximation of the PV cell temperature.

5. If you want the PVA-600 to extract the irradiance mathematically from the measured I-V data, select **Determine irradiance from I-V curve**.

6. If you are using a manual sensor to measure irradiance, select **Enter solar irradiance manually** and enter the irradiance in the **Irradiance (POA)** text box.

7. If you are using the PVA Sensor Kit to transmit the irradiance wirelessly, select **Use wireless irradiance sensor**. In the **Cal Factor** box, enter the calibration factors from the sensor label.

Enter Array Slope and Azimuth

If you are using the Sandia Performance Model and a wireless or manual irradiance sensor, perform the following steps.

1. Click on the **Array Plane** button to access the screen used to enter the slope and azimuth of the specific array as shown in Figure 30.

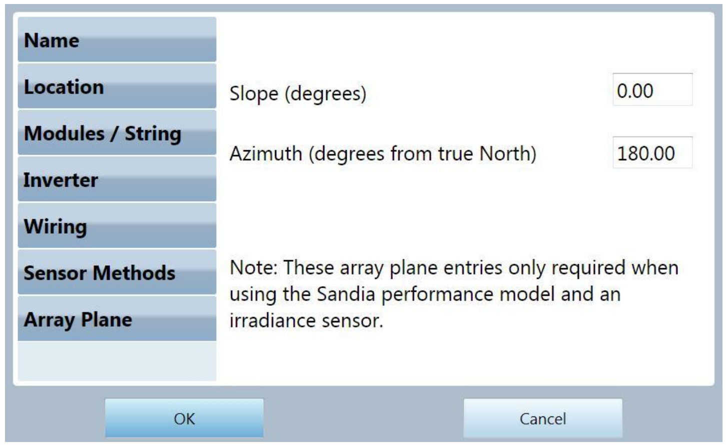

Figure 30. Array Plane screen

2. Click in the Slope (degrees) text box and enter the slope of the array.

3. Click in the Azimuth (degrees from true North) text box and enter the azimuth of the array in degrees from true North.

4. Click on the **OK** button.

Copying an Existing Model File

Making a copy of an existing model file can save time by allowing you to quickly edit only those parameters that require change, then saving these changes to a new file name.

1. Select **Copy…** in the **Model** menu. The Model screen appears as shown in Figure 31.

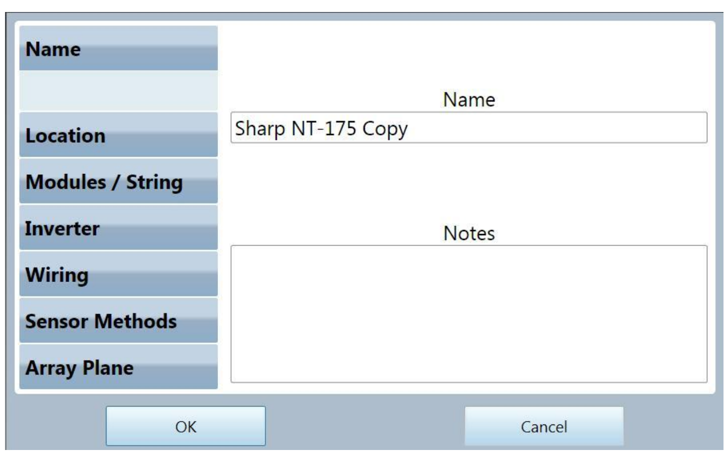

Figure 31. Copying a model file

2. Click in the **Name** text box to enter a new filename. The file will be saved to the **Models** folder.

3. At this point you can make any other required changes to location, modules/strings, inverter, wiring, sensor methods, and array plane.

4. Click on the **OK** button.

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.

4. If you are using the PVA 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.

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

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

6. Turn on the irradiance and temperature transmitters by pressing the **I/0** button once.

NOTE Always turn on the wireless transmitters AFTER starting the PVA-600 application.

7. To open an existing Model file, select **Browse…** in the **Model** menu, as shown in Figure 32, then open a file using the **Open** dialog box.

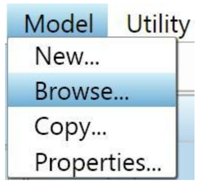

Figure 32. Open a Model file

8. If you need to set up a new model, refer to Setting Up a New Model.

9. Turn on the I-V Measurement Unit by pressing the red power button shown in Figure 33. 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.

NOTE If communication is not established within one minute:

a. Move the PC closer to the I-V Measurement Unit.
b. Reset the I-V Measurement Unit.
c. Remove and replace the Wireless USB Adapter.

Figure 33. Turn on the I-V Measurement Unit

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

    a. Click on the **Sensors** tab to access the screen shown in Figure 34.

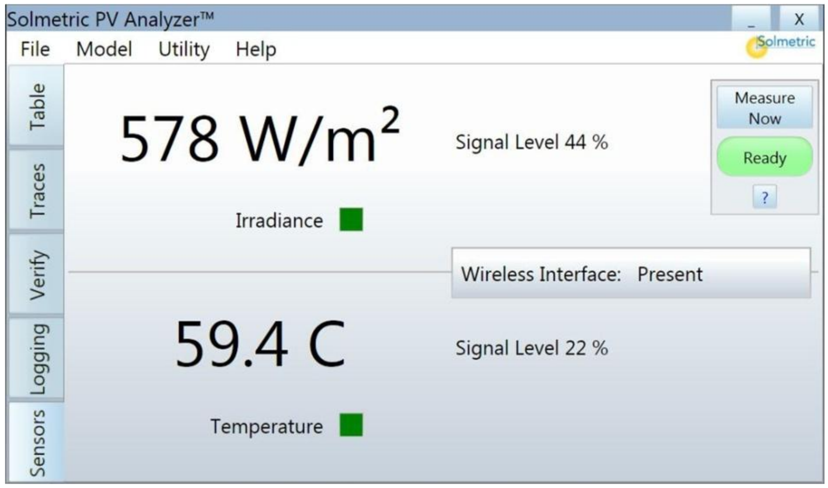

Figure 34. Irradiance and temperature communication status

b. If the **Wireless Interface: Not Found** message appears, select **Settings** from the **Utility** menu and set up the wireless sensor USB interface manually. Select the communications ports with the "+" sign.

c. Ensure that the **Irradiance** box blinks green every two seconds. If the box 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. Refer to Setting Up the Optional PVA Sensor Kit for setup information.

d. Ensure that the **Temperature** box blinks green every ten seconds. If the box 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. Refer to Setting Up the Optional PVA 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.

12. Observe the measurement data in the **Predicted** and **Measured** columns in the **Table** tab as shown in Figure 35.

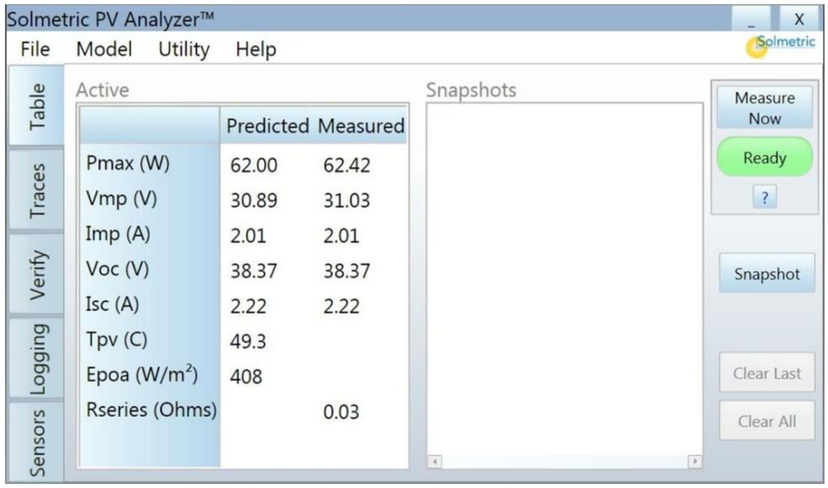

Figure 35. Predicted/Measured columns in Table tab

13. Click on the **Traces** tab to view the I-V and P-V graphs as shown in Figure 36.

NOTE The first time a measurement is made, the data may not scale properly because the PVA-600 uses the first measurement to check the voltage and current details of the circuit under test before choosing the most appropriate internal settings. After the second measurement, the data will scale properly and should be similar to the graph shown in Figure 36.

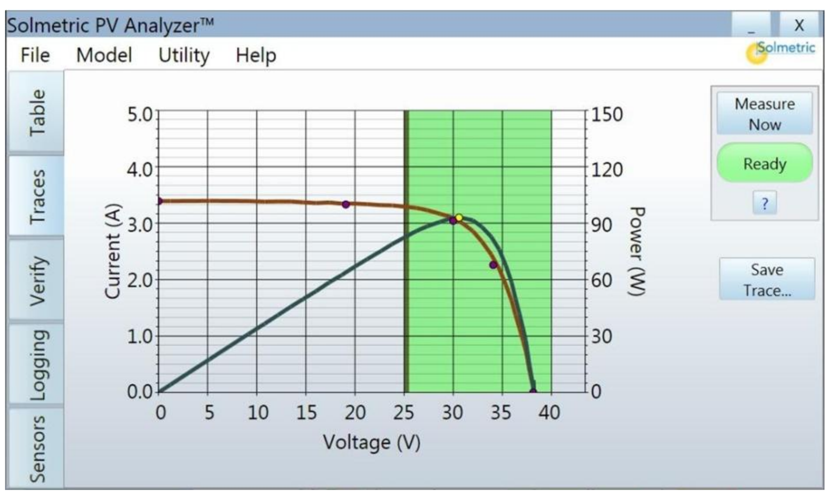

Figure 36. I-V and P-V graphs

14. To save the data to a csv file, click on the **Save Trace…** button then enter a filename in the **Save As** dialog box. The trace data file will be saved in the **Traces** folder.

NOTE Refer to Saving Data to a Directory Tree for information about organizing your data.

15. Click on the **Verify** tab to view the numeric **Performance Factor** value as shown in Figure 37. The **Performance Factor** is the ratio of actual to predicted maximum power as a percentage.

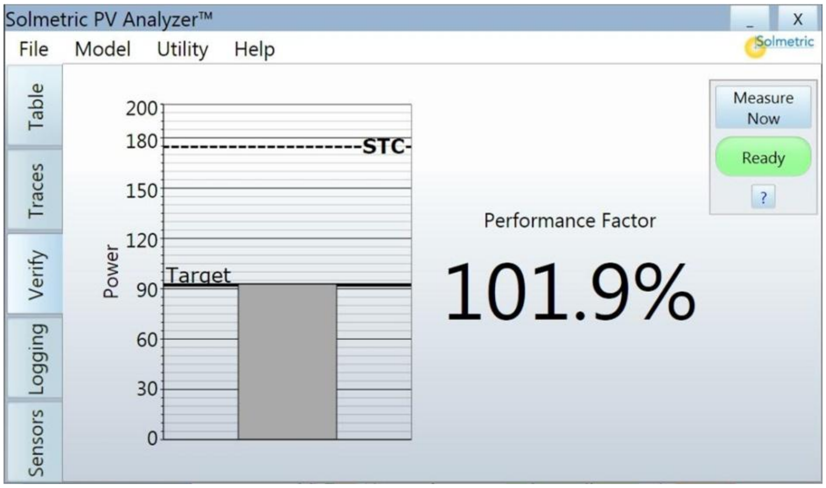

Figure 37. Performance Factor value

16. Pause the measurement sequence of the PVA-600 by pressing the power button shown in Figure 33.

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

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

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

Saving Data to a Directory Tree

To streamline the process of saving I-V data to your PC, create a directory tree before going to the job site. The directory tree is a nested set of folders that has the same structure as the PV array to be tested.

Then, when saving an I-V trace on-site, just direct the Save File dialog box to the appropriate folder. Name each I-V file with the string number of the PV string being tested. The file extension .csv will be appended automatically.

Figure 38 is an example of a directory tree for a PV system with 6 inverters, two combiner boxes per inverter, and 22 strings per combiner box.

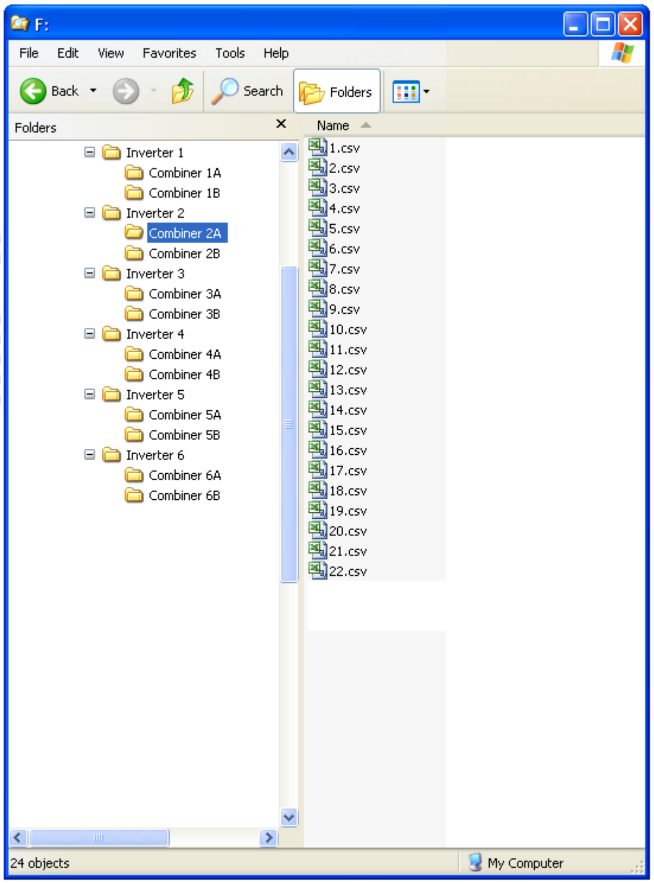

Figure 38. Creating a directory tree

In Figure 38 measurement result files are shown in one of the combiner folders.

Saving Trace Data

The **Traces** tab is the main screen for graphically analyzing I-V measurement results. After measuring an I-V curve, trace data can be saved as a csv file for future analysis.

1. While viewing measured data in the **Traces** tab, click on the **Save Trace…** button.

2. In the **Save As** dialog box, enter a filename and select the storage location. The default storage location is the **Traces** folder. Data will be saved in the csv file format.

NOTE To save time in the field, set up a Windows® directory tree with the same architecture as the PV system under test. Refer to Saving Data to a Directory Tree for details.

Using Snapshot

The Snapshot feature places the most recent measurement results in a column in the right hand table for comparison with previous or subsequent measurements. You can store up to 25 columns of data.

1. Click on the **Table** tab.

2. Click on the **Snapshot** button. The data column is displayed in the **Snapshots** table as shown in Figure 39.

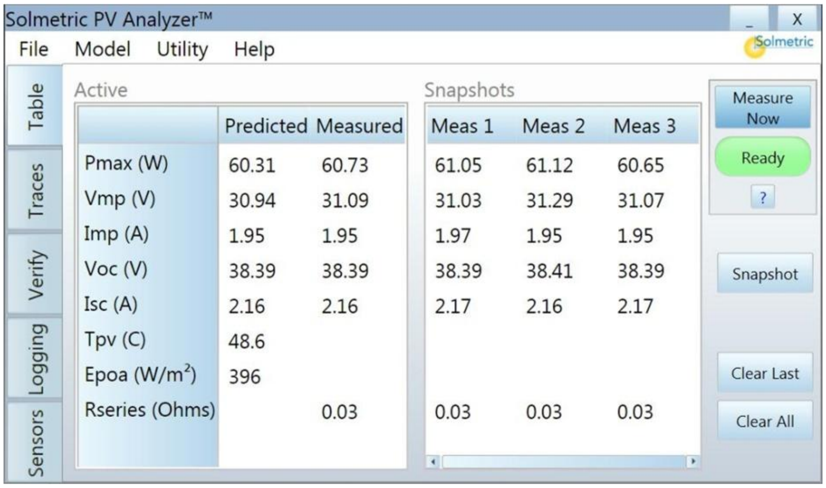

Figure 39. Snapshot table

3. To clear the last Snapshot column, click on the **Clear Last** button.

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

Saving a Screen Image

To save an image of the current screen, click the camera icon in the lower right corner of the screen.

Viewing and Analyzing Your Data

After saving trace data as described in Saving Trace Data, the information can be viewed and analyzed using a program that can read a csv file, such as Excel®.

Figure 40 is an example of a csv file showing trace data (not all columns and rows of data are shown).

1	Conversion	XF1	MA00158D00000A8125	LV3D0C83A9:C019A859	HV3E5363B8:C16B8C35	LC3B61EB98:BEC28CBD	HC3BD9D925:BF06DEFC	TA3D2A3055:C2700000
2	Raw Trace	MR2	MA00158D00000A8125	DT091020110000	VR0	CR0	VO77881917	IS49479680
3	MR	2						
4	MA	00158D00000A8125						
5	DT	########						
6	VR	0						
7	CR	0						
8	VO	38.3669						
9	IS	2.222709						
10	TA	-59.9987						
11	TP	-59.9985						
12	EW	0						
13	Sandia IV Pairs							
14	SC	2.222709	0					
15	X	2.179411	19.18352					
16	MP	2.007377	30.88554					
17	XX	1.528534	34.62629					
18	OC	0	38.36703					
19	Volts	Amps	Watts					
20	38.45665	0	0					
21	38.35373	0	0					
22	38.42235	0	0					
23	38.45665	0	0					
24	38.42235	0	0					
25	2.091085	2.222709	4.647873					

Figure 40. Trace data

The first 12 lines of the csv file contain information used for debugging, servicing, or troubleshooting of the system by Solmetric engineers.

If the Sandia or 5 Parameter Performance Model is used, Lines 13 through 18 display the five predicted current and voltage points of the selected model (the Simple Performance Model has no predicted points):

- 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

Figure 41 shows the five predicted points on the measured trace.

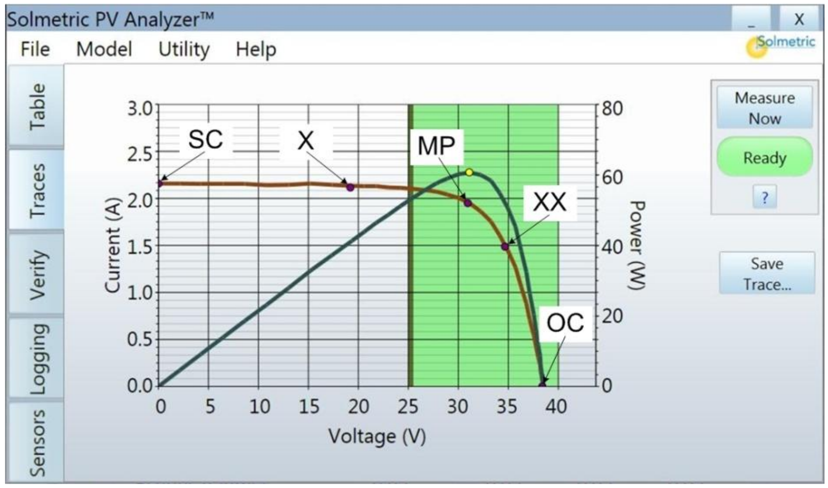

Figure 41. Predicted current, voltage, and maximum power points

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 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 PVA Sensor Kit, the end points may not match the predicted points when using the Sandia or 5 Parameter Performance Models.

The remainder of the csv file contains the actual measured voltage, current, and power points.

Setting Up Data Logging Mode

Data logging mode is used for data collection over a period of time. After setting up the sample rate (from 1 to 60 minutes) and filename, data is collected automatically.

After each measurement sweep, the measured maximum power is displayed on the PC screen as well as stored to a specified csv file. Each horizontal line of the csv file corresponds to one complete sweep.

The results can be reloaded at a later time and displayed on the PC using the **Load File…** button in the **Logging** tab.

NOTE While in logging mode, all measurement data is stored in the PC. Therefore, be sure the PC is always within communication range of the I-V Measurement Unit. If communication is temporarily lost, logging will continue but data values of 0 will be displayed and stored.

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

2. Click on the **Logging** tab to access the screen shown in Figure 42.

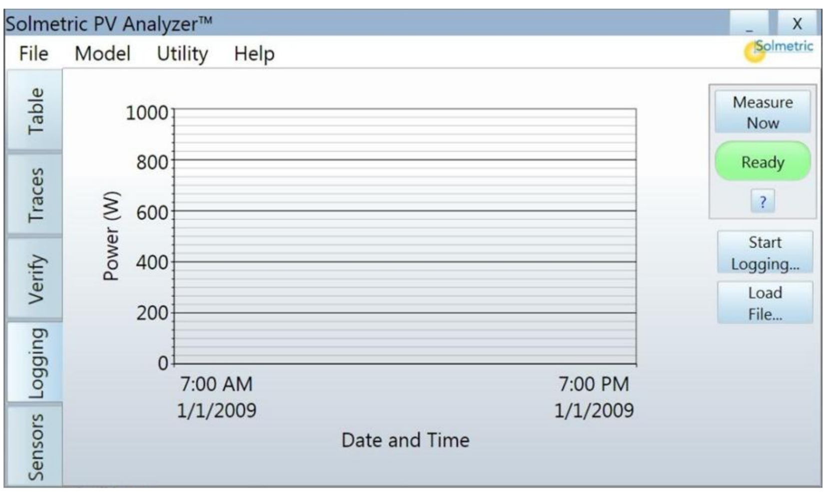

Figure 42. Logging screen

3. Click on the **Start Logging…** button to enter sample rate and log file as shown in Figure 43.

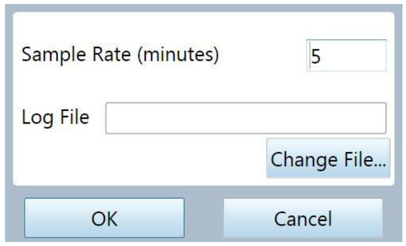

Figure 43. Start Logging screen

4. Click in the **Sample Rate (minutes)** text box and enter the sample rate (from 1 to 60 minutes).

5. Click on the **Change File…** button to enter a filename and select a storage location for the log file. You can also enter the path and filename by typing it into the **Log File** text box. The default location is the **Log Files** folder. Data will be saved in the csv file format.

6. Click on the **OK** button. The current graph is cleared, the date and time is updated from the PC, and logging begins immediately. The graph shows measured array power (in Watts) over time.

Viewing and Analyzing Logging Data

In Logging mode, as each value is acquired by the PVA-600 it is stored in a csv file in the **Log Files** folder in the following format:

- Date (mm/dd/yyyy)
- Time (24 hour format-hour/minute/seconds)
- Target Array Power (Target or predicted maximum power – Watts)
- Measured Array Power (Measured maximum power – Watts)
- Measured Epoa (Measured irradiance – W/m^2)
- Predicted Epoa (Predicted irradiance – W/m^2)
- Measured Tpv (Measured temperature – deg C)
- Predicted Tpv (Predicted temperature – deg C)
- Voc (Measured open circuit voltage)
- Isc (Measured short circuit current)
- Vmp (Measured voltage at maximum power point)
- Imp (Measured current at maximum power point)

Figure 44 is an example of a csv file showing logging data. Each row corresponds to one measurement.

Date	Time	Target Array Power	Measured Array Power	Measured Epoa	Predicted Epoa	Measured Tpv	Predicted Tpv	Voc	Isc	Vmpp	Impp
8/18/2010	15:18:40	230.39	230.11	#N/A	747.41	53.33	50.01	79.7	4.07	63.24	3.64
8/18/2010	15:19:40	230.12	229.82	#N/A	746.8	53.33	50.06	79.68	4.07	62.97	3.65
8/18/2010	15:20:40	229.77	229.05	#N/A	744.5	5536.67	49.77	79.76	4.06	63.17	3.63
8/18/2010	15:21:39	228.37	228.31	#N/A	740.88	5536.67	49.99	79.66	4.04	63.12	3.62
8/18/2010	15:22:40	227.25	227.27	#N/A	736.75	5536.67	49.85	79.68	4.01	63.12	3.6
8/18/2010	15:23:40	227.27	226.51	#N/A	736.76	5536.67	49.83	79.68	4.01	62.96	3.6
8/18/2010	15:24:40	225.65	225.56	#N/A	733.65	5536.67	50.36	79.5	4	62.8	3.59
8/18/2010	15:25:40	225.16	224.74	#N/A	733.56	5536.67	50.74	79.38	4	62.78	3.58
8/18/2010	15:26:40	224.42	224.24	#N/A	730.62	5536.67	50.6	79.4	3.98	62.69	3.58
8/18/2010	15:27:40	224.32	224.1	#N/A	728.37	5536.67	50.1	79.54	3.97	62.83	3.57
8/18/2010	15:28:40	223.12	223.75	#N/A	725.9	5536.67	50.46	79.41	3.95	63	3.55
8/18/2010	15:29:40	222.73	221.68	#N/A	725.27	5536.67	50.61	79.36	3.95	62.71	3.53
8/18/2010	15:30:40	221.64	221.14	#N/A	721.15	5536.67	50.45	79.38	3.93	62.82	3.52

Figure 44. Logging data

Troubleshooting PVA-600 Operation

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

"Disabled" message

If the message "Disabled" appears in the indicator panel directly below the Measure Now button, it means that the I-V Unit has turned itself off to protect against a condition of over-voltage, -current, or –temperature. Click on the **[?]** icon below the indicator, and follow the displayed instructions.

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.

"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.

"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.

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 Interface Not Found

When using the wireless sensor kit, this message may appear in the status indicator in the Sensors tab. 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.

First trace of a session is noisy

The first trace of a new measurement session (after turning the instrument on, or following a reset) is taken with special settings inside the I-V Unit, allowing it to detect what sort of test device it is connected to. Using information from this first I-V sweep, the I-V Unit optimizes its internal settings for the measurements to follow. Simply press Measure Now again to begin collecting valid data.

Subsequent traces are noisy

If each trace is 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.

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 PV Analyzer's mathematical models predict the ideal shape for this curve for thousands of different PV modules and configurations. Occasionally the shape of the measured I-V curve will deviate from the shape predicted by the model. These changes from the ideal shape contain information about the performance of the PV System. This section describes the most common deviations 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 module characteristics (available for over 2000 model numbers)
- 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
- Cell temperature
- For some instrument modes it is also necessary to provide: latitude, longitude, time zone, and array orientation.

Inverter characteristics are used only to illustrate the maximum power tracking range. They do not affect the PV array 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 45. PV modules of a given manufacturer and model will have similar fill factors if performing normally.

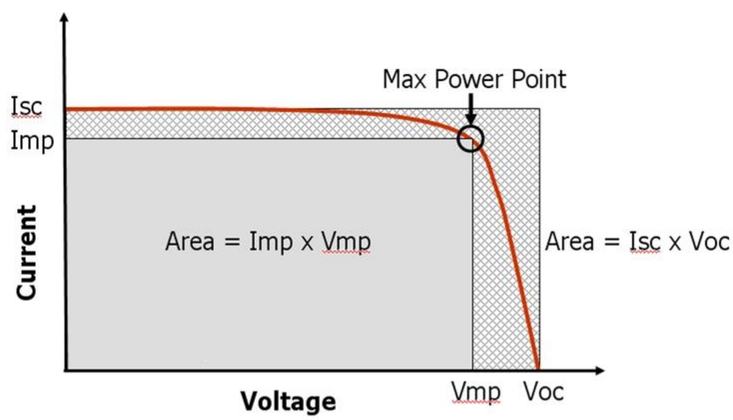

Figure 45. The Fill Factor is defined as Imp x Vmp (the gray area) divided by Isc x Voc (the cross-hatched area).

Series and shunt losses have a pronounced effect on the fill factor by changing the slopes of the I-V curve near Voc and Isc, respectively, as shown in Figure 46.

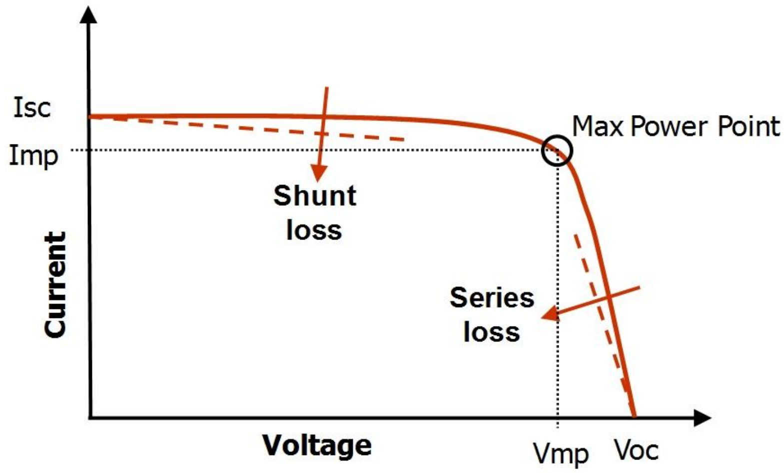

Figure 46. Effect of series and shunt losses on the shape of the I-V curve

The fill factor is the ratio of two areas defined by the I-V curve. These areas represent electrical power (watts) because they are the product of a voltage and a current. Fill factor is the area represented by the max power point, divided by the area represented 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.

The Shape of a Normal I-V Curve

Figure 47 shows a normal I-V curve (red line), as a starting point for the discussion. The predicted I-V curve shape is shown by the five dots. The power versus voltage curve is also visible (blue line). Power is calculated as the product of measured current and voltage at each I-V point.

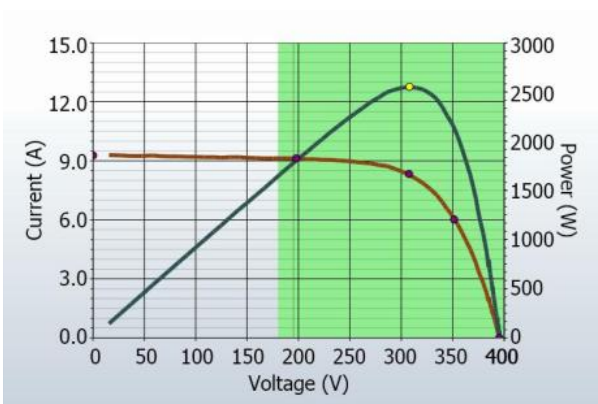

Figure 47. A normal I-V curve for the parallel combination of two strings of eight 175-watt modules, showing conformance with five points predicted by the PV model.

A normal I-V curve has a smooth shape with three distinct voltage regions as shown in Figure 47:

1. A slightly sloped region above 0 V
2. A steeply sloped region below Voc
3. A bend or ‘knee’ in the curve in the region of the maximum power point

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 have more gradual knees.

The five 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 shows higher or lower current 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

A single I-V curve may show one or more of these deviations. One or more of these deviations may indicate a reduction in maximum power produced by the module or string under test.

NOTE Deviations from the ideal IV curve may be due to physical problems with the PV array under test, or may be the result of incorrect model values, settings or measurement connections. Always select the correct PV module from the on-board PV module list, double check the measurement connection, and ensure the proper temperature and irradiance values are used.

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

1. The measured I-V Curve Shows Higher or Lower Current than Predicted

An example of this type of deviation is shown in Figure 48.

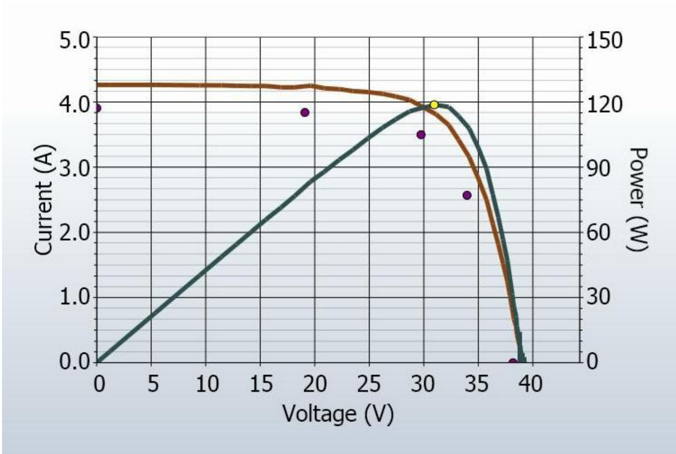

Figure 48. Example of a measured I-V curve that shows higher current than predicted

Potential causes of this deviation 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 oriented incorrectly
- Irradiance sensor calibration factor is entered incorrectly
- Reflections contribute additional irradiance
- Irradiance is too low, or the sun is too close to the horizon
- Manual irradiance sensor is not well calibrated

PV Array Is Soiled

The effect of uniform soiling is like pulling a window screen over the entire array, or reducing the actual irradiance; the overall shape of the I-V curve is correct, but the current at each voltage is reduced. 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 extends 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.

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 Model

PV modules with similar 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.

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

When measuring irradiance with an external irradiance sensor, the time delay between the irradiance measurement and the I-V measurement can translate into measurement error.

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 reliably hold 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 reading. Then tilt the sensor slightly and notice how much the reading changes.

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.

Reflections Contribute Additional Irradiance

The energy production of PV modules can be increased by reflections from nearby buildings, automobiles, and other reflecting surfaces. The error is most pronounced if the reflections are not uniform across the array and/or are not captured by the irradiance sensor.

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

Crystalline silicon PV modules behave somewhat differently in low light conditions. Also, early and late in the day, sunlight hits the surface of the PV module at glancing angles, and differences in the reflectivity of the surfaces become more important. 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.

Manual Irradiance Sensor Is Not Well Calibrated

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 PV Analyzer sensor kit is of high quality and is well calibrated, with a spectral response similar to 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 49.

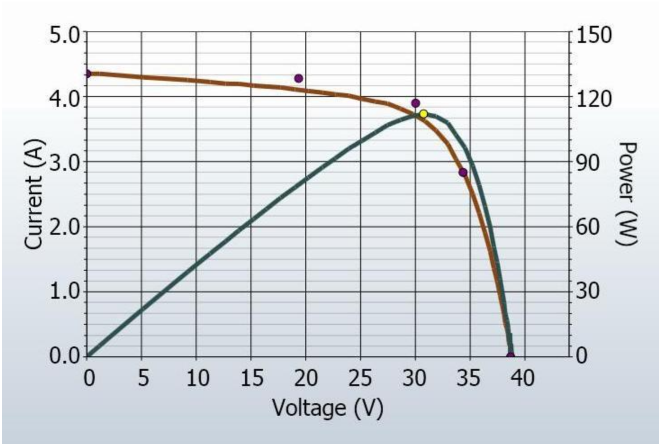

Figure 49. An I-V curve showing more slope than expected in the region above Isc

The slope of the I-V curve in this region is affected by the amount of shunt resistance (or shunt conductance - the inverse of shunt resistance) in the electrical circuit. Reduced shunt resistance (increased shunt conductance) results in a steeper slope in the I-V curve near Isc and a reduced fill factor. A decrease in shunt resistance may be due to changes within the PV cells or modules.

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
- Shunt paths exist in the PV cell interconnects
- 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

A reduction in slope of an I-V curve for a series string 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, different installation angles, or partial soiling. The impact on the I-V curve from Isc mismatch will not be as obvious as a partial shading condition (refer to 4. The I-V Curve Has Notches or Steps) and may only be visible as a slight change in I-V slope and the fill factor.

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

An example of this type of deviation is shown in Figure 50.

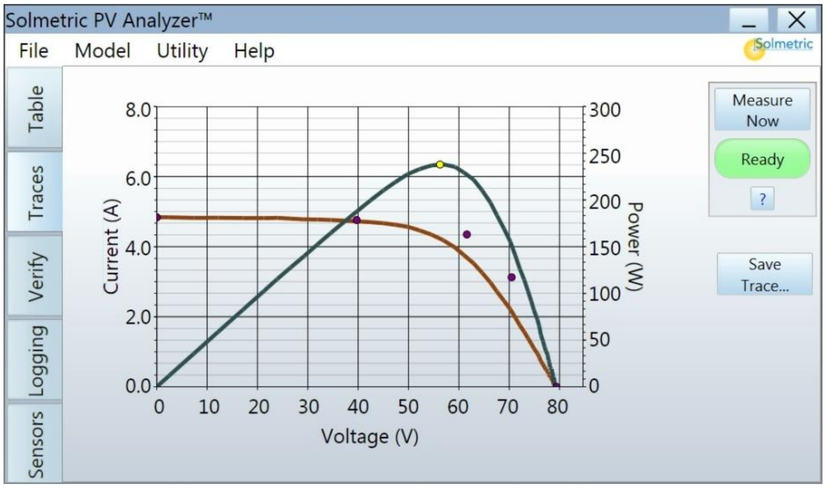

Figure 50. An I-V curve in which the slope of the measured I-V curve near Voc does not match the predicted slope

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. The resistance of additional wire between the PV modules and the PV Analyzer should be accounted for by entering the wire gauge and length in the Wiring section of the model.

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. If additional test leads are attached to the primary leads, be sure that these test leads are of a heavy gauge wire in order to add minimal resistance. Small-gauge test leads can add significant resistance and corresponding measurement error.

Note that wire sizing guidelines for safety considerations (NEC tables, etc.) may not be sufficient to minimize DC power losses from series resistance in cabling. Some sizing guidelines call for a maximum 1% voltage drop due to cabling, which could result in larger sized cabling than would be required to meet code safety considerations.

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, and if using test leads with alligator clips, be sure the clips have a good grip on a clean metal surface.

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. 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 or heating.

4. The I-V Curve Has Notches or Steps

Examples of this type of deviation are shown in Figure 51, Figure 52, and Figure 53.

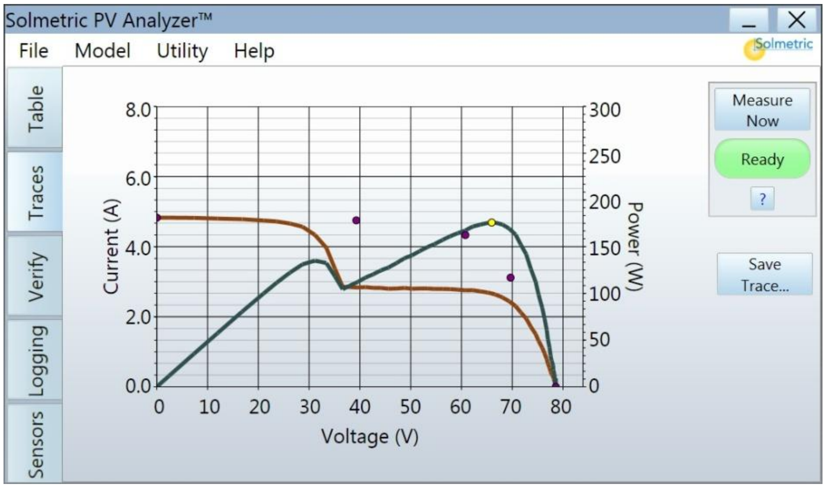

Figure 51. The effect of partial shading on two paralleled strings of eight 175-watt modules

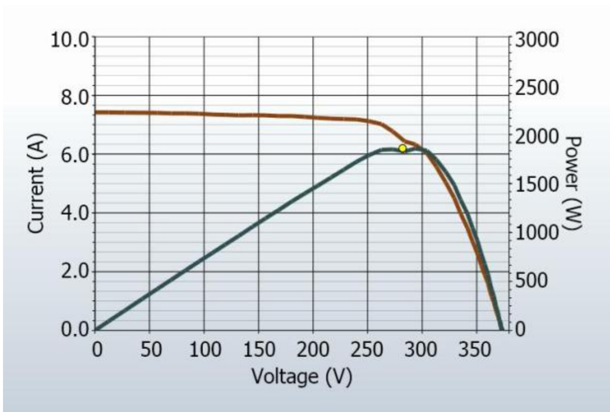

Figure 52. The shading impact of placing a business card on a single cell in a string of fifteen 180-watt modules

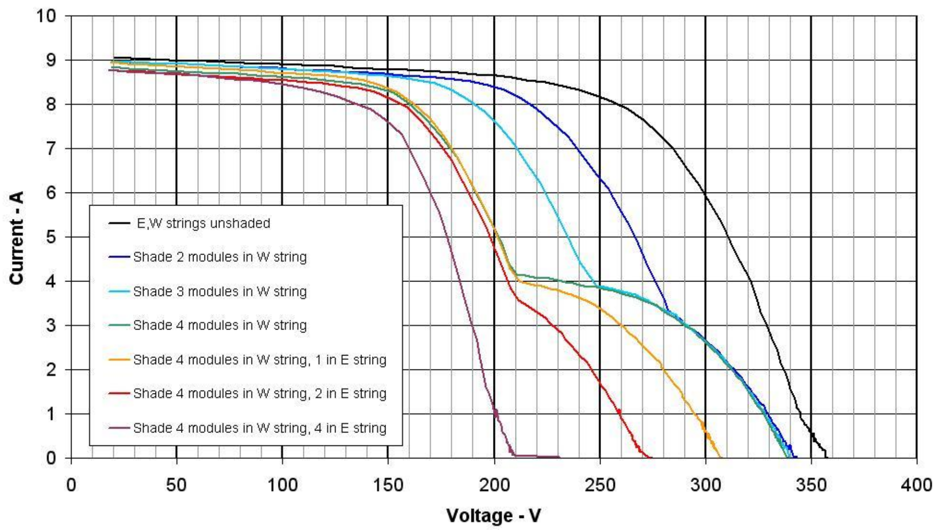

Figure 53. The effect of intentionally shading entire modules in different combinations, in two parallel-connected strings

NOTE	The graphic shown in Figure 53 is not a screen generated by the PVA-600 Software interface.

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 in series connected modules are activating and passing current around the affected module(s).

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 that can be generated by 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 are present to prevent that section of cells 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 short them out. 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 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 distortion or notch, as shown in Figure 53. 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 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 54.

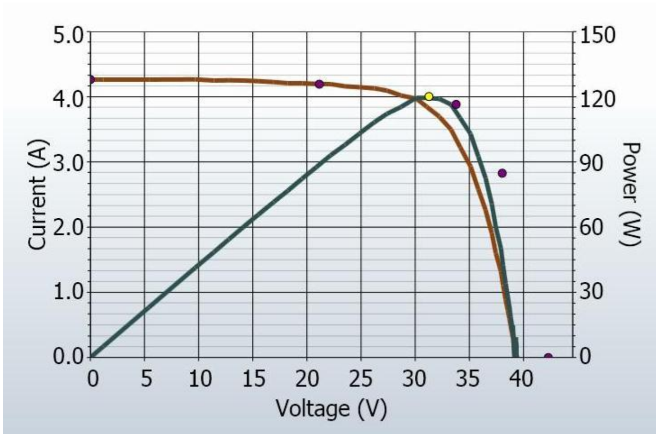

Figure 54. Example of an I-V curve with lower Voc value than predicted

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. In this case, it may be necessary to take a shaded front-side measurement.

One or More Cells or Modules Are Completely Shaded

Shading a cell or module with very high opacity (hard shade) causes its bypass diode to begin conducting when any current passes through it. In this case, the notch in the I-V curve discussed in 4. The I-V Curve Has Notches or Steps occurs at zero amps. As such, it may be difficult to differentiate the shape of this notched I-V curve from a normal curve with a reduced Voc.

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. If the reduction in Voc is approximately equal to a multiple of the Voc of a module cell string (in 72 cell modules, typically Voc/3) look for a module(s) with conducting or shorted bypass diodes. Start by inspecting module front and backsides for burn marks. You can also use selective shading to locate the module(s). When completely shaded, good modules will drop the string's Voc value by similar amounts. In contrast, a module with conducting or shorted bypass diodes will reduce the string Voc by a smaller amount when shaded, due to the fact that one or more of its cell strings are not contributing voltage.