



## Solmetric PV Analyzer I-V Curve Tracer

PVA-1500S with SolSensor 300

PVA-1000S with SolSensor™

PVA-600<sup>+</sup> with SolSensor™



User's Guide

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

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# Contents

<b>1 GETTING STARTED .....</b>	<b>1-1</b>
OVERVIEW .....	1-1
COMPUTER MINIMUM SYSTEM REQUIREMENTS .....	1-2
EQUIPMENT .....	1-2
Curve Tracer Equipment (PVA-1500S, PVA-1000S, PVA-600+).....	1-3
SolSensor Equipment.....	1-3
SPECIFICATIONS .....	1-4
PVA-1500S Specifications .....	1-4
PVA-1000S Specifications .....	1-5
PVA-600+ Specifications .....	1-6
SolSensor 300 Specifications.....	1-7
SolSensor (Original) Specifications.....	1-9
SAFETY AND REGULATORY.....	1-11
PVA-1500S Safety and Regulatory .....	1-11
Warnings, Cautions, and Notes .....	1-11
Declaration of Conformity.....	1-11
Cleaning.....	1-11
Instrument Markings .....	1-11
PVA-1000S Safety and Regulatory.....	1-12
Warnings, Cautions, and Notes .....	1-12
Declaration of Conformity.....	1-12
Cleaning.....	1-12
Instrument Markings .....	1-12
PVA-600+ Safety and Regulatory .....	1-13
Warnings, Cautions, and Notes .....	1-13
Declaration of Conformity.....	1-13
Cleaning.....	1-13
Instrument Markings .....	1-13
SolSensor 300 Safety and Regulatory.....	1-14
Warnings, Cautions, and Notes .....	1-14
Declaration of Conformity .....	1-14
Cleaning.....	1-14
Instrument Markings .....	1-15
SolSensor (original) Safety and Regulatory.....	1-15
Warnings, Cautions, and Notes .....	1-15
Declaration of Conformity .....	1-15
Cleaning.....	1-16
Instrument Markings .....	1-16
PRECAUTIONS .....	1-17
PVA-1500S Precautions .....	1-17
Using PV Connector Saver Jumpers.....	1-17
PV/Electrical Safety Precautions.....	1-17
Battery Precautions.....	1-19
Measuring High-Efficiency PV Modules .....	1-19
PVA-1000S Precautions .....	1-19
Using PV Connector Saver Jumpers.....	1-19

PV/Electrical Safety Precautions .....	1-20
Battery Precautions.....	1-21
Measuring High-Efficiency PV Modules .....	1-21
PVA-600+ Precautions .....	1-21
Using PV Connector Saver Jumpers.....	1-21
PV/Electrical Safety Precautions .....	1-22
Battery Precautions.....	1-23
Measuring High-Efficiency PV Modules .....	1-23
SolSensor and SolSensor 300 Precautions.....	1-24
Covering the Irradiance Sensor .....	1-24
Cleaning the Irradiance Sensor.....	1-24
Battery Precautions.....	1-24
INSTALLATION PROCEDURE .....	1-25
I-V Measurement Unit Installation Procedure .....	1-25
Hardware Installation .....	1-25
Software Installation.....	1-25
Updating the PV Equipment Databases.....	1-29
SolSensor Installation Procedure .....	1-29
CHARGING THE BATTERY .....	1-30
Charging the Battery on the PVA-1500S I-V Measurement unit .....	1-30
Charging the SolSensor 300 Battery .....	1-30
Charging the Battery on the PVA-1000S and PVA-600+ I-V Measurement Unit .....	1-31
Charging the SolSensor Battery of the Original SolSensor .....	1-32
YOUR WIRELESS NETWORK.....	1-32
Your PVA-1500S/SolSensor 300 Wireless Network.....	1-32
Your PVA-1000S/600+/SolSensor Wireless Network .....	1-33
<b>2 SETTING UP AND USING THE I-V MEASUREMENT UNIT AND SOLSENSOR .....</b>	<b>2-1</b>
SYSTEM CONTROLS AND SETTINGS.....	2-1
Operational States of the PVA-1500S I-V Measurement Unit .....	2-2
SETTING UP THE I-V MEASUREMENT UNIT.....	2-4
SETTING UP SOLSENSOR.....	2-4
MOUNTING SOLSENSOR TO A PV MODULE FRAME.....	2-5
OPTIMIZING WIRELESS TRANSMISSION RANGE .....	2-9
MOUNTING SOLSENSOR ON A TRIPOD .....	2-9
CONNECTING TO THE SOLAR PV EQUIPMENT .....	2-11
POWERING-UP THE I-V MEASUREMENT UNIT.....	2-13
I-V MEASUREMENTS.....	2-14
SWEEP DISABLED.....	2-14
OVER-TEMPERATURE PROTECTION .....	2-14
Thermal Capacity of the PVA-1500S .....	2-15
Operating Under High-Temperature Conditions.....	2-15
OVER-VOLTAGE PROTECTION .....	2-15
PVA-1500S Over-voltage Protection.....	2-15
PVA-1000S Over-voltage Protection.....	2-16
PVA-600+ Over-voltage Protection .....	2-16
OVER-CURRENT PROTECTION.....	2-16
REVERSE POLARITY PROTECTION.....	2-16

<b>3 SOFTWARE OVERVIEW .....</b>	<b>3-1</b>
USING PROJECTS .....	3-1
USING THE SYSTEM TREE .....	3-2
MAIN SCREEN OVERVIEW .....	3-2
MENU BAR .....	3-3
File Menu .....	3-3
Browse Project .....	3-3
Recent Projects .....	3-3
Export Trace for Active Measurement .....	3-3
Export Traces for Entire System .....	3-3
Export Meg Test Data .....	3-4
New Project .....	3-4
Selecting your PV Module .....	3-9
Creating the System Tree .....	3-10
Using the Symmetrical Tree Builder .....	3-11
CLONING, MODIFYING, AND REUSING A PREVIOUS PROJECT .....	3-13
Properties Menu .....	3-13
View Menu .....	3-14
Trace view options... .....	3-14
Show Meg Test Tab .....	3-14
Utility Menu .....	3-14
Help Menu .....	3-17
USING THE TAB SCREENS .....	3-18
Traces Tab .....	3-18
Table Tab .....	3-22
History Tab .....	3-24
Meg Test Tab .....	3-25
DESCRIPTION OF THE EXPORTED I-V DATA FILE .....	3-26
BASIS OF PV PERFORMANCE PREDICTIONS .....	3-31
SolSensor Irradiance Calibration .....	3-31
Irradiance Measurement .....	3-31
Prediction of PV Performance .....	3-32
Translation of Measured Values to STC .....	3-32
Measurement of $I_{sc}$ .....	3-32
<b>4 MAKING MEASUREMENTS.....</b>	<b>4-1</b>
INTRODUCTION .....	4-1
BEFORE YOU GO TO THE FIELD TO MAKE MEASUREMENTS .....	4-1
Charge the equipment .....	4-1
Check that you are using the latest PVA software .....	4-1
Create a Project in the PVA software. ....	4-1
Make sure you have all your equipment .....	4-2
Assure adequate irradiance for your measurements.....	4-2
MAKING MEASUREMENTS IN THE FIELD .....	4-2
Place the I-V Unit near the PV circuits to be measured.....	4-2
Connect the test leads to the PVA.....	4-2
Launch the PVA software .....	4-3
Load your Project.....	4-3

Insert the wireless USB adapter (PVA-1000S and PVA-600+).....	4-3
Mount SolSensor.....	4-3
Attach SolSensor’s thermocouple.....	4-3
Turn on the I-V Measurement Unit, and connect wirelessly to your PC.....	4-4
Turn on SolSensor.....	4-4
Prepare the PV source circuits for measurement.....	4-4
Connect the test leads to the PV equipment.....	4-4
Select the first PV circuit to be measured.....	4-5
Make your first measurement.....	4-5
Select the next PV circuit and take another measurement.....	4-6
View the consistency of your data before moving on.....	4-6
From time to time, back up your data.....	4-7
<b>5 TROUBLESHOOTING PVA OPERATION .....</b>	<b>5-1</b>
TROUBLESHOOTING USING STATUS MESSAGES.....	5-1
TROUBLESHOOTING BY SYMPTOM.....	5-4
<b>6 MEASURING IRRADIANCE, TEMPERATURE, AND TILT .....</b>	<b>6-1</b>
INTRODUCTION.....	6-1
MEASURING IRRADIANCE WITH SOLSENSOR.....	6-3
SolSensor irradiance sensor.....	6-3
Preliminary Irradiance.....	6-3
SolSensor Precautions.....	6-3
Covering the Irradiance Sensor.....	6-3
Cleaning the Irradiance Sensor.....	6-3
Orienting and mounting the irradiance sensor.....	6-4
Albedo effects.....	6-4
Diffuse light.....	6-4
DETERMINING IRRADIANCE FROM THE MEASURED I-V CURVE.....	6-5
Entering Irradiance Manually.....	6-5
MEASURING PV MODULE BACKSIDE TEMPERATURE WITH A THERMOCOUPLE.....	6-6
Selecting a thermocouple wire gauge.....	6-7
Selecting a thermocouple tip.....	6-7
Selecting a tape for thermocouple attachment.....	6-7
Attaching the thermocouple to the module backside.....	6-8
Choosing a location to mount the thermocouple on the module or array.....	6-8
MEASURING PV MODULE TEMPERATURE WITH AN INFRARED THERMOMETER.....	6-9
DETERMINING CELL TEMPERATURE FROM THE MEASURED I-V CURVE.....	6-10
USING SMARTTEMP TO MEASURE CELL TEMPERATURE.....	6-11
<b>7 INTERPRETING MEASURED I-V CURVES .....</b>	<b>7-1</b>
INTRODUCTION.....	7-1
INPUTS TO THE PV MODEL.....	7-1
I-V CURVE TERMINOLOGY.....	7-2
Performance Factor.....	7-2
Fill Factor.....	7-2
THE SHAPE OF A NORMAL I-V CURVE.....	7-3
INTERPRETING I-V CURVES.....	7-4
1. NOTCHES OR STEPS.....	7-6

Array Is Partially Shaded, or non-uniform soiling or debris is present.....	7-8
PV Cells Are Damaged.....	7-8
Cell String Conductor Is Short Circuited.....	7-8
2. LOW CURRENT.....	7-8
Uniform soiling.....	7-9
Strip shade.....	7-9
Dirt dam.....	7-9
Module Degradation.....	7-9
Incorrect PV Module Is Selected for the PV Model.....	7-9
Number of PV Strings in Parallel Is Not Entered Correctly in the Model.....	7-10
Irradiance Changed Between Irradiance and I-V Measurements.....	7-10
Irradiance Sensor Is Not Oriented in the Plane of Array.....	7-10
Albedo Effects (reflection) Contribute Additional Irradiance.....	7-10
Irradiance Is Too Low, or the Sun Is Too Close to the Horizon.....	7-10
Manual Irradiance Sensor Is Not Accurate.....	7-11
3. LOW VOLTAGE.....	7-11
PV Cell Temperature Is Hotter than the Measured Temperature.....	7-11
One or More Cells or Modules Are Completely Shaded.....	7-12
One or More Bypass Diodes Are Conducting or Shorted.....	7-12
4. ROUNDER KNEE.....	7-12
5. STEEPER SLOPE IN HORIZONTAL LEG.....	7-13
Shunt Paths Exist In PV Cells or Modules.....	7-13
Module $I_{sc}$ Mismatch.....	7-14
Tapered shade or dirt dam.....	7-15
6. LESS STEEP SLOPE IN VERTICAL LEG.....	7-15
PV Wiring Has Excess Resistance or Is Insufficiently Sized.....	7-15
Electrical Interconnections in the Array Are Resistive.....	7-16
Series Resistance of PV Modules Has Increased.....	7-16
<b>8 TRANSLATION OF I-V DATA TO STANDARD TEST CONDITIONS.....</b>	<b>8-1</b>
PARAMETER DEFINITIONS.....	8-1
DEFINITION OF THE TRANSLATION PROCESS.....	8-2

## Figures

FIGURE 1. WELCOME SCREEN.....	1-25
FIGURE 2. PREREQUISITES DIALOG.....	1-26
FIGURE 3. INSTALLATION DEFAULT LOCATION DIALOG.....	1-26
FIGURE 4. INSERT WIRELESS USB ADAPTER DIALOG.....	1-27
FIGURE 5. INSERT WIRELESS USB ADAPTER (PVA-600+ AND PVA-1000S ONLY).....	1-27
FIGURE 6. INSTALLATION COMPLETE DIALOG.....	1-28
FIGURE 7. LAUNCHING THE PVA SOFTWARE.....	1-28
FIGURE 8. SPLASH SCREEN.....	1-28
FIGURE 9. THE SOFTWARE USER INTERFACE SHARED BY THE PVA-1500, PVA-1000S (SHOWN HERE), AND PVA-600 <sup>+</sup> .....	1-29
FIGURE 10. DIRECTORY STRUCTURE OF PVA SOFTWARE.....	1-29
FIGURE 11. BATTERY CHARGER CONNECTOR ON THE I-V MEASUREMENT UNIT.....	1-30

FIGURE 12. CHARGER CONNECTED.....	1-31
FIGURE 13. BATTERY CHARGER CONNECTOR ON THE I-V MEASUREMENT UNIT .....	1-31
FIGURE 14. CHARGER CONNECTED.....	1-32
FIGURE 15. THE WiFi NETWORK OF THE PVA-1500S, SOLSENSOR 300, AND YOUR PC.....	1-33
FIGURE 16. NETWORK ICON .....	1-34
FIGURE 17. NETWORK DIAGRAMS .....	1-34
FIGURE 18. LED-ILLUMINATED BUTTON SWITCH (SHOWN FOR THE PVA-1500S I-V MEASUREMENT UNIT).....	2-1
FIGURE 19. SOLSENSOR MOUNTED ON THE FRAME OF A PV MODULE.....	2-5
FIGURE 20. SOLSENSOR'S TOOL LANYARD SECURED TO A RACKING MEMBER. ....	2-6
FIGURE 21. SOLSENSOR CORRECTLY SEATED ALONG THE UPPER HORIZONTAL LEG OF THE MODULE FRAME. ....	2-6
FIGURE 22. TIP OF FRAME CLAMP PROPERLY SEATED ON INSIDE SURFACE OF MODULE FRAME .....	2-7
FIGURE 23. THERMOCOUPLE PLUGGED INTO THE TC1 CONNECTOR. ....	2-7
FIGURE 24. LOCATING THE THERMOCOUPLE TIP ON A SINGLE FREE-STANDING MODULE.....	2-8
FIGURE 25. SOLSENSOR PUSHBUTTON WITH LED LIT. LED BLINKS UNTIL WIRELESS NETWORK IS ESTABLISHED, AFTER WHICH IT REMAINS ON.....	2-9
FIGURE 26. TRIPOD MOUNTING SETUP .....	2-10
FIGURE 27. EXAMPLE OF I-V MEASUREMENT UNIT TEST LEADS CLIPPED TO THE BUSS BARS OF A PV COMBINER BOX .....	2-12
FIGURE 28. POWERING-UP THE I-V MEASUREMENT UNIT .....	2-13
FIGURE 29. PVA SOFTWARE MAIN SCREEN .....	3-2
FIGURE 30. FILE MENU.....	3-3
FIGURE 31. THE SITE INFO SCREEN OF THE NEW PROJECT WIZARD .....	3-4
FIGURE 32. ROOF AZIMUTH TOOL.....	3-5
FIGURE 33. ROOF AZIMUTH TOOL WITH THE IMAGE OF A ROOFTOP PV SITE.....	3-5
FIGURE 34. FINDING THE AZIMUTH VALUE USING THE ROOF MEASUREMENT TOOL.....	3-6
FIGURE 35. FINDING YOUR SITE'S LATITUDE AND LONGITUDE USING THE OFFLINE LIST FEATURE. ....	3-7
FIGURE 36. CONTROLS IN THE SITE INFO SCREEN, SET FOR A FIXED ARRAY WITH 180-DEGREE AZIMUTH. ....	3-7
FIGURE 37. SETTINGS FOR A HORIZONTAL SINGLE-AXIS TRACKING SYSTEM. ....	3-8
FIGURE 38. THE TIME ZONE CONTROL IN THE SITE INFO SCREEN.....	3-8
FIGURE 39. THE PV MODULE SCREEN OF THE NEW PROJECT WIZARD.....	3-9
FIGURE 40. SELECTION OF THE PV MODULE'S MANUFACTURER AND MODEL NUMBER, AND CORRESPONDING LIST OF MODULE PERFORMANCE PARAMETERS.....	3-9
FIGURE 41. ARRAY NAVIGATOR WITH SYMMETRICAL TREE BUILDER. THIS IS THE FINAL STEP IN CREATING A PROJECT.....	3-10
FIGURE 42. FINISHED ARRAY TREE FOR A UTILITY PV FIELD. ....	3-10
FIGURE 43. THE DEFAULT SYSTEM TREE IN THE SYMMETRICAL TREE BUILDER.....	3-11
FIGURE 44. CONTROLS FOR EDITING THE STRING WIRING PROPERTIES OF YOUR ARRAY TREE. ....	3-12
FIGURE 45. DIRECTORY STRUCTURE USED BY THE PVA SOFTWARE.....	3-13
FIGURE 46. PROPERTIES MENU.....	3-14
FIGURE 47. UTILITY MENU, USED TO CONTROL HOUSEKEEPING FUNCTIONS. ....	3-14
FIGURE 48. HELP MENU .....	3-17
FIGURE 49. TRACES TAB, SHOWING THE MEASURED I-V CURVE AND THE EXPECTED LOCATIONS OF ISC, MAXIMUM POWER POINT, AND VOC.....	3-18
FIGURE 50. TABLE TAB.....	3-23
FIGURE 51. HISTORY TAB .....	3-24
FIGURE 52. MEG TEST TAB.....	3-25
FIGURE 53. HEADER INFORMATION SECTION OF THE EXPORTED CSV FILE.....	3-27
FIGURE 54. THE MEASUREMENT VS. MODEL SECTION OF THE EXPORTED CSV FILE.....	3-27
FIGURE 55. THE SOLSENSOR MEASUREMENTS SECTION OF THE EXPORTED CSV FILE.....	3-28

FIGURE 56. MODEL DETAILS SECTION OF THE EXPORTED CSV FILE .....	3-29
FIGURE 57. THE VOLTAGE, CURRENT, AND POWER DATA FROM THE I-V MEASUREMENT .....	3-30
FIGURE 58. RESULTS OF AN I-V CURVE MEASUREMENT .....	4-5
FIGURE 59. STATUS INDICATOR.....	5-1
FIGURE 60. DEFINITION OF THE FILL FACTOR. ....	7-3
FIGURE 61. A NORMAL I-V CURVE FOR THE PARALLEL COMBINATION OF TWO STRINGS OF EIGHT 175-WATT MODULES, SHOWING CONFORMANCE WITH FIVE POINTS PREDICTED BY THE PV MODEL. ....	7-3
FIGURE 62. DEVIATIONS IN THE SHAPE OF THE I-V CURVE FALL INTO ONE (OR A COMBINATION) OF THESE SIX CATEGORIES.....	7-5
FIGURE 63. THE EFFECT OF PARTIAL SHADING ON A STRING I-V CURVE.....	7-6
FIGURE 64. THE SHADING IMPACT OF PLACING A BUSINESS CARD ON A SINGLE CELL IN A STRING OF FIFTEEN 180-WATT MODULES.....	7-7
FIGURE 65. THE EFFECT OF INTENTIONALLY SHADING ENTIRE MODULES IN DIFFERENT COMBINATIONS, IN TWO PARALLEL-CONNECTED STRINGS .....	7-7
FIGURE 66. MEASUREMENT WITH LESS STEEP THAN PREDICTED SLOPE IN THE VERTICAL LEG OF THE I-V CURVE....	7-11
FIGURE 67. I-V CURVE MEASUREMENT SHOWING ROUNDER KNEE THAN PREDICTED BY THE PV MODEL. ....	7-12
FIGURE 68. AN I-V CURVE SHOWING STEEPER SLOPE IN THE HORIZONTAL LEG OF THE I-V CURVE. ....	7-13
FIGURE 69. MEASUREMENT WITH LESS STEEP SLOPE IN THE VERTICAL LEG OF THE I-V CURVE. ....	7-15

## Tables

TABLE 1. PVA-1500S ELECTRICAL AND MECHANICAL SPECIFICATIONS .....	1-4
TABLE 2. PVA-1000S ELECTRICAL AND MECHANICAL SPECIFICATIONS .....	1-5
TABLE 3. PVA-600 <sup>+</sup> ELECTRICAL AND MECHANICAL SPECIFICATIONS .....	1-6
TABLE 4. SOLSENSOR 300 SPECIFICATIONS .....	1-7
TABLE 5. SOLSENSOR SPECIFICATIONS.....	1-9
TABLE 6. DIRECT AND INDIRECT WIRELESS LINKS BETWEEN PC, PVA, AND SOLSENSOR .....	1-35
TABLE 7. I-V OPERATIONAL STATES OF THE PVA-1500S.....	2-2
TABLE 8. I-V OPERATIONAL STATES OF THE PVA-1000S & 600 <sup>+</sup> .....	2-3
TABLE 9. UTILITY MENU DESCRIPTION .....	3-15
TABLE 10. HELP MENU DESCRIPTION.....	3-17
TABLE 11. TRACES TAB DESCRIPTION .....	3-19
TABLE 12. TABLE TAB DESCRIPTION .....	3-23
TABLE 13. MEG TEST TAB DESCRIPTION.....	3-25
TABLE 14. DESCRIPTION OF THE HEADER INFORMATION SECTION OF THE EXPORTED CSV FILE .....	3-27
TABLE 15. DESCRIPTION OF THE SOLSENSOR MEASUREMENTS SECTION OF THE EXPORTED CSV FILE.....	3-28
TABLE 16. DESCRIPTION OF THE MODEL DETAILS SECTION OF THE EXPORTED CSV FILE .....	3-29
TABLE 17. SENSOR CHOICES .....	6-2

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# 1 Getting Started

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## Overview

This User Guide covers the PVA-1500S, PVA-1000S, and PVA-600+ I-V Measurement Units and SolSensor.

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

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

The current-voltage (I-V) curve of a PV module, string, harness, or array provides a detailed description of its energy conversion ability. The curve nominally ranges from the short circuit current ( $I_{sc}$ ) at zero volts, to the open circuit voltage ( $V_{oc}$ ) at zero current. At the ‘knee’ of a normal I-V curve are the maximum power current and voltage ( $I_{mp}$ ,  $V_{mp}$ ), the point at which the array generates maximum electrical power. All of these important voltages and currents are captured when the I-V curve is measured. The detailed shape of the curve between these points gives additional information about the health of the PV module, string, or array under test.

The value of a measured I-V curve is greatly increased when it can be compared with a predicted I-V curve derived from an accurate PV model. Models take into account the specifications of the PV modules, the number of modules in series and strings in parallel, and the losses in system wiring. Other data used by the models include the irradiance in the plane of the array, the module temperature, and array orientation.

The PC software that controls the PV analyzer contains a powerful Array Navigator tool for saving and managing your measurement data. The New Project Wizard guides you in setting up the PV model and customizing the Array Navigator to your project.

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

---

**NOTE**

Version 4.x PVA software, which supports the PVA-1500S and SolSensor 300, will not operate the PVA-1000S, PVA-600+, or earlier hardware.

Version 4.x software will not add new measurements to a Project created on version 3.x software. However, version 4.x software will open version 3.x Project files, and will display and export their data.

Version 4.x and 3.x PVA software is not compatible with the Solmetric Wireless Sensor Kit, the predecessor of SolSensor.

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

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

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## Computer Minimum System Requirements

- Test and Supported Operating System: Windows 10<sup>®</sup>, Windows 8<sup>®</sup>, Windows 7<sup>®</sup> (32 and 64-bit versions), and Windows Vista<sup>®</sup> (32-bit versions only)
- At least one USB port.
- Display Resolution: 1024 X 600 (minimum)
- Processor Speed: >1 GHz, 1.5 GHz recommended. A Windows Experience Index (Processor component) of 2.3 or greater is recommended. This value is available on your PC's Control Panel under "Performance Information and Tools".
- RAM: > 1 GB minimum, 2 GB recommended
- Available Disc Space: 100 Mbytes or more

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

---

## Equipment

***Curve Tracer Equipment (PVA-1500S, PVA-1000S, PVA-600+)***

- I-V Measurement Unit
- Soft Case
- Wireless USB Adapter (not required or provided with PVA-1500S)
- PVA Software Application (available at <http://www.solmetric.com/downloads-pva.html>)
- AC Wall Plug Charger
- MC-4 to MC-4 Connector-Saver Cable (2)
- Test leads, MC-4 to 4mm banana plug with plug-on alligator clips (for PVA-1000S and PVA-600+, 1 set)
- Test leads, MC4-EVO2 to 4mm banana plug with plug-on alligator clips (for PVA-1500S, rated to 1500 volts, 1 set)
- MC-4 connector tool
- User's Guide — (available in the HELP menu of the PVA software and from <http://www.solmetric.com/downloads-pva.html>).
- Quick Reference Card

***SolSensor Equipment***

- SolSensor unit (The PVA-1500S operates with the SolSensor 300).
- K-type thermocouple temperature sensors (2)
- Wireless USB Adapter (not required or included for PVA-1500S)
- Soft Case
- Module Frame Clamp
- AC Wall Plug Charger
- Adhesive discs for thermocouple attachment (50)
- SolSensor tool lanyard
- Irradiance sensor cleaning supplies (micro-fiber cloth and distilled water spray)

## Specifications

### ***PVA-1500S Specifications***

**Safety Rating: Measuring Category CAT III 1500V.**

**Table 1. PVA-1500S electrical and mechanical specifications**

Parameter	Specification
Voltage range	0 – 1500 V
Current range <sup>1</sup>	0 – 30 A
Voltage accuracy (0 to 45C)	±0.5% ±0.25 V
Current accuracy (0 to 45C)	±0.5% ±0.04 A
Voltage resolution	25 mV
Current resolution	2 mA
Measurement cycle time	6-23s typical measurement-to-measurement (depending on voltage) <sup>2</sup>
I-V sweep duration <sup>3</sup>	0.05 - 2s. Typically 0.2s for PV strings.
Number of I-V trace points	100 or 500 (user controlled)
Wireless range (direct to PC, open line of sight)	100m US only. (Range for Europe pending evaluation at European mandated maximum radiated power level).
Operating temperature range	-10 to +45°C
Storage temperature range	-20 to +65°C
Operating humidity	<90% RH, non-condensing. Avoid exposing a cold instrument to warm and humid air as condensation will result. Store the instrument in the same conditions in which it will be used.
Battery charging time	6 hr.
Battery run time	8 hours
Protective features	Over-voltage, over-current, over-temperature, reverse polarity
PV connector	Staubli MC4-EVO2

Parameter	Specification
Weight <sup>4</sup>	6.6 kg (including soft case, test leads & charger)
Height	38 cm (not including primary PV leads)
Width	20 cm (not including handle)
Depth	13 cm (not including gear pouch)

<sup>1</sup> 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.

<sup>2</sup> Time between pressing "Measure Now" and display of measurement result.

<sup>3</sup> Automatically selected. Measurement sweep time depends upon the characteristics of the test device (PV module, string, or array) electrical characteristics.

<sup>4</sup> The measurement is controlled via wireless link from the user's tablet or notebook PC.

### ***PVA-1000S Specifications***

**Safety Rating: Measuring Category CATIII 1000V.**

**Table 2. PVA-1000S electrical and mechanical specifications**

Parameter	Specification
Voltage range	0 – 1000 V
Current range <sup>1</sup>	0 – 20 A
Voltage accuracy (0 to 55C)	±0.5% ±0.25 V
Current accuracy (0 to 55C)	±0.5% ±0.04 A
Voltage resolution	25 mV
Current resolution	2 mA
Measurement duration	4s (typical) <sup>2</sup>
I-V sweep duration <sup>3</sup>	0.05 - 2s. Typically 0.2s for PV strings.
Minimum recommended repetition rate:	15s
Number of I-V trace points	100 or 500 (user controlled)
Wireless range (direct to PC, open line of sight)	100m US only. (Range for Europe pending evaluation at European mandated maximum radiated power level).

Parameter	Specification
Operating temperature range	-10 to +65°C
Storage temperature range	-20 to +65°C
Operating humidity	<90% RH, non-condensing. Avoid exposing a cold instrument to warm and humid air as condensation will result. Store the instrument in the same conditions in which it will be used.
Battery charging time	6 hr.
Battery run time	12 hours of continuous operation; more than 1000 measurement sweeps
Protective features	Over-voltage, over-current, over-temperature, reverse polarity
PV connector	MC-4
Weight <sup>4</sup>	5.4 kg (including soft case, test leads & charger)
Height	38 cm (not including primary PV leads)
Width	20 cm (not including handle)
Depth	13 cm (not including gear pouch)

<sup>1</sup> 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.

<sup>2</sup> Time between pressing "Measure Now" and display of measurement result.

<sup>3</sup> Automatically selected. Measurement sweep time depends upon the characteristics of the test device (PV module, string, or array) electrical characteristics.

<sup>4</sup> The measurement is controlled via wireless link from the user's tablet or notebook PC.

### ***PVA-600<sup>+</sup> Specifications***

**Safety Rating: Measuring Category CATIII 600V.**

**Table 3. PVA-600<sup>+</sup> electrical and mechanical specifications**

Parameter	Specification
Current Measurement Range <sup>1</sup>	0 to 20 A dc
Voltage Measurement Range (Voc)	20 to 600 V dc
Load Type	Capacitive (3 capacitance values, automatically selected)

Parameter	Specification
Measurement Sweep Time <sup>2</sup>	50 ms to 240 ms
Measurement Points per Trace (typical)	100
Wireless Communications Range	10 m typical, open line of sight
Battery Life	≈20 hours (normal use)
Charging Time	6 hours
Operating Temperature	+0 to +50°C
Storage Temperature	-20 to +60°C
Operating Humidity	The normal humidity range is 80% relative humidity for temperatures up to 31°C, decreasing linearly to 50% at 40°C. Higher humidity levels should not affect the performance or safety of the PVA-600 <sup>+</sup> .
PV Connectors <sup>3</sup>	MC-4
Weight	9.2 lbs (not including weight of the soft case)
Height	15 in
Width	8 in
Depth	5 in

<sup>1</sup> 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.

<sup>2</sup> Automatically selected. Measurement sweep time depends upon the characteristics of the test device (PV module, string, or array) electrical characteristics.

<sup>3</sup> At ends of the primary test leads permanently attached to the I-V Measurement Unit.

### ***SolSensor 300 Specifications***

**Table 4. SolSensor 300 specifications**

Parameter	Specification
<b>Irradiance</b>	
Sensor type	Silicon photodiode with corrections for temperature, spectral, and angular effects
Measurement range	100 – 1,500 W/m <sup>2</sup>

## 1 Getting Started

Parameter	Specification
Accuracy	Typically, $\pm 2\%$ when used to predict the performance of well characterized poly- and monocrystalline PV modules in mid-day direct sun conditions. Contact Solmetric Application Engineering for more information on accurate irradiance measurements.
Resolution	1 W/m <sup>2</sup>
Measurement interval	0.1 s (Measurement bandwidth approximately 10 Hz)
<b>Temperature</b>	
Sensor type	Type K thermocouple. Two inputs.
Measurement range	0 – 100°C
Accuracy	Typically, less than 2C including inherent thermocouple limitations
Resolution	0.1°C
Measurement interval	1 s
<b>Tilt</b>	
Sensor type	Electronic
Measurement range	0 – 90 deg from horizontal
Accuracy	$\pm 2$ deg typical (0-45 deg)
<b>General</b>	
Measurement synchronization with I-V curve	Typically, less than 1s
Wireless range (open line of sight)	10m US only. (Range for Europe pending evaluation at European mandated maximum radiated power level).
Operating temperature range	-10 to 45°C
Storage temperature range	-20 to 65°C
Operating humidity	<90% RH, non-condensing. Avoid exposing a cold instrument to warm and humid air as condensation will result. Store the instrument in the same conditions in which it will be used.
Battery charging time	6 hr.

Parameter	Specification
Battery run time	Greater than 16 hours typical use
Weight	0.9 kg (not including soft case and accessories)
Height	38 cm
Width	11 cm
Depth	7 cm
Ingress protection	IP65

### ***SolSensor (Original) Specifications***

**Table 5. SolSensor specifications**

Parameter	Specification
<b>Irradiance</b>	
Sensor type	Silicon photodiode with corrections for temperature, spectral, and angular effects
Measurement range	0 – 1,500 W/m <sup>2</sup>
Accuracy	Typically, ±2% when used to predict the performance of well characterized poly- and monocrystalline PV modules in mid-day direct sun conditions. Contact Solmetric Application Engineering for more information on accurate irradiance measurements.
Resolution	1 W/m <sup>2</sup>
Measurement interval	0.1 s (Measurement bandwidth approximately 10 Hz)
<b>Temperature</b>	
Sensor type	Type K thermocouple. Two inputs.
Measurement range	0 – 100°C
Accuracy	Typically, less than 2C including inherent thermocouple limitations
Resolution	0.1°C
Measurement interval	1 s

Parameter	Specification
<b>Tilt</b>	
Sensor type	Electronic
Measurement range	0 – 90 deg from horizontal
Accuracy (0 – 45 deg tilt)	±2 deg (typical)
<b>General</b>	
Measurement synchronization with I-V curve	Typically, less than 1 s
Wireless range (open line of sight)	10m US only. (Range for Europe pending evaluation at European mandated maximum radiated power level).
Operating temperature range	-10 to 65°C
Storage temperature range	-20 to 65°C
Operating humidity	<90% RH, non-condensing. Avoid exposing a cold instrument to warm and humid air as condensation will result. Store the instrument in the same conditions in which it will be used.
Battery charging time	6 hr.
Battery run time	Greater than 16 hours typical use
Weight	0.9 kg (not including soft case and accessories)
Height	38.cm
Width	11 cm
Depth	7 cm
Ingress protection	IP65

---

## Safety and Regulatory

### ***PVA-1500S Safety and Regulatory***

#### ***Warnings, Cautions, and Notes***

Before operating the PVA-1500S, 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.**

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#### **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.*

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#### **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-1500S, use a dry or slightly dampened cloth only.

---

#### **WARNING**

**To prevent electrical shock, disconnect the PVA-1500S 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-1500S have the following markings on the front and/or rear panel. Familiarize yourself with these markings before operating the PVA-1500S.



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

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



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

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

## ***PVA-1000S Safety and Regulatory***

### ***Warnings, Cautions, and Notes***

Before operating the PVA-1000S, familiarize yourself with the following notations.

---

#### **WARNING**

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

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#### **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.*

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---

#### **NOTE**

*A Note provides important or special information.*

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### ***Declaration of Conformity***

A declaration of conformity is available upon request.

### ***Cleaning***

To remove dirt or dust from the external case and/or hard enclosure of the PVA-1000S, use a dry or slightly dampened cloth only.

---

#### **WARNING**

**To prevent electrical shock, disconnect the PVA-1000S from the PV system and/or battery charger before cleaning. Use only a dry cloth or cloth slightly dampened with water to clean the external case and hard enclosure parts. Do not attempt to clean internally.**

---

### ***Instrument Markings***

The PVA-1000S have the following markings on the front and/or rear panel. Familiarize yourself with these markings before operating the PVA-1000S.



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

The CE mark is the manufacturer's declaration that the product meets the requirements of the applicable EC directives.



The C-tick mark is the manufacturer's declaration that the product complies with the EMC regulations of Australia and New Zealand.



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



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



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

## ***PVA-600<sup>+</sup> Safety and Regulatory***

### ***Warnings, Cautions, and Notes***

Before operating the PVA-600<sup>+</sup>, 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.***

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#### **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.*

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#### **NOTE**

*A Note provides important or special information.*

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### ***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<sup>+</sup>, use a dry or slightly dampened cloth only.

---

#### **WARNING**

***To prevent electrical shock, disconnect the PVA-600<sup>+</sup> 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***

## 1 Getting Started

The PVA-600<sup>+</sup> have the following markings on the front and/or rear panel. Familiarize yourself with these markings before operating the PVA-600<sup>+</sup>.



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



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



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



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



This symbol marks the position of the power switch.

### ***SolSensor 300 Safety and Regulatory***

#### ***Warnings, Cautions, and Notes***

Before operating SolSensor 300, 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.***

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---

**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.*

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**NOTE**

*A Note provides important or special information.*

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#### ***Declaration of Conformity***

A declaration of conformity is available upon request.

#### ***Cleaning***

To remove dirt or dust from the SolSensor 300 enclosure, use a dry or slightly dampened cloth only.

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

---

**WARNING** To prevent electrical shock, disconnect SolSensor 300 from the battery charger before cleaning. Use only a dry cloth or cloth slightly dampened with water to clean the external enclosure parts. Do not attempt to clean internally.

**WARNING** The irradiance sensor (white disc) is a precision instrument and is easily damaged if cleaned improperly. See the SolSensor 300 Precautions/Cleaning section for the proper cleaning process.

---

### ***Instrument Markings***

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



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

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

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

### ***SolSensor (original) Safety and Regulatory***

#### ***Warnings, Cautions, and Notes***

Before operating SolSensor, familiarize yourself with the following notations.

---

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

---



---

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

---



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**NOTE** A *Note* provides important or special information.

---

#### ***Declaration of Conformity***

A declaration of conformity is available upon request.

### ***Cleaning***

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

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

---

**WARNING**

**To prevent electrical shock, disconnect SolSensor from the battery charger before cleaning. Use only a dry cloth or cloth slightly dampened with water to clean the external enclosure parts. Do not attempt to clean internally.**

**WARNING**

**The irradiance sensor (white disc) is a precision instrument and is easily damaged if cleaned improperly. See the SolSensor Precautions/Cleaning section for the proper cleaning process.**

---

### ***Instrument Markings***

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



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

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

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

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## Precautions

### ***PVA-1500S Precautions***

#### ***Using PV Connector Saver Jumpers***

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

---

**CAUTION**

*When the lifetime of the connector-saver jumpers has been reached (typically 100 connection/disconnection cycles), remove them, cut them in half to prevent further use, and recycle them. Replace them with fresh connector-saver jumpers, which can be ordered from Solmetric.*

*Using the connector-saver jumpers as described here will extend the life of the PVA-1500S PV connectors by 100 times.*

---

### ***PV/Electrical Safety Precautions***

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

---

**WARNING**

**The information below is important but not necessarily complete; the operator must assess the potential dangers of each PV system, and take appropriate precautions.**

**FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.**

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- Never work alone.
- Do not use the PVA-1500S in wet environments.
- Do not operate or subject the PVA-1500S 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-1500S.
- Do not use the PVA-1500S 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-1500S by installing connector-saver jumpers. Replace the connector-saver jumpers when they have reached 100 connections.
- Special 1500v test leads and alligator clips are provided with the PVA-1500S. Do not substitute other test leads. Also, do not use the test leads from a PVA-1000S, which are rated only to 1000v.

---

**WARNING**

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

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

### ***Battery Precautions***

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#### **CAUTION**

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

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#### **WARNING**

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

---

### ***Measuring High-Efficiency PV Modules***

High-efficiency PV modules produce a short but intense inrush current at the start of the I-V measurement. In extreme cases this inrush current can trigger the I-V Measurement Unit's over-current protection circuit, causing the Unit to temporarily enter the over-current "Disabled" mode. The magnitude of the inrush current is multiplied by the number of modules measured in parallel. For this reason, modules and strings of high-efficiency PV modules should not be measured in parallel; measure only one high-efficiency PV module or string at a time. If you will be measuring harnessed (paralleled) strings of high-efficiency modules, plan to isolate each string from the harness for measurement.

### ***PVA-1000S Precautions***

#### ***Using PV Connector Saver Jumpers***

PV connectors, regardless of manufacturer, are not designed for large numbers of connection/disconnection cycles. For this reason, the PVA-1000S is shipped with connector-saver jumpers attached to its own PV connectors. The connector-saver jumpers are intended to take wear and tear, greatly extending the life of the PVA-1000S PV connectors. Leave the connector-saver jumpers in place at all times. Make all your PV circuit and test lead connections/disconnections to the connector-saver jumpers, not to the PVA-1000S connectors.

---

#### **CAUTION**

*When the lifetime of the connector-saver jumpers has been reached (typically 100 connection/disconnection cycles), remove them, cut them in half to prevent further use, and recycle them. Replace them with fresh connector-saver jumpers, which can be ordered from Solmetric.*

---

*Using the connector-saver jumpers as described here will extend the life of the PVA-1000S PV connectors by 100 times.*

---

### ***PV/Electrical Safety Precautions***

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

---

#### **WARNING**

**The information below is important but not necessarily complete; the operator must assess the potential dangers of each PV system, and take appropriate precautions.**

**FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.**

---

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

- Special 1000v test leads and alligator clips are provided with the PVA-1000S. Do not substitute other test leads. Also, do not use the test leads from a PVA-600<sup>+</sup>, which are rated only to 600v.

**WARNING**

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

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

***Battery Precautions*****CAUTION**

*The PVA-1000S contains a small lithium battery and should not be disposed of with general refuse. Dispose of the battery in accordance with all local codes and regulations for products containing lithium batteries. Contact your local environmental control or disposal agency for further details.*

**WARNING**

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

***Measuring High-Efficiency PV Modules***

High-efficiency PV modules produce a short but intense inrush current at the start of the I-V measurement. In extreme cases this inrush current can trigger the I-V Measurement Unit's over-current protection circuit, causing the Unit to temporarily enter the over-current "Disabled" mode. The magnitude of the inrush current is multiplied by the number of modules measured in parallel. For this reason, modules and strings of high-efficiency PV modules should not be measured in parallel; measure only one high-efficiency PV module or string at a time. If you will be measuring harnessed (paralleled) strings of high-efficiency modules, plan to isolate each string from the harness for measurement.

***PVA-600<sup>+</sup> Precautions******Using PV Connector Saver Jumpers***

PV connectors, regardless of manufacturer, are not designed for large numbers of connection/disconnection cycles. For this reason, the PVA-600<sup>+</sup> is shipped with connector-saver jumpers attached to its own PV connectors. The connector-saver jumpers are intended to take wear and tear, greatly extending the life of the PVA-600<sup>+</sup> PV

connectors. Leave the connector-saver jumpers in place at all times. Make all your PV circuit and test lead connections/disconnections to the connector-saver jumpers, not to the PVA-600<sup>+</sup> connectors.

---

**CAUTION**

*When the lifetime of the connector-saver jumpers has been reached (typically 100 connection/disconnection cycles), remove them, cut them in half to prevent further use, and recycle them. Replace them with fresh connector-saver jumpers, which can be ordered from Solmetric.*

*Using the connector-saver jumpers as described here will extend the life of the PVA-600<sup>+</sup> PV connectors by 100 times.*

---

***PV/Electrical Safety Precautions***

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

---

**WARNING**

**The information below is important but not necessarily complete; the operator must assess the potential dangers of each PV system, and take appropriate precautions.**

**FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.**

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- Never work alone.
- Do not use the PVA-600<sup>+</sup> in wet environments.
- Do not operate or subject the PVA-600<sup>+</sup> 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<sup>+</sup>.
- Do not use the PVA-600<sup>+</sup> 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<sup>+</sup> by installing connector-saver jumpers. Replace the connector-saver jumpers when they have reached 100 connections.
- Special 600v test leads and alligator clips are provided with the PVA-600<sup>+</sup>. Do not substitute other test leads.

**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.
- Keep PV connectors away from soil and dirt. Always inspect PV connectors for damage and dirt before connecting. Do not use if damaged.
- Do not use the I-V 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<sup>+</sup> contains a small lithium battery and should not be disposed of with general refuse. Dispose of the battery in accordance with all local codes and regulations for products containing lithium batteries. Contact your local environmental control or disposal agency for further details.*

**WARNING**

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

***Measuring High-Efficiency PV Modules***

High-efficiency PV modules produce a short but intense inrush current at the start of the I-V measurement. In extreme cases this inrush current can trigger the I-V Measurement Unit's over-current protection circuit, causing the Unit to temporarily enter the over-current "Disabled" mode. The magnitude of the inrush current is multiplied by the number of modules measured in parallel. For this reason, modules and strings of high-efficiency PV modules should not be measured in parallel; measure only one high-efficiency PV module or string at a time. If you will be measuring harnessed (paralleled) strings of high-efficiency modules, plan to isolate each string from the harness for measurement.

### ***SolSensor and SolSensor 300 Precautions***

#### ***Covering the Irradiance Sensor***

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

---

**WARNING**

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

---

#### ***Cleaning the Irradiance Sensor***

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

---

**WARNING**

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

---

#### ***Battery Precautions***

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**CAUTION**

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

---

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**WARNING**

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

---

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## Installation Procedure

### ***I-V Measurement Unit Installation Procedure***

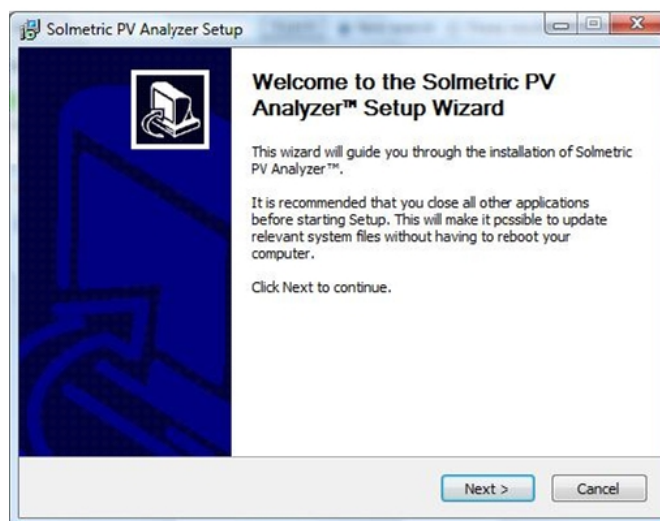
#### ***Hardware Installation***

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

#### ***Software Installation***

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

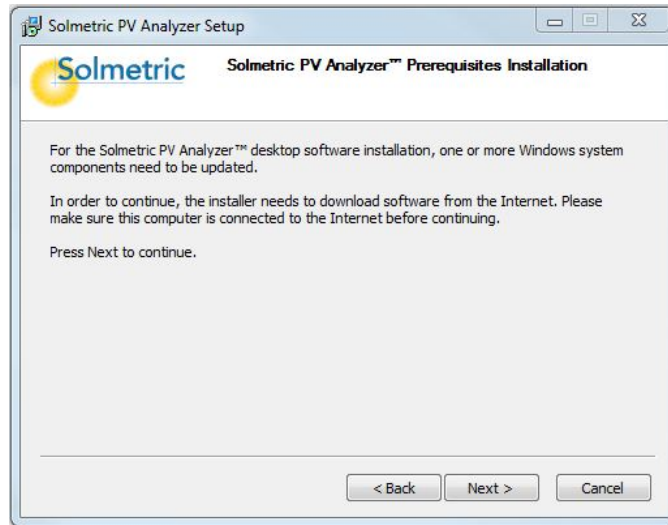
1. Insert the PVA software USB flash drive into the slot on your Windows® computer.
2. If the welcome screen does not automatically open as shown in Figure 1, either double-click on the **setup.exe** file on the USB flash drive or run **setup.exe** from the **Run** dialog. Alternately, the installation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



**Figure 1. Welcome screen**

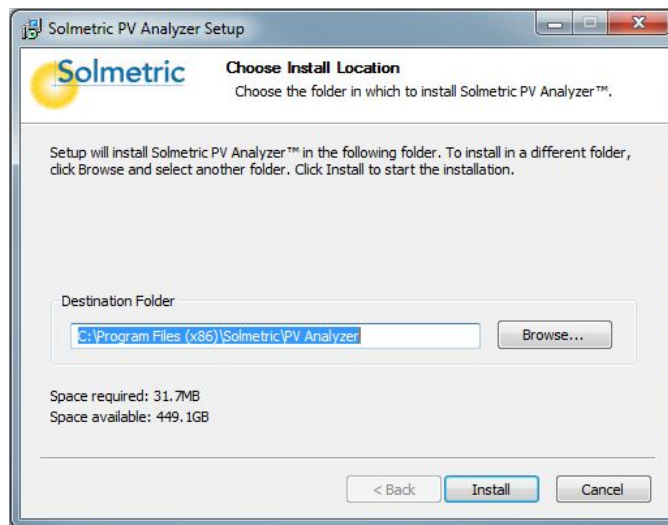
3. Follow the instructions in the welcome screen to install the PVA software. The drivers for the wireless USB adapter will also be installed.
4. During installation, the following dialog may appear. Connect your computer to the Internet to allow downloading of the required prerequisites.

## 1 Getting Started



**Figure 2. Prerequisites dialog**

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



**Figure 3. Installation default location dialog**

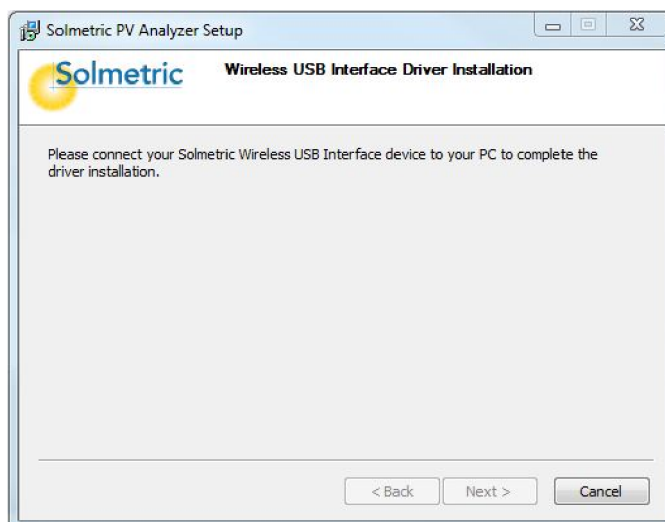
6. Partway through the installation of the PVA-1000S or PVA-600+, the following screen will appear, asking you to insert the wireless USB adapter that will communicate with the I-V Unit.

---

**NOTE**

The wireless USB installation is not required for PVA-1500S. Go to step 9.

---



**Figure 4. Insert wireless USB adapter dialog**

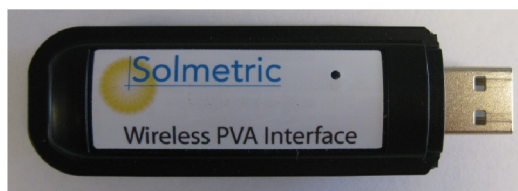
7. Insert the wireless USB adapter shown below.

---

**NOTE**

If you are working with a PVA-1000S or PVA-600<sup>+</sup> and the Wireless USB Adapter is not available, you can complete the basic software installation by clicking Cancel. You will be asked whether the software installed correctly. Click Yes. At this point the software will operate normally but will not be able to communicate with the I-V Measurement Unit or SolSensor. When you later insert the Wireless USB Adapter while the PVA software is running, driver software will be loaded from the Wireless USB Adapter. This completes the software installation.

---



**Figure 5. Insert wireless USB adapter (PVA-600<sup>+</sup> and PVA-1000S only)**

8. When the Wireless USB Adapter driver installation completes, you will be asked whether the software installed correctly. Click **Yes**.
9. When the installation process is finished, the following dialog appears.

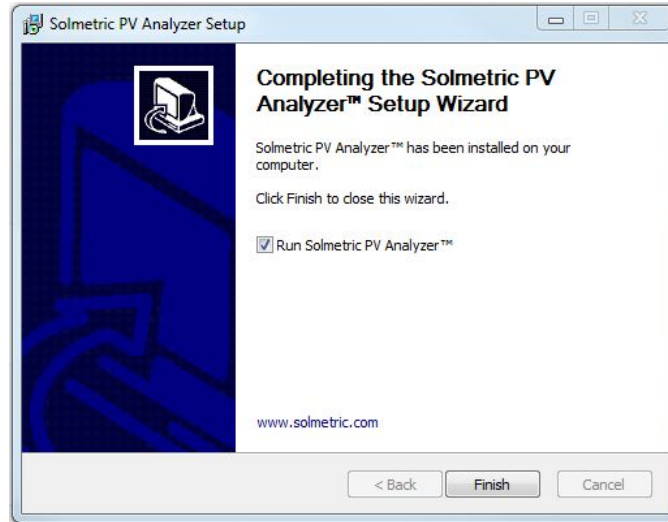


Figure 6. Installation complete dialog

10. If the Run Solmetric PV analyzer box is selected, the PVA software will launch when you click **Finish**. Alternately, you can start the PVA software by double-clicking on the shortcut icon on your desktop as shown in Figure 7. Or, select the list of programs in the **Start** menu, then select **Solmetric > PV analyzer >Solmetric PV Analyzer**. The icons differ by the version number of the PVA software; "v3" for the PVA-1000S and PVA-600+, and "v4" for the PVA-1500S.



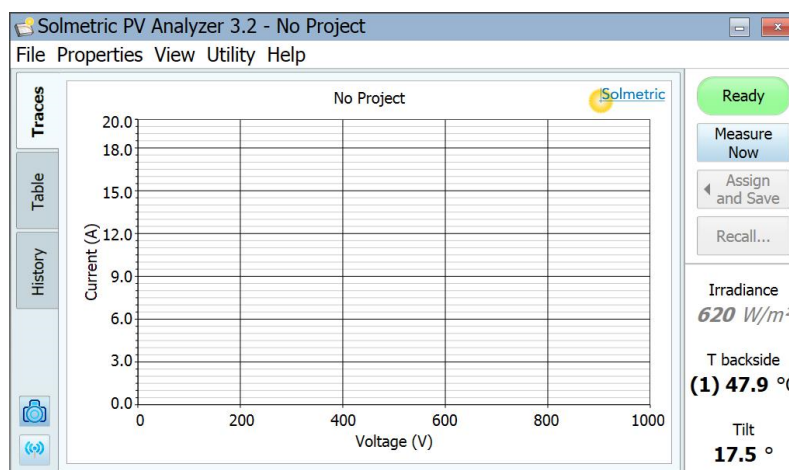
Figure 7. Launching the PVA software

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



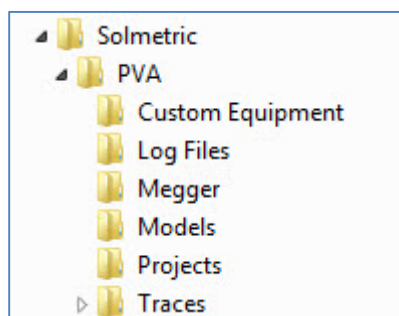
Figure 8. Splash screen

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



**Figure 9. The software user interface shared by the PVA-1500, PVA-1000S (shown here), and PVA-600<sup>+</sup>**

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



**Figure 10. Directory structure of PVA software**

### ***Updating the PV Equipment Databases***

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

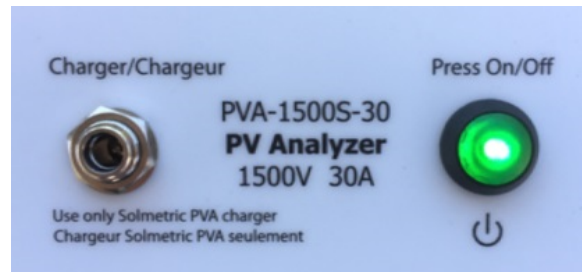
### ***SolSensor Installation Procedure***

No installation steps are required for the SolSensor 300 or the original SolSensor.

## Charging the Battery

### ***Charging the Battery on the PVA-1500S I-V Measurement unit***

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



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

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

The PVA software interface will warn you when the battery level is low and close to shutting down the I-V Measurement Unit. Also, you can check the battery voltage level by clicking on the Ready button following an I-V measurement.

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

### ***Charging the SolSensor 300 Battery***

The SolSensor battery is not removable. It may be recharged by attaching the battery charger to the charging connector on SolSensor shown in Figure 12 and plugging the charger into an AC wall-plug.



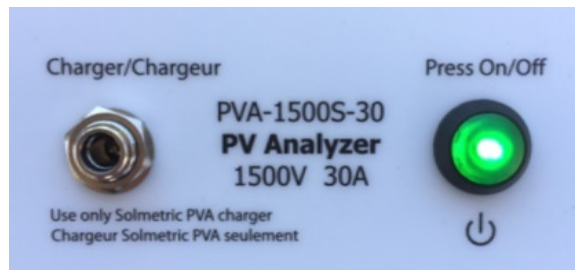
**Figure 12. Charger connected**

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

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

### ***Charging the Battery on the PVA-1000S and PVA-600+ I-V Measurement Unit***

The battery in the I-V Measurement Unit is not removable. It may be recharged by attaching the battery charger to the connector on the I-V Measurement Unit shown in Figure 13 and plugging the charger into an AC wall-plug.



**Figure 13. Battery charger connector on the I-V Measurement Unit**

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

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

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

---

**CAUTION**

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

---

***Charging the SolSensor Battery of the Original SolSensor***

The SolSensor battery is not removable. It may be recharged by attaching the battery charger to the charging connector on SolSensor shown in Figure 14 and plugging the charger into an AC wall-plug.



**Figure 14. Charger connected**

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

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

---

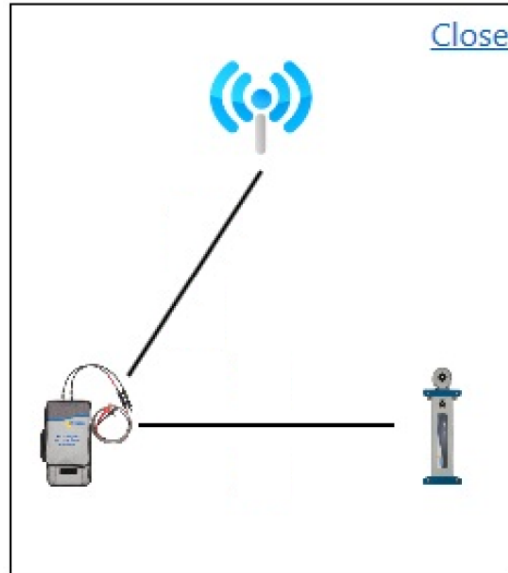
## Your Wireless Network

***Your PVA-1500S/SolSensor 300 Wireless Network***

Communication between your PC and the I-V Measurement Unit is by conventional WiFi. The I-V Unit creates a hotspot when you turn it on. Just find that hotspot in your PC's network list and connect to it. The SSID (hotspot name) has the format "pva1500\_XXXXXX" where XXXXXX is the unique identifier of the I-V Unit.

The I-V Measurement Unit also relays communications between your PC and the SolSensor 300, which automatically links to the I-V Measurement Unit when both instruments are turned on.

To see a diagram of your wireless network, click the network icon at the lower left corner of any screen in the PVA software.



**Figure 15. The WiFi network of the PVA-1500S, SolSensor 300, and your PC.**

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

When you are using the PVA-1500S and the WiFi link to the I-V Unit hotspot temporarily drops, there is some chance that the PC will attempt to automatically connect with another frequently-used network that is set up in your network list to connect automatically. This nuisance can be avoided by pulling up the network list on your PC, checking the "connect automatically" box for the PVA-1500S I-V Unit hotspot, and unchecking the same box for the unwanted network.

### ***Your PVA-1000S/600+ /SolSensor Wireless Network***

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

---

#### **NOTE**

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

Network ID  
0F96E4A7

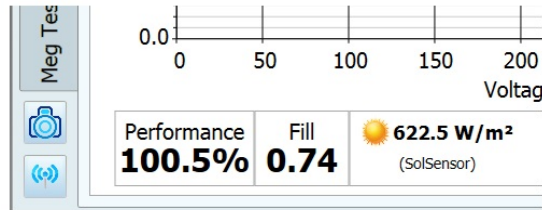
This protects their communication network from interference from any other sets of PVA equipment working nearby.

If you own multiple sets of PV Analyzer equipment, be aware that each is a matched set. This protects their communication network from interference from any other sets of PVA

equipment working nearby. To avoid confusion and communications problems, avoid mixing the components between PVA systems.

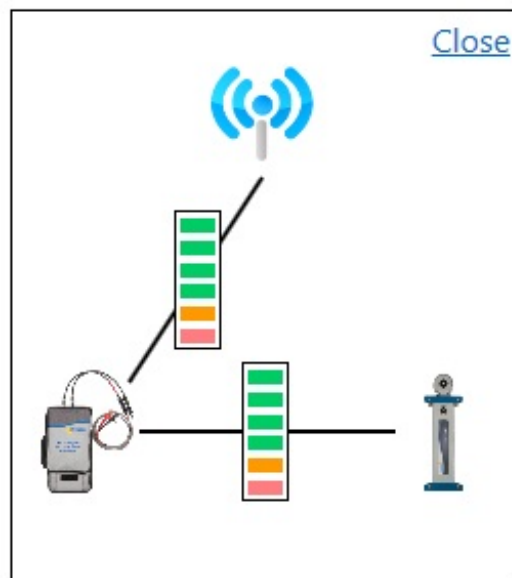
---

To see a diagram of the network, click on the network icon at the lower left corner of your measurement screen, as shown in Figure 16.



**Figure 16. Network icon**

The network diagram appears, as shown in Figure 17.



**Figure 17. Network diagrams**

Communication can be direct from the PC to each of the instruments or either of the instrument can act as a relay, as described in Table 6.

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

**Table 6. Direct and indirect wireless links between PC, PVA, and SolSensor**

<b>Communication route</b>	<b>Interface to I-V Measurement Unit</b>	<b>Interface to SolSensor</b>
PC to I-V Measurement Unit	Direct	
PC to SolSensor		Direct
PC to I-V Measurement Unit to SolSensor	Direct	Indirect
PC to SolSensor to I-V Measurement Unit	Indirect	Direct

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

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

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

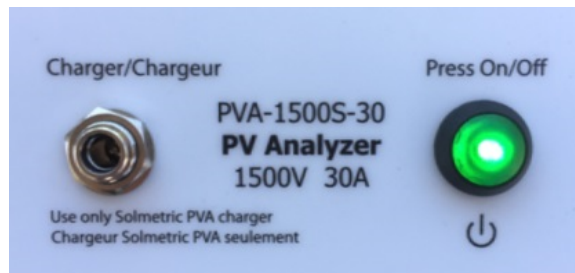
---

### System Controls and Settings

The LED pushbutton switch on the I-V Unit, shown in Figure 18, is used to enable, pause, and reset the I-V unit. The LED indicates these various operational states, including the status of the wireless network.

There are differences in the operation of the LED pushbutton between the PVA-1500S and the PVA-1000S/600+, and differences in the networks themselves.

When the PVA-1500S is turned on, it creates a Wi-Fi hotspot to which you will connect your PC by selecting it on your PC's network list. When the PVA-1000S or PVA-600+ is turned on, it searches for the matched Wireless USB Adapter. For the network to be established the Wireless USB Adapter must be plugged into your PC, the PV Analyzer software must be launched, and the COM port into which the USB Adapter is plugged must be selected in the Utility menu.



**Figure 18. LED-illuminated button switch (shown for the PVA-1500S I-V Measurement Unit).**


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

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

**Operational States of the PVA-1500S I-V Measurement Unit**

Table 7 describes the operational states of this instrument. The table is an abbreviated guide, and more detailed descriptions follow.

**Table 7. I-V Operational States of the PVA-1500S**

<b>I-V Unit LED </b>	<b>I-V Unit State</b>	<b>Pushbutton</b>
Off	Off	Press once to turn on
Rapid Blinking	Searching for PC	Press 3x to turn off
Very Slow Blinking	Paused (will turn off automatically in 15 minutes)	Press once to enable sweep, or 3x to turn off
On	Connected to PC, sweep enabled	Press once to pause, or 3x to turn off

**To reset IV-Unit or SolSensor:** Hold the pushbutton down 5 seconds and then release.

When you turn the PVA-1500S I-V Measurement Unit on by pressing the pushbutton once, the LED blinks rapidly until it connects with your PC. Once it connects, LED stays steadily lighted.

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

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


If the network connection is lost, the LED blinks rapidly to indicate it’s trying to establish a network. It should reconnect within 20-30 seconds.

If it is necessary to reset either the PVA-1500S I-V Unit or the SolSensor 300, just hold the LED pushbutton down for 5 seconds and release. Following the reset, the instruments will attempt to re-connect.

**Operational States of the PVA-1000S & 600+ I-V Measurement Unit**

Table 8 describes the operational states of this instrument. The table is an abbreviated guide, and more detailed descriptions follow.

**Table 8. I-V Operational States of the PVA-1000S & 600+**

I-V Unit LED 	I-V Unit State	Pushbutton
Off	Off	Press once to turn on
Blinking	Searching for Wireless USB Adapter	Wait 10-20 seconds for the network to connect.
On	Network exists, sweep enabled.	Press once to pause. Turns off automatically if paused more than 15 minutes.
Blinks once	Signals start of I-V sweep	

**To reset IV-Unit:** Hold the pushbutton down 5 seconds and then release.

When you turn the PVA-1000S or PVA-600+ I-V Measurement Unit on by pressing the pushbutton once, the LED blinks on and off until it connects with the Wireless USB Adapter plugged into your PC. Once it connects, LED stays steadily lighted.

Before connecting the I-V Unit’s test leads to the PV circuit, press the pushbutton once to pause the I-V Unit. This prevents accidentally triggering while you are making electrical connections. The LED stays unlighted during the pause state for these instruments. If the I-V Unit is left in the paused state for longer than 15 minutes, it will turn itself off to conserve battery power. When this happens, just turn it back on with a single button push.

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

If the network connection is lost, the LED begins blinking on and off again, to indicate it’s trying to establish a network. It should reconnect within 10-20 seconds.

If it is necessary to reset either the I-V Unit or the SolSensor, just hold the LED pushbutton down for 5 seconds and release. Following the reset, the instruments will attempt to re-connect.

## Setting Up the I-V Measurement Unit

1. Place the I-V Measurement Unit near the PV circuits to be measured.
2. Ensure that the connector-saver jumpers are installed on the primary test leads. The connector-saver jumpers protect the PVA's main lead connectors from wear and tear. They should not be removed except for replacement.
3. If necessary, connect alligator clip leads or extension cables to the connector-saver jumpers. Use only clip leads or cables that are rated for at least the maximum current and voltage of the I-V Measurement Unit. The Solmetric PVA test leads are recommended for this application. These heavy duty armored test leads have MC-4 connectors at one end and 4-mm sheathed banana plugs with jumbo alligator clips at the other end. **PVA-1500 test leads are specially designed for 1500v use. Do not re-use PVA-1000 test leads with the PVA-1500.**
4. If long PV 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. This step is not necessary for PVA-1500S because communication is by WiFi.
6. If you will be using the Solmetric SolSensor, refer to Setting Up SolSensor for setup information.

---

## Setting Up SolSensor

Below Figure 19 shows the SolSensor Wireless PV Reference sensor mounted on the frame of a PV module.



**Figure 19. SolSensor mounted on the frame of a PV module**

---

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

---

---

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

---

---

## Mounting SolSensor to a PV module frame

Below Figure 20 shows SolSensor attached to a PV module with the Module Frame Clamp, and secured with the Tool Lanyard.

---

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

---



**Figure 20. SolSensor tool lanyard secured to a racking member.**

To mount SolSensor, follow these steps:

1. Remove SolSensor, the Module Frame Clamp, and the tool lanyard from the soft case.
2. Attach the tool lanyard to an eyelet on SolSensor. Then loop the lanyard around a racking member and clip it back on itself, as shown in Figure 20.
3. Place SolSensor against the top horizontal leg of the module frame, with its metal posts and ears seated against the frame surfaces, as shown in Figure 21.



**Figure 21. SolSensor correctly seated along the upper horizontal leg of the module frame.**

4. Holding SolSensor in that position, slip the tip of the Module Frame Clamp inside the frame of the module. Seat the tip of the clamp on the flat inner surface

of the frame as shown in Figure 22 and not on a shelf or ridge from which it could slip, allowing SolSensor to come loose.

5. Squeeze the clamp mechanism until SolSensor is firmly held against the side of the module frame.



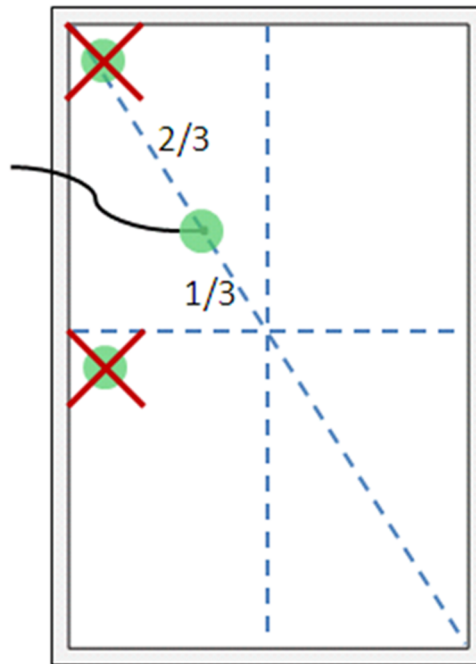
**Figure 22. Tip of frame clamp properly seated on inside surface of module frame**

6. Inspect the mounting and assure that the posts and blue ears are in contact with the upper edge of the module frame. If there is space under one or both of the blue ears, the irradiance sensor will not be in the plane of the array as desired; loosen the clamp slightly, reposition SolSensor, and re-tighten the clamp.
7. Connect the thermocouple to SolSensor, inserting the yellow plug of the thermocouple wire into the upper left yellow receptacle labeled TC1 (see Figure 23).



**Figure 23. Thermocouple plugged into the TC1 connector.**

8. Tape the tip of the thermocouple into firm contact with the module backside, far enough under the module to avoid the cooler outer edges. When testing single, free-standing modules, attach the thermocouple tip as shown in Figure 24. For most accurate temperature measurements, use a wide piece of high temperature polyester tape. Other types of tape will sag at high temperature, allowing the tip of the thermocouple to pull away from the backsheet of the module. Use firm pressure to roll the tape over the thermocouple tip, forcing the tip into intimate contact with the module backside.



**Figure 24. Locating the thermocouple tip on a single free-standing module.**

9. Remove the protective cover from SolSensor irradiance sensor.
10. Press the button to turn SolSensor on, as shown in Figure 25. The LED will blink on and off as it attempts a wireless connection, and will glow steadily when the connection is made. The SolSensor 300 links to the PVA-1500S I-V unit, which relays its communications with the PC. Make sure the I-V Unit is turned on. The original SolSensor links to the wireless USB adapter plugged into your PC.



**Figure 25. SolSensor pushbutton with LED lit. LED blinks until wireless network is established, after which it remains on.**

---

## Optimizing wireless transmission range

Follow these practices to realize as much of the SolSensor line-of-sight transmission range as possible.

1. Position SolSensor in line-of-sight to your PC. Avoid locations where the signal must transmit through PV modules and racking.
2. Avoid placing the PC on a metal surface (for example metal roofs and metal HVAC boxes), which reduces wireless range.
3. If it is not possible to achieve the required transmission range with SolSensor mounted along the edge of a PV module, SolSensor can be mounted on a tripod and oriented to the correct azimuth and tilt. Choose a location that has sky exposure similar to the array itself.

---

## Mounting SolSensor on a tripod

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

1. *Sturdy tripod*

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

2. *Tripod level indicator*  
This is typically a disc with a bubble level that mounts between the tripod and the rest of the fittings described here. Some tripods have a built-in level indicator. Note: level indicators vary widely in their sensitivity and accuracy.
3. *Tripod leveling head*  
This device enables you to quickly and conveniently create a level mounting surface, without needing to adjust the legs of the tripod.
4. *Panning unit*  
This device rotates about the vertical axis, allowing you to adjust the azimuth of SolSensor independent of the tilt.
5. *Tilt unit*  
This device rotates about a horizontal axis, allowing you to set the tilt independent of the azimuth. Typically, you will mount the tilt unit on the panning unit, which is in turn mounted on the leveling indicator and the leveling unit and the tripod itself.
6. *Adapter plate*  
Firmly attach this plate to the bottom of SolSensor and to the top of the tilt unit.

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

1. Assemble SolSensor and the tripod-related hardware as shown in Figure 26.



**Figure 26. Tripod mounting setup**

2. Chose a location to set up the tripod. Consider the following factors:
  - Location should have an open view of the sky, similar to the array itself. Avoid locations where trees or built structures obscure parts of the sky, especially on cloudy days where diffuse light makes up a significant part of

total irradiance. Also avoid locations that have substantial albedo effects (reflections).

- Location should have good line of sight to the combiner boxes or other locations where you will be using your PC.
  - If you plan to use thermocouples to measure module backside temperature, locate the tripod close enough to a sub-array that you can attach the tip of the thermocouple well under the modules, away from the cooler outer edges of the array. A thermocouple extension cable may be useful; contact [support@solmetric.com](mailto:support@solmetric.com) for recommendations.
3. Fully spread the legs of the tripod and seat them firmly.
  4. Connect the thermocouple wire to SolSensor and attach the thermocouple tip to the backside of a PV module. Avoid attaching it near the edges of the module, which run cooler than normal.
  5. If you will be averaging the readings of two thermocouples, also deploy the second thermocouple.
  6. Adjust the leveling unit to center the bubble, and then lock the leveling unit.
  7. Rotate the panning unit to orient SolSensor to the desired true azimuth, then lock panning unit. Be sure your compass has been adjusted for the local magnetic declination. A magnetic declination calculator is available at <http://www.ngdc.noaa.gov/geomag-web/?id=declinationFormId>
- To avoid distortion of the earth's magnetic field by components in SolSensor or the tripod mounting hardware, separate the compass horizontally from SolSensor by inserting a non-ferrous rectangular spacer.
8. Rotate the tilt unit until the tilt angle indicated in the PV Analyzer software matches the actual tilt of the PV array, and then lock the tilt unit.

---

**CAUTION:**

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

---

## Connecting to the Solar PV Equipment

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

---

**WARNING**

**The procedure described below is important but does not cover all situations; the operator must assess the potential dangers of each PV system, and take appropriate precautions.**

**FAILURE TO TAKE APPROPRIATE SAFETY PRECAUTIONS COULD LEAD TO PERSONAL INJURY OR LOSS OF LIFE.**

---

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

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

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

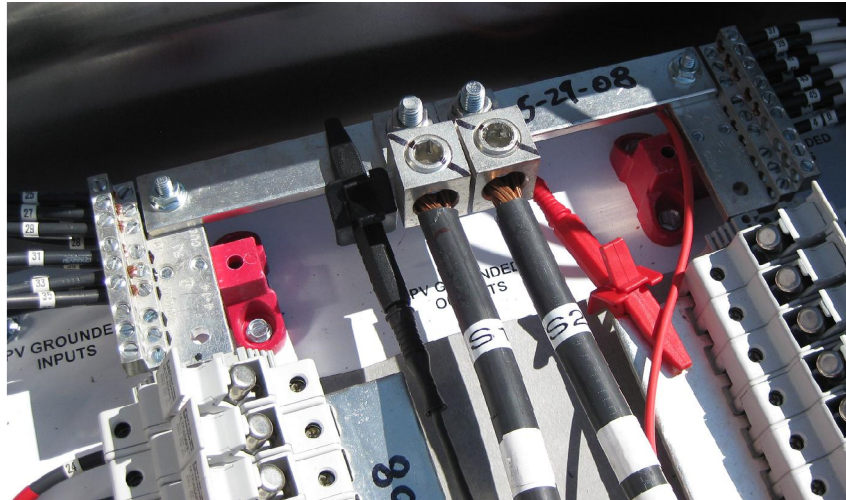
---

**WARNING**

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

---

3. Following safe operating procedures, connect the PV leads of the I-V Measurement Unit to the PV source to be measured. The connection can be made at the PV module itself, or at the ends of home run cables, or at a combiner box. If your strings run directly to the inverter, isolate them from one another and from the inverter by pulling their fuses. Connect the Solmetric PVA test leads to the string to be measured. In some cases, you can attach an alligator clip to the fuse clip, using it as a test point.



**Figure 27. Example of I-V Measurement Unit test leads clipped to the buss bars of a PV combiner box**

4. If the distance between the test device and the I-V Measurement Unit requires the use of extension cables, use a PV cable that is properly rated for the maximum

system voltage, with correctly installed connectors. Select a wire gauge that will result in a suitably small voltage drop.

5. When extension cables are longer than 10 feet (one-way), lay the cables close to one another to minimize added cable inductance.
6. If connecting at a fused combiner box, insert only one fuse at a time, to select the string you wish to measure.

---

## Powering-Up the I-V Measurement Unit

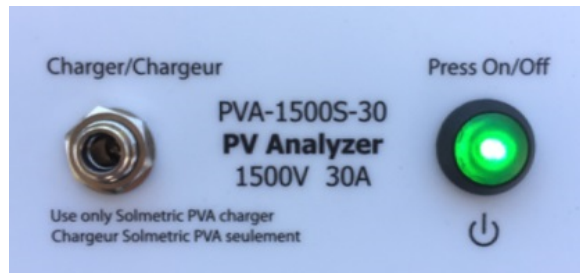
---

### NOTE

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

---

Press the power button once on the I-V Measurement Unit. Refer to Figure 28 below.



**Figure 28. 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 your PC and the PVA software is running, a network will be established and the LED will become continuously lit (no blinking). If a network is not established within 15 minutes, the I-V Measurement Unit will turn off to conserve the battery.

In normal use, the I-V Measurement Unit will not go into sleep mode if the LED is steady ON. However, the I-V Measurement Unit does enter sleep mode 15 minutes after it has been placed in Pause mode by pressing the On/Off button (in Pause mode the LED is not illuminated).

## I-V Measurements

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

---

## Sweep Disabled

PV current is stopped automatically at the end of each I-V measurement. However, before connecting or disconnecting test leads or cables, press the red button on the front of the I-V Measurement Unit to disable the measurement sequence. Pressing the red button again restarts the measurement sequence. Manually disabling the I-V Measurement Unit in this way will assure that an I-V measurement is not accidentally taken when it is not expected.

---

**WARNING**

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

---

## Over-Temperature Protection

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

The I-V Measurement Unit absorbs energy with each measurement, and across a series of measurements the instrument's internal temperature gradually increases. Some of this built-up heat is shed during the time between measurements and while the equipment is being moved around the site between measurement sessions. If, on average, the heat gain exceeds the heat loss, the internal temperature continues to rise until the internal temperature sensor is triggered. When that happens, the I-V Measurement Unit shuts down to allow the instrument to cool down, and the PVA software posts **Disabled** message in the Status indicator, directly above the Measure Now button.

---

**CAUTION**

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

---

### ***Thermal Capacity of the PVA-1500S***

The thermal capacity of the PVA-1500S is the number of I-V measurements that can be made before the maximum allowable internal temperature is reached. Thermal capacity decreases with higher Voc, higher outdoor ambient temperatures, and shorter wait time between measurements. For example, if a PV plant with 16 strings per combiner box and string Voc of 1300V is measured at the rate of one string every 17 seconds, followed by 5 minutes of no measurements (e.g. while moving to the next combiner box), then the thermal capacity is more than 800 measurements at 25 deg C ambient temperature, and 250 measurements at 45 deg C ambient. After reaching the thermal capacity, every minute of cooling (i.e. no measurements) increases the number of subsequent measurements that will be allowed before thermal capacity will be reached again.

---

#### **CAUTION**

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

---

### ***Operating Under High-Temperature Conditions***

The most demanding thermal conditions for the measurement unit are:

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

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

---

## Over-Voltage Protection

### ***PVA-1500S Over-voltage Protection***

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

### ***PVA-1000S Over-voltage Protection***

If a voltage in excess of 1100 V is detected, the I-V Measurement Unit switches into disabled mode and the status indicator displays "Disabled". Reduce the voltage below 1000V to resume normal operation.

If a voltage more than 1500 V is detected, the I-V Measurement Unit is immediately reprogrammed into a disabled state to prevent continued use of a damaged unit. Resetting or restarting the I-V Measurement Unit will not re-enable it. Please contact Solmetric to arrange for repairs.

### ***PVA-600+ Over-voltage Protection***

If an input voltage greater than 650 V is detected, the I-V Measurement Unit is automatically reprogrammed to a disabled state and the user is instructed to return the unit and wireless USB adapter to Solmetric for service.

---

**WARNING**

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

---

---

## Over-Current Protection

If the I-V Unit detects a current that exceeds the maximum specified current of the instrument, a warning appears onscreen. Reduce the source current before continuing. It may be necessary to reset the I-V Unit by holding the LED button down for 5 seconds.

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 I-V Measurement Unit switches into disabled mode, and an I-V measurement does not take place. The software also posts the warning "Voltage Out of Range".

## 3 Software Overview

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### Using Projects

The PV Analyzer stores all of your setup information and measurement results in a specialized Windows file type file type called a Project file.

The PV Analyzer software guides you through the steps of creating a Project for a particular array. All PV modules within a Project must be of the same type and must be mounted at the same azimuth.

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

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

---

**NOTE** To preserve software responsiveness for large PV sites, consider creating multiple projects. For example, in a 50 MW project, create a separate Project for each pad or each inverter. This will also improve the speed of the Data Analysis Tool that you will use to analyze your data.

---

---

**NOTE** Be sure that your PC is set to the correct date and time, and that the time zone and daylight savings setting are correct. These parameters are used to calculate the position of the sun at the exact moment of the I-V curve measurement. This allows the software to calculate the angle of incidence of the direct sunlight and use that information to optimize the accuracy of irradiance sensor and the PV model. **Errors in these settings will introduce errors in the predicted performance of the PV modules under test, and as a result will also cause errors in the Performance Factor** (measured maximum power / predicted maximum power).

I-V measurements are automatically "stamped" with the date and time at the instant the measurement is performed.

If your computer is connected to the internet, each time you open the New Project Wizard, the PVA PC software checks a web time server for the correct Universal Time

### 3 Software Overview

and adjusts your computer's clock as needed. Choose the time zone and daylight savings setting.

All dates and times associated with the saved measurement data are preserved even if the Project is subsequently opened in another time zone.

---

## Using the System Tree

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

---

## Main Screen Overview

The PVA software runs on a PC and is your interface for making measurements and storing, viewing, and exporting data. The main screen is shown below, with the Traces tab selected.

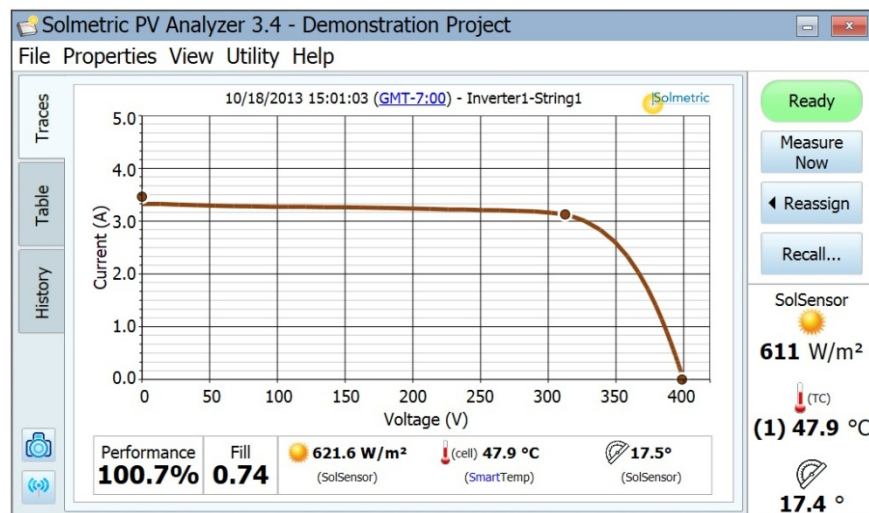


Figure 29. PVA software main screen

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

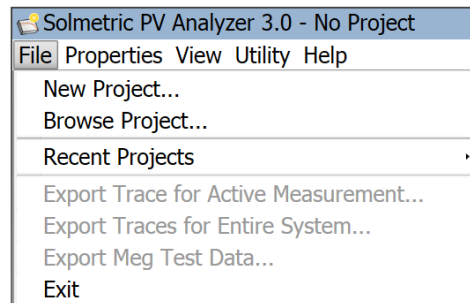
The Menu Bar provides access to additional controls and options.

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

## Menu Bar

### ***File Menu***

The File Menu, shown in Figure 30, is used to create a new project, browse and load existing projects, load recent projects, and export measurement data.



**Figure 30. File Menu**

### ***Browse Project***

Used to access previously saved Projects for retrieval.

### ***Recent Projects***

Provides convenient access to recent Projects.

### ***Export Trace for Active Measurement***

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

### ***Export Traces for Entire System***

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

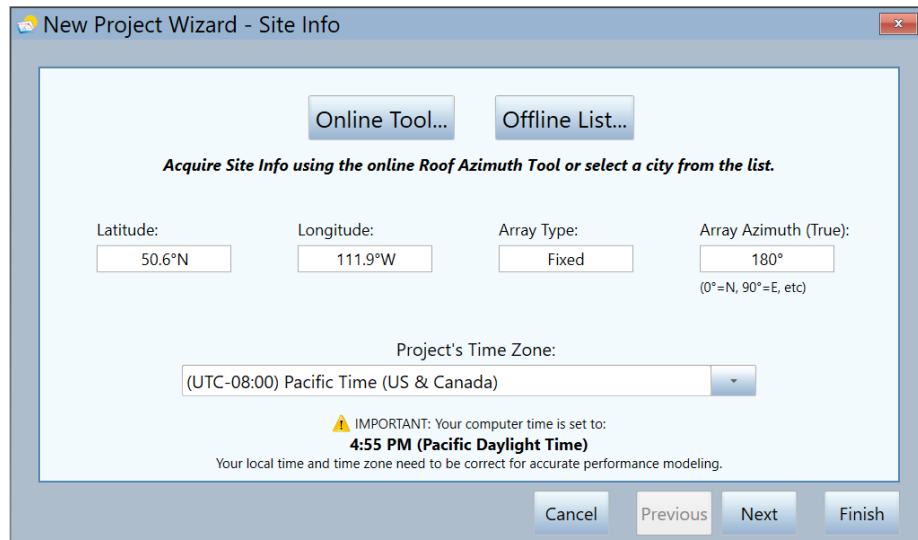
Data in this hierarchical format can be analyzed automatically by the Solmetric Data Analysis Tool.

### **Export Meg Test Data**

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

### **New Project**

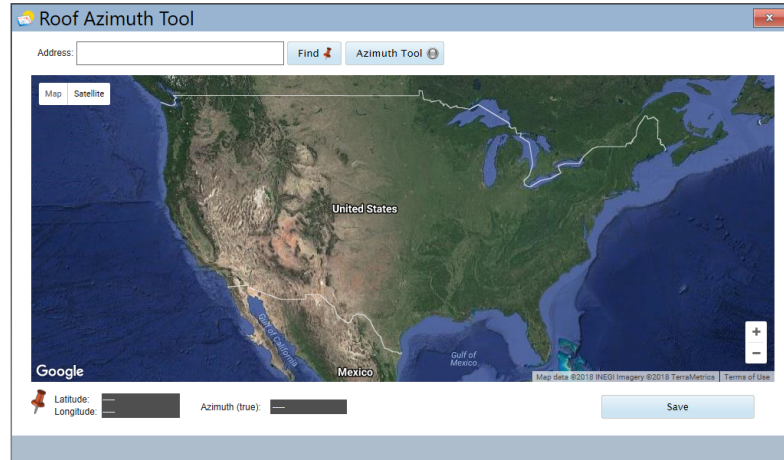
Clicking **New Project...** brings up the Site Info screen, shown in Figure 31. This is the first of three screens of the New Project Wizard.



**Figure 31. The Site Info screen of the New Project Wizard**

Enter the latitude and longitude of the PV installation, and the azimuth (true compass heading toward which the PV modules are tilted). These parameters must be accurately entered because they affect the accuracy of the PV model that predicts the performance of the PV modules under test, and the accuracy of the Performance Factor (measured maximum power / predicted maximum power). You can use the number boxes, the Offline List, or if your PC is on the web, click the button to use the **Online Tool...** (also called the **Roof Azimuth Tool**).

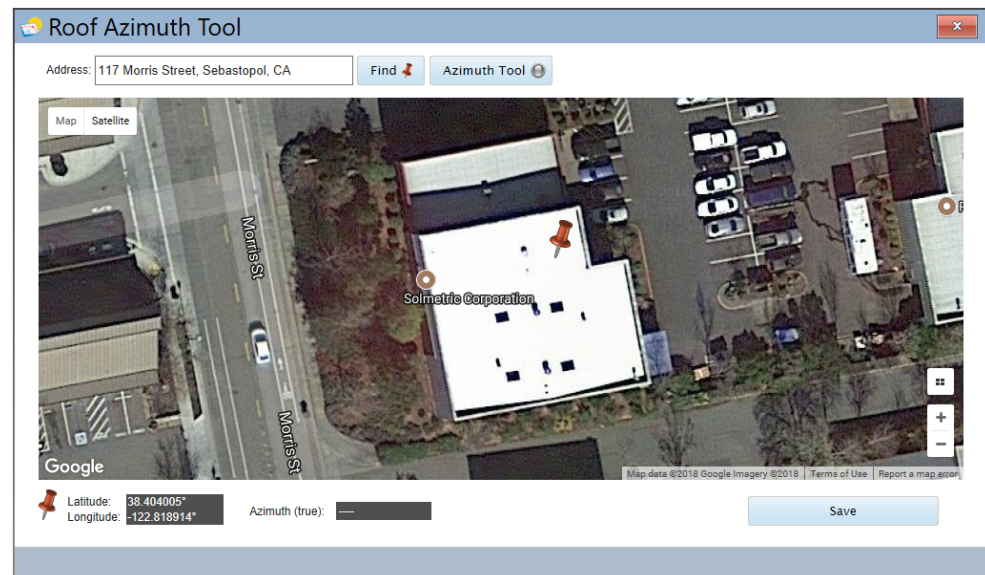
The Roof Azimuth Tool is shown in Figure 32.



**Figure 32. Roof Azimuth Tool**

The Roof Azimuth Tool returns the latitude and longitude of your site. If your array is aligned with the edge of a building or other satellite-visible edge (such as a road or fence line), the Tool can also return the azimuth of your array.

To use the Roof Azimuth Tool, enter the address of your site. Then click Find and you will see your site, as shown in Figure 33. Zoom in by holding down the Ctrl button on your PC and scrolling. Move the image around by left-click dragging the image.



**Figure 33. Roof Azimuth Tool with the image of a rooftop PV Site**

At this point in the process, the Roof Azimuth Tool has found the site's latitude and longitude (see values at lower left), but has not yet found the array azimuth. If you press Save at this point, the latitude and longitude will be copied into the Site Info screen.

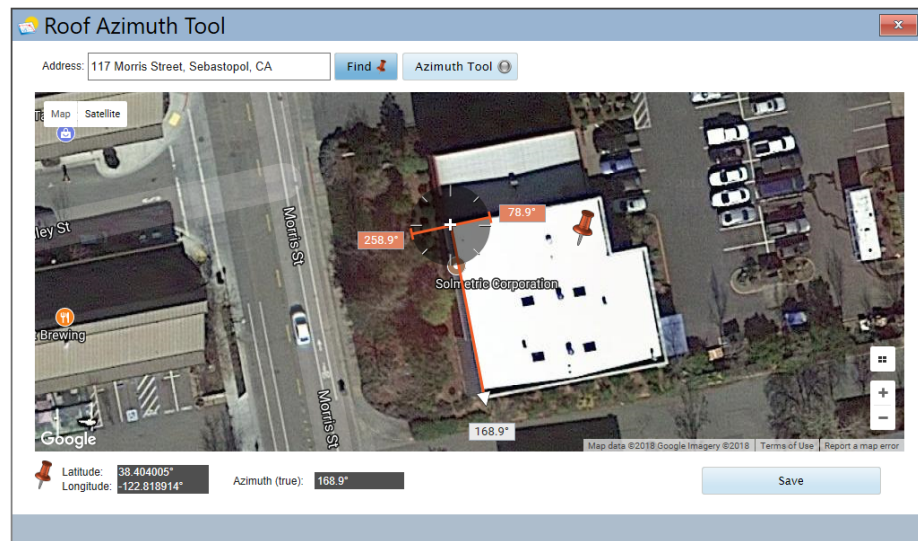
To also find the building azimuth, follow these steps. This example assumes that a tilt-up array will be installed on the main roof of a building, and that the modules will be tilted

### 3 Software Overview

toward the southern-most edge of the roof. Note: In these images, azimuth values are ‘true’, not ‘magnetic’.

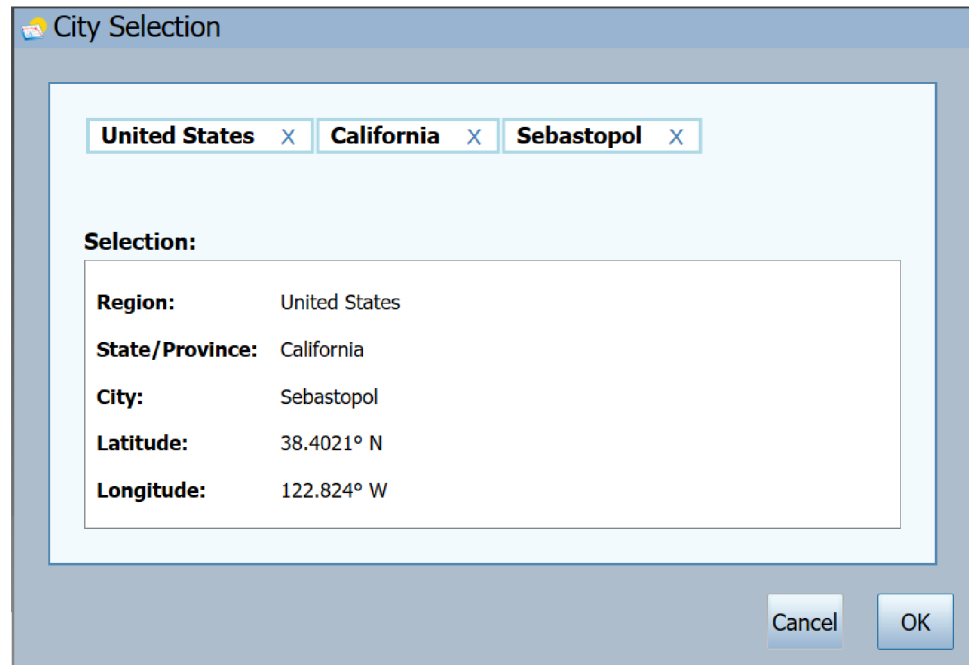
1. Click on the Azimuth Tool button.
2. Left-click (in this example) the northwest corner of the main roof.
3. Slide your cursor downward and left-click a second time at the southwest corner of the main roof.

After the second click an arrow appears, as shown in Figure 34, indicating the azimuth of that edge of the roof, and thus the azimuth of the array. Now when you click Save, all three parameter values – latitude, longitude, and azimuth – are copied into the Site Info screen. When you freeze the rectangle, an arrow and azimuth value appear at the bottom of the view, as shown in Figure 34. When you click **OK**, the azimuth value is returned to the New Project Wizard, along with the latitude and longitude of the site.



**Figure 34. Finding the Azimuth Value Using the Roof Measurement Tool**

You can also find the site latitude and longitude using the **Offline List...** button, shown in Figure 35.

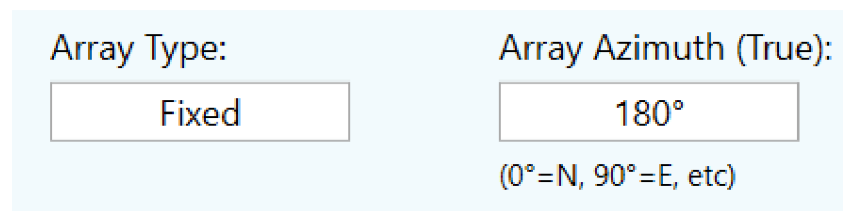


**Figure 35. Finding your site's latitude and longitude using the Offline List feature.**

Start by typing the name of your country. Once you have found and selected it, repeat the process until you have selected the nearest city. Then click **OK** and the latitude and longitude of that city will be copied into the Site Info screen.

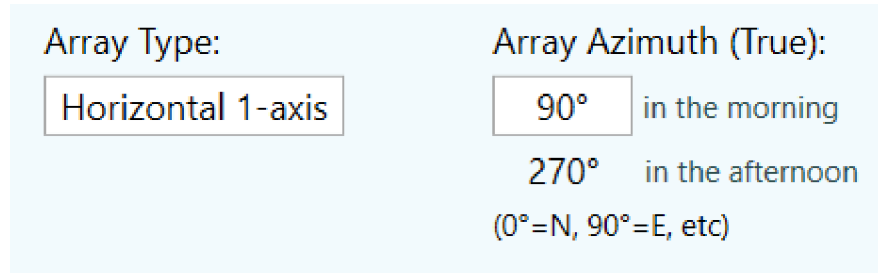
The Site Info screen has a special feature for horizontal single-axis tracking systems, which allows the I-V curves to be taken while the tracker is working. This has the advantage of taking all of your measurements at the greatest possible irradiance level. The user enters the morning azimuth of the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

The setup for a fixed array is shown in Figure 36. [filename is fixed array]



**Figure 36. Controls in the Site Info screen, set for a fixed array with 180-degree azimuth.**

For a horizontal single-axis tracker with its torque tube running true north-south, set the controls as shown in Figure 37. [filename is horizontal single-axis tracker]



**Figure 37. Settings for a horizontal single-axis tracking system.**

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

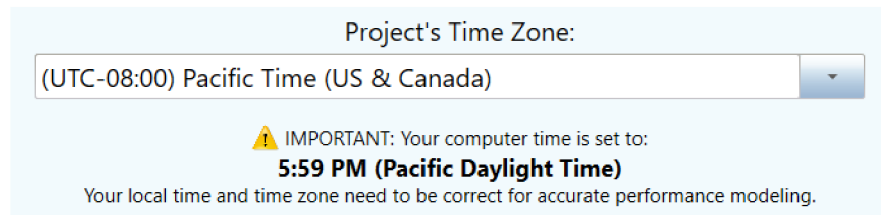
**CAUTION**

*Each measurement you make is stamped with the technician’s PC’s values of time, date, and time zone. These values must be correct for the irradiance sensor to correctly interpret the irradiance, and for the PVA software to correctly calculate the Performance Factor. The time, date, and time zone cannot be corrected after the measurements have been taken.*

*This caution applies to the PC that is controlling the I-V curve measurement process, not the PC on which the PVA project file was originally created. At the start of a measurement session, always be sure the PC’s time, date, and time zone are correct.*

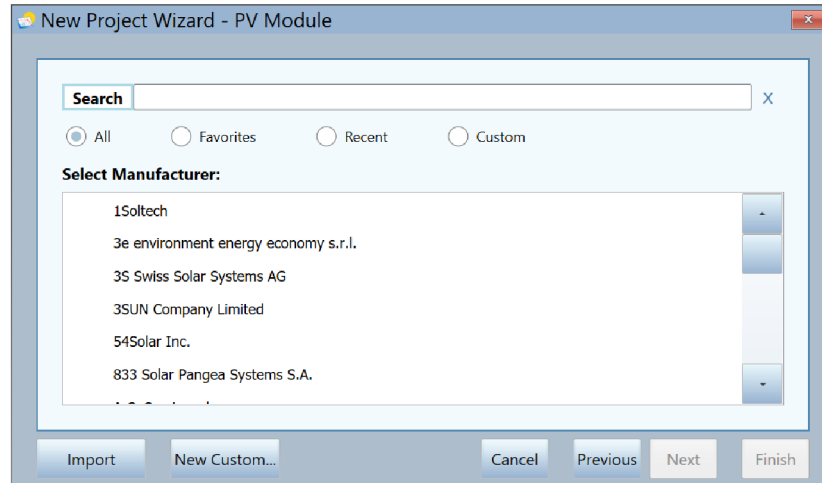
*When the operator launches the software at the PV system site for a day of measurements, the first thing to do is to check the PC’s clock to make sure that the date, time, and time zone are correct.*

In the drop list control, select the time zone of the PV project installation site, as shown in the example in Figure 38. [filename Computer Clock]



**Figure 38. The time zone control in the Site Info screen.**

When the latitude, longitude, azimuth, date, time, and time zone are entered correctly, click **Next** to advance to the PV Module screen, shown in Figure 39.



**Figure 39. The PV Module screen of the New Project Wizard.**

### Selecting your PV Module

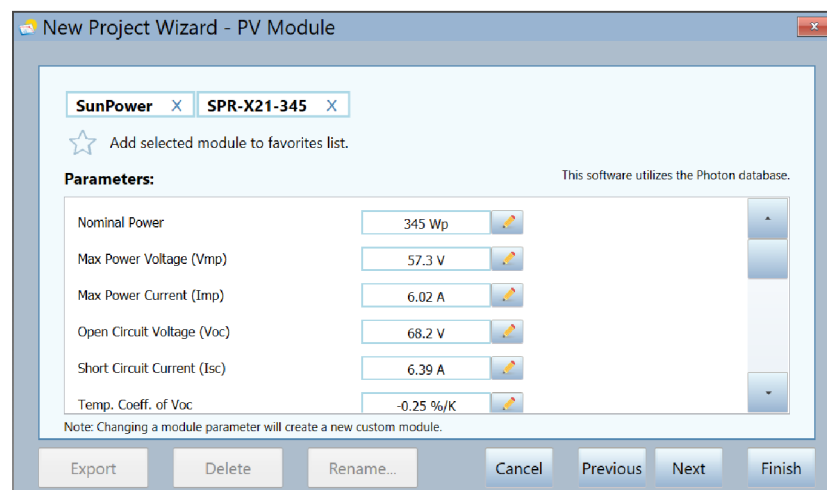
Selecting your PV module (Figure 39) makes the module's performance parameters available to the Project so that the software can calculate the expected I-V curve and the Performance Factor.

Start by typing the name of the manufacturer. When your manufacturer appears in the short list, click on it to select it.

Then repeat that process for the model number of the PV module.

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

After you have selected the model number, the performance parameters for that module appear in the scrolling table, as shown in Figure 40.

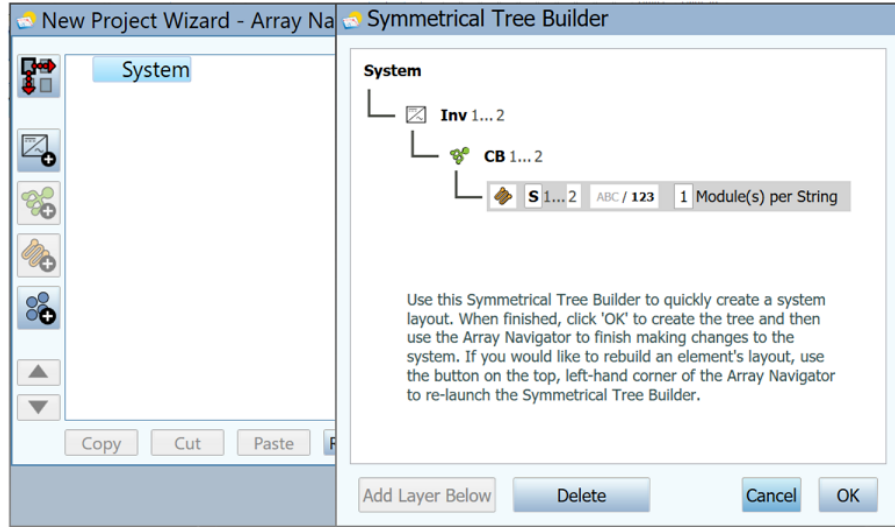


**Figure 40. Selection of the PV module's manufacturer and model number, and corresponding list of module performance parameters.**

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

**Creating the System Tree**

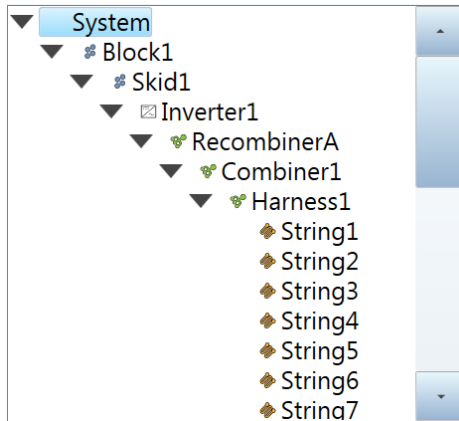
When you have finished selecting or editing your PV module, click Next to advance to the final step in the New Project Wizard, shown in Figure 41.



**Figure 41. Array Navigator with Symmetrical Tree Builder. This is the final step in creating a Project.**

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

An example of a finished array tree is shown in Figure 42. For clarity, the names of the 'layers' of the tree have been completely spelled out. In practice you should abbreviate the names so that the 'tree' fits in the horizontal space of the display.

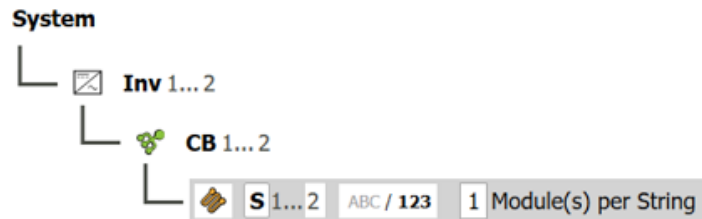


**Figure 42. Finished array tree for a utility PV field.**

The process of creating your tree has two parts. First, use the Symmetrical Tree Builder screen (shown in Figure 43) to create the basic structure of the tree. If it is a large utility-scale project, the design is likely to be modular, and in this first screen you will describe that modular, ‘symmetric’ structure that repeats again and again across the field. The second part of the process is to use the Array Navigator screen, which appears when you click **OK** on the Tree Builder, to customize your tree.

### Using the Symmetrical Tree Builder

The Symmetrical Tree Builder opens with a default system tree, shown in Figure 43.



**Figure 43. The default system tree in the Symmetrical Tree Builder.**

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

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

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

Name the layers to agree with the naming conventions used in your engineering drawings, so that there will be no confusion about where measurements were made.

Try not to use more ‘non-electrical’ layers than necessary (‘block’, ‘field’, ‘parking lot’, etc.). Also, abbreviate the names of the layers to keep them as short as possible. This is important because it will allow more of the layer’s ‘path name’ to appear in the software display.

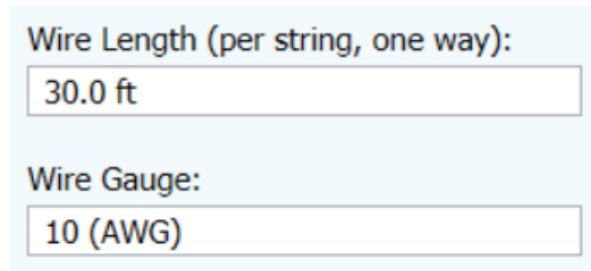
In each layer there are editable fields, which appear with white background when you highlight a layer. Use these fields to customize the name of the layer (for example, change Combiner to Harness), to change the quantity, to use numbers or letters, and in the case of strings, to indicate the number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

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

Try not to use more 'non-electrical' layers than necessary ('block', 'field', 'parking lot', etc.). Also, abbreviate the names of the layers to keep them as short as possible. This is important because it will allow more of the layer's 'path name' to appear in the software display.

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

When you have finished editing the structure of your tree, you can edit the array's string wiring properties. The controls are shown in Figure 44.



**Figure 44. Controls for editing the string wiring properties of your array tree.**

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

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

---

**TIP:**

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

---

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

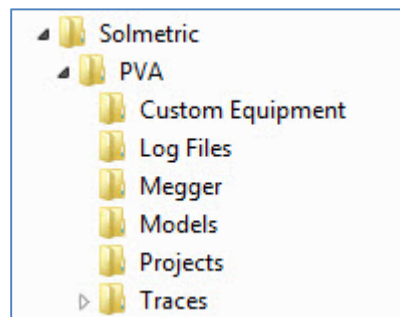
When you are finished creating your system tree, click **Finish** and save your Project.

---

## Cloning, Modifying, and Reusing a Previous Project

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

1. If you are not sure where to find the Projects folder, launch the PVA software, open the **File** menu, click on **Browse Project...**, and you will see the path to the Projects folder.
2. Navigate to your Projects folder, as shown in Figure 45.



**Figure 45. Directory structure used by the PVA software**

3. Highlight the Project file you want to recycle, and copy and paste it.
4. Rename the copy with the name of your new project.
5. From the PVA software **File** menu, select **Browse Project...**, and navigate to the new Project file.
6. Use the screens in the Properties menu to edit the Project as needed. You will need to delete all of the data to avoid confusion with the new data. The easiest way to do this is to delete the inverters and build a new tree.

### ***Properties Menu***

The Properties menu, shown in Figure 46, enables you to view and edit the settings of the currently loaded Project. The items in this menu access the same screens that appeared in the New Project Wizard. See the File Menu/New Project... section for details on the use of these screens. [filename is Properties Menu].

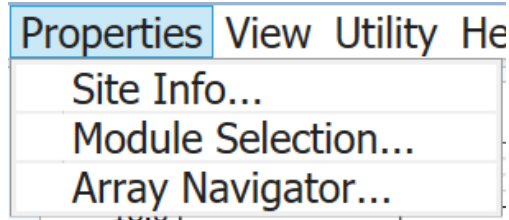


Figure 46. Properties Menu

***View Menu***

***Trace view options...***

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

- I-V Measured current vs. voltage curve
- I-V (STC) Measured current vs. voltage curve translated to STC
- P-V Power vs. voltage curve calculated from measured I-V curve.
- Inverter Green shading indicating the max power voltage tracking range for the selected inverter.

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

***Show Meg Test Tab***

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

***Utility Menu***

The Utility Menu provides access to housekeeping functions and miscellaneous tools. The Utility Menu is shown in Figure 47 and described in Table 9.

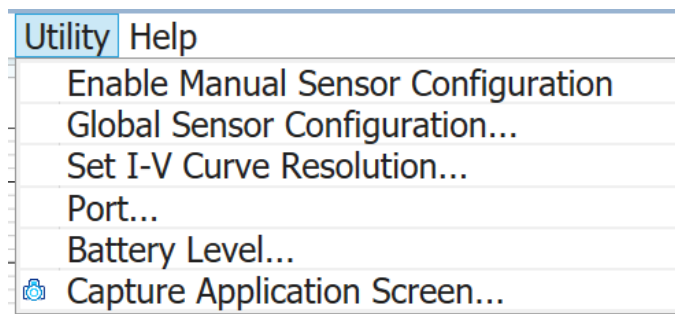
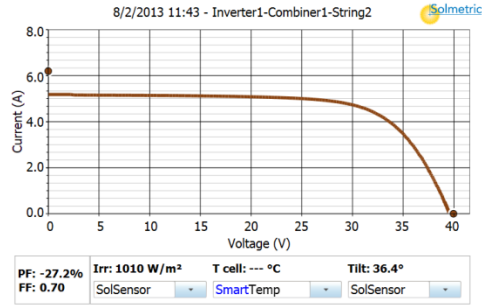


Figure 47. Utility Menu, used to control housekeeping functions.

**Table 9. Utility menu description**

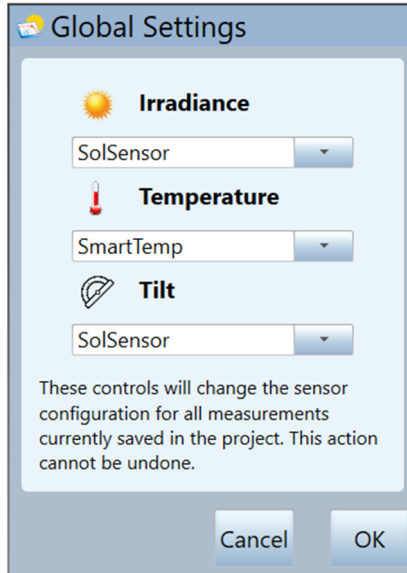
Name	Description
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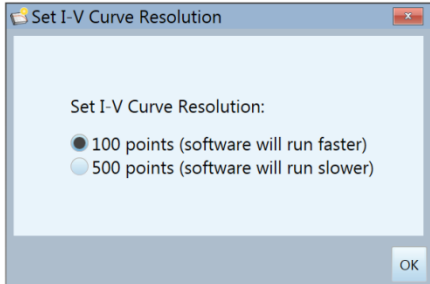
**Enable manual sensor configuration** Check this menu item to display, as shown here the controls for selecting your irradiance, temperature, and tilt sensing options. See Chapter 6 [Measuring Irradiance, Temperature, and Tilt](#) for guidance on sensor choices.



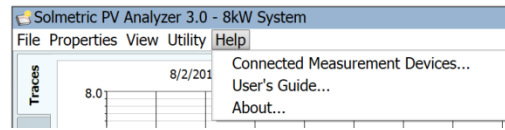
**Global Sensor Configuration...** The controls shown in the figure below allow you to change the sensor choices for all of the measurements currently saved in the project. Select the desired sensors from the dropdown lists. **CAUTION: This action cannot be undone. Create a backup file before taking this action.**

See Chapter 6 [Measuring Irradiance, Temperature, and Tilt](#) for information on your sensor choices.



Name	Description
<b>Set I-V Curve Resolution...</b>	<p>Displays controls for selecting the number of measurement points in your I-V curve. Select 100 points for commissioning and most troubleshooting. Select 500 points for some research and more detailed troubleshooting applications. The resolution can be changed at any time, and will remain in effect for subsequent measurements, until you change it again.</p> <p>The software responds much more quickly when using 100 points.</p> 
<b>Ports...</b>	<p>This menu item appears only in the software for the PVA-1000S and PVA-600+, where the control is used to identify the COM port into which the wireless USB adapter is plugged.</p>
<b>Battery Level...</b>	<p>To check the battery voltage, select <b>Battery Level...</b> in the Utility menu, or just click on the Status indicator any time the indicator is displaying <b>Ready</b>. Battery voltages are also listed in many of the popup messages that accompany status and disable messages. The battery voltage at which the unit will shut down is also reported.</p> <p>In the PVA-1500S software, the battery levels of both the I-V Measurement Unit and SolSensor 300 are reported. In the PVA-1000S and PVA-600+ software, only the I-V Unit voltage is reported.</p> <p>The instruments shut down when the battery voltage has dropped to a preset lower limit. A warning appears in the software approximately one hour before the shutdown.</p> <p>The shutdown voltage levels are:</p> <p>PVA-1500S I-V Measurement Unit and SolSensor 300: 3.05V</p> <p>PVA-1000S, PVA-600+, and original SolSensor: 2.9V</p> <p>The type of Lithium ion battery used in these instruments has a very square discharge curve, so there is relatively slight variation in battery voltage from the fully charged state to the shutdown level.</p>
<b>Capture Application Screen</b>	<p>Captures and saves the currently displayed screen.</p>

**Help Menu**



**Figure 48. Help Menu**

**Table 10. Help menu description**

Name	Description
<p><b>Connected Measurement Devices...</b></p>	<p>The figure below shows the network diagram, which represents your PC, I-V Measurement Unit, SolSensor, and the WiFi signal levels between them. The SolSensor always communicates indirectly, through the I-V Unit.</p>
<p><b>User's Guide</b></p>	<p>Accesses the PVA User's Guide. The guide can be downloaded and printed if desired; a hard copy of the guide is not provided with the products. In addition, the User Guide is available in the Support page of the Solmetric website, under Downloads.</p>
<p><b>About</b></p>	<p>Accesses the software version number and software build date. Please have this information ready if you call Solmetric about your PVA.</p>

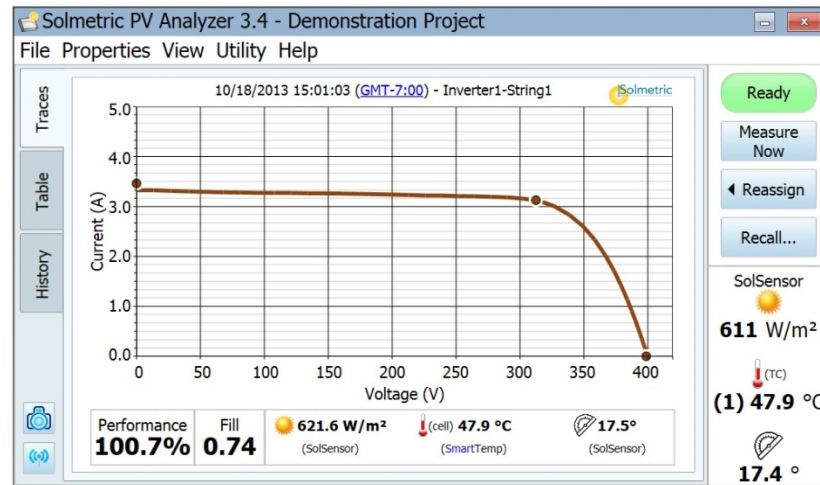
## Using the Tab Screens

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

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

### Traces Tab

Displays the most recent measurement results along with the predicted shape of the I-V curve (if a PV model is selected). Figure 49 is an example of the Traces tab screen.



**Figure 49. Traces tab, showing the measured I-V curve and the expected locations of Isc, maximum power point, and Voc.**

The graph area can display four types of information, selectable by the user from the View menu:

- I-V curve. This solid red curve displays the measured I-V points transmitted from the I-V Measurement Unit. Points below 0 V are not displayed.
- I-V curve prediction markers. The three red dots are the predicted I-V points for the short circuit current  $I_{sc}$  ( $I_{sc}, 0$ ), the maximum power point ( $I_{mp}, V_{mp}$ ), and the open circuit voltage  $V_{oc}$  ( $0, V_{oc}$ ).
- P-V curve. This solid blue curve displays the power available from the test device (module or string), calculated from the I-V curve by multiplying  $I \times V$  for each I-V point. The blue point marks the maximum value on the P-V curve. This value is calculated by fitting a mathematical curve to the top of the P-V curve and then calculating the maximum value of the fitted curve. This reduces the

impact of electrical noise on measurement accuracy. The location of the blue marker is not derived from the PV model.

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

**Table 11. Traces tab description**

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

Name	Description
<b>Measuring (in Status indicator)</b>	During a measurement, the <b>Measuring</b> label blinks.
<b>Assign and Save Reassign</b>	<p>Before the PV model points for a new measurement can be displayed on the I-V graph, the measurement must be assigned or saved to a location in the System Tree in the Array Navigator. This allows the model to 'read' information it requires from the Tree, such as the number of PV modules in a string, and the wiring characteristics. Follow these steps.</p> <ol style="list-style-type: none"> <li>1. After a fresh measurement is taken, the I-V curve is displayed, and the System Tree is temporarily displayed alongside it.</li> <li>2. Click the location in the System Tree at which the measurement was taken. Then use the Assign and Save button to save your data to that location. If you want the model points to appear but don't want to save the trace, just click the <b>Assign</b> button.</li> </ol> <p>After a measurement has been saved, the <b>Assign and Save</b> button becomes the <b>Reassign</b> button. Click the <b>Reassign</b> button if you accidentally saved a measurement to the wrong location in the system tree. When the tree appears, just click on the correct location and then click <b>Assign and Save</b> again. The location will change and the Measurement ID above the I-V curve will show the new location.</p>
<b>Recall Measurement...</b>	Recalls measurement data from the system tree. When the tree appears, click on the location of interest. If more than one measurement is stored at that location, click on the Date/Time of the measurement of interest and then click <b>Recall Measurement</b> .
<b>Paused (in Status indicator)</b>	<p>Displayed when the I-V measurement process is Paused. In this state, PV source connections may be changed without interrupting a measurement.</p> <hr/> <p><b>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.</b></p> <hr/>
<b>Disabled (in Status indicator)</b>	<p>Displayed when a problem exists other than communication between the PC and I-V Measurement Unit. Problems could be related to low battery, over current, over voltage, over temperature, reversed polarity, and so on. No measurements can be taken while in this state.</p> <p>When "Disabled" is displayed, click on the status indicator or the question mark icon for information to aid in troubleshooting the problem.</p>

Name	Description
<b>Searching for I-V Unit</b> <b>(in Status indicator)</b> <b>PVA-1500S</b>	<p>When this is displayed, click on the question mark icon for tips on establishing your connection. This status should change to Ready within seconds of connecting your PC to the I-V Unit's WiFi hot spot. If there is a problem it is typically because they are out of wireless range of one another, or you connected with a different I-V Unit that was in the same vicinity (uncommon).</p>
<b>No USB Wireless</b> <b>(in Status indicator)</b> <b>PVA-1000S, PVA-600+</b>	<p>Check that the USB wireless adapter is plugged into a port on your PC, and that the correct COM port is selected in the Utility menu.</p>
<b>No I-V Unit</b> <b>(in Status indicator)</b> <b>PVA-1000S, PVA-600+</b>	<p>Displayed when communication between the I-V Measurement Unit and the USB wireless adapter at the PC is not established. Click on the question mark icon for information to aid in troubleshooting the problem.</p> <p>The most common reasons for this state include wireless out-of-range, or the I-V Measurement Unit has turned itself off after 15 minutes in the Paused condition to conserve battery power.</p>
<b>SolSensor Displays</b>	<p>If SolSensor is turned on and within wireless range, its sensor values are displayed in the lower right corner of this screen.</p> <p>If the SolSensor 300 is turned off or out of wireless range of the I-V Unit, Searching for SolSensor is displayed in this area. If the original SolSensor (PVA-100S or 600+) is turned off or out of wireless range of the PC, or the wireless USB adapter is not</p> <p>If two thermocouples are connected to SolSensor, both temperatures will be displayed as shown below. However, it is most common to use only a single thermocouple.</p> <p>If two thermocouples are connected to SolSensor, both temperatures will be displayed as shown below.</p> <p>If a PV model and a Project have not yet been created, the irradiance value is a preliminary value and the value is displayed in gray, italic font as shown here:</p> <div style="text-align: center;"> <p>Irradiance  <i>1030 W/m<sup>2</sup></i></p> <p>T backside  <b>(1) 55.8 °C</b>  <b>(2) 54.1 °C</b></p> <p>Tilt  <b>36.4 °</b></p> </div> <p>The preliminary irradiance value is an estimate of the actual irradiance, because without a Project, the software does not know how the irradiance sensor is oriented and cannot apply full correction for sun angle effects.</p> <p>Once a Project is created and loaded, irradiance is</p>

Name	Description					
	<p>displayed in black, regular font, as shown here:</p> <div style="text-align: center;"> <p>Irradiance  <b>1031 W/m<sup>2</sup></b></p> <p>T backside  <b>(1) 55.8 °C</b>  <b>(2) 54.1 °C</b></p> <p>Tilt  <b>36.4 °</b></p> </div>					
<p><b>Searching for SolSensor</b>  <b>(in SolSensor display area)</b>  <b>PVA-1500S</b></p>	<p>Displayed if the SolSensor 300 is turned off or out of wireless range of the I-V Unit, or the PC has not yet connected to the I-V Unit hotspot.</p>					
<p><b>No SolSensor</b>  <b>(in SolSensor display area)</b>  <b>PVA-1000S, PVA-600+</b></p>	<p>Displayed if SolSensor is turned off or out of wireless range of the PC. However, if the wireless USB adapter is not plugged in, or that COM port is not selected in the Utility menu, the message will be No USB Wireless.</p>					
<p><b>Summary Bar</b></p>	<p>Located directly below the displayed I-V curve, the Summary Bar displays the results of the currently displayed measurement.</p> <div style="border: 1px solid black; padding: 5px; margin: 10px 0;"> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px;">Performance <b>100.5%</b></td> <td style="padding: 2px;">Fill <b>0.74</b></td> <td style="padding: 2px; text-align: center;"> <b>622.5 W/m<sup>2</sup></b>  <small>(SolSensor)</small> </td> <td style="padding: 2px; text-align: center;"> <b>47.9 °C</b>  <small>(SmartTemp)</small> </td> <td style="padding: 2px; text-align: center;"> <b>17.4°</b>  <small>(SolSensor)</small> </td> </tr> </table> </div> <p>The Performance Factor represents the measured maximum power value as a percentage of the value predicted by the PV model.</p> <p>The Fill Factor (FF) is an indication of the squareness of the I-V curve (a more square 'knee' of the curve indicates greater efficiency of conversion from sunlight to electric power). It is defined as <math>(I_{mp} \times V_{mp}) / (I_{sc} \times V_{oc})</math> and is discussed in detail in Chapter 7 Interpreting Measured I-V Curves.</p> <p>Irradiance, temperature, and tilt are also displayed.</p>	Performance <b>100.5%</b>	Fill <b>0.74</b>	<b>622.5 W/m<sup>2</sup></b> <small>(SolSensor)</small>	<b>47.9 °C</b> <small>(SmartTemp)</small>	<b>17.4°</b> <small>(SolSensor)</small>
Performance <b>100.5%</b>	Fill <b>0.74</b>	<b>622.5 W/m<sup>2</sup></b> <small>(SolSensor)</small>	<b>47.9 °C</b> <small>(SmartTemp)</small>	<b>17.4°</b> <small>(SolSensor)</small>		

**Table Tab**

Presents summaries of the predicted and measured I-V data and a translation of the measurement results to Standard Test Conditions. Figure 50 is an example of the Table tab screen. This section describes the table itself. See the Traces Tab section for explanations of other controls and displays on this screen.

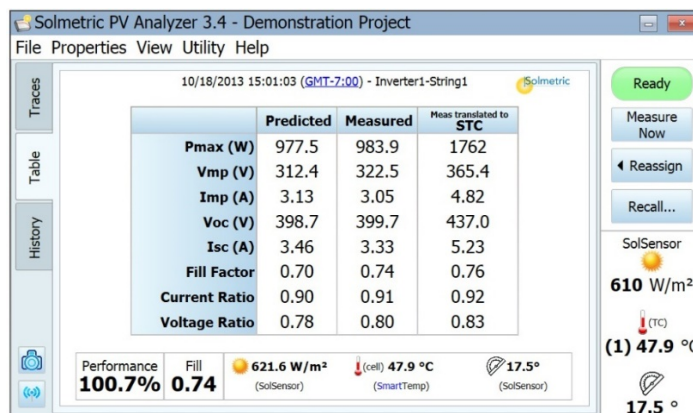


Figure 50. Table tab

Table 12. Table tab description

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

Name	Description
	Chapter 7 - Interpreting Measured I-V Curves.
<b>Irradiance, temperature and tilt</b>	The irradiance, temperature, and tilt associated with the current measurement are displayed in the Summary Bar, directly below the table.

**History Tab**

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

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

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

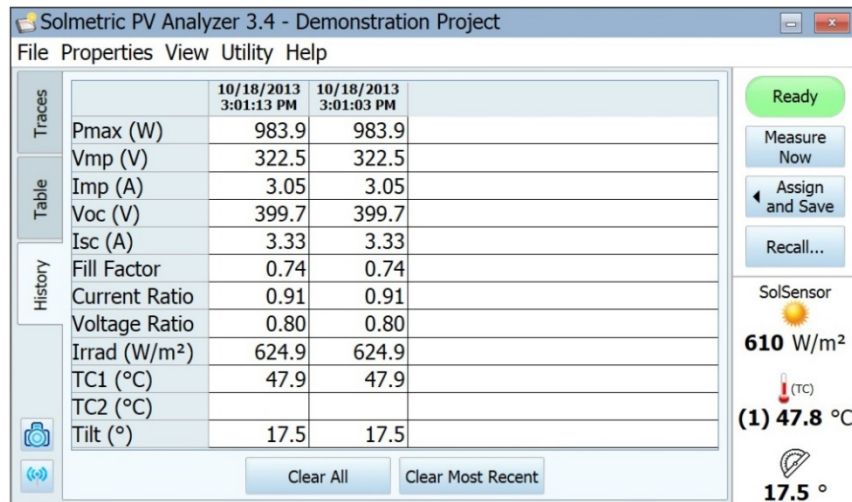


Figure 51. History tab

## Meg Test Tab

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

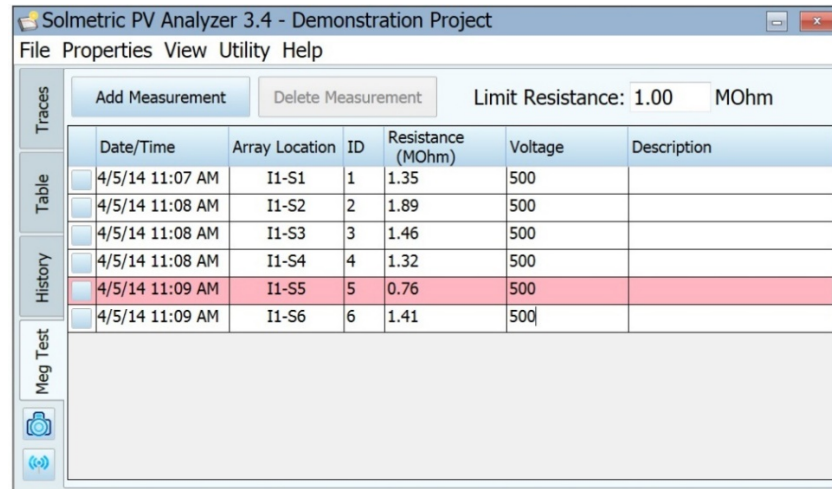


Figure 52. Meg Test tab

Table 13. Meg Test tab description

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

Name	Description
<b>Voltage</b>	The voltage at which the insulation resistance was measured. Click in this field to enter the value manually.
<b>Description</b>	Optional description of the device under test.

---

## Description of the Exported I-V Data File

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

PV Analyzer users typically analyze their measurement results using the Solmetric I-V Data Analysis Tool (DAT), which automates the analysis and reporting process. To use the DAT, you will first export your Project data from the PV Analyzer, and then import it into the DAT.

When you export Project data, the PVA software creates a Windows folder tree on your hard drive that has the same hierarchy as your Network Navigator system tree. Your I-V trace data is exported to this folder structure in the form of comma separated value (.csv) files. If you measured strings of PV modules but did not save measurements of the individual modules in the strings, the lower-level directories in your folder structure will contain the string I-V trace .csv files.

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

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

Figure 53 shows the header information section of the csv file, and the following table describes its contents.

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

**Figure 53. Header Information section of the exported csv file**

**Table 14. Description of the Header Information section of the exported csv file**

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

Figure 54 shows the cardinal values of the measured and predicted I-V curves. The abbreviations represent maximum power, maximum power voltage and current, open circuit voltage, and short circuit current.

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

**Figure 54. The Measurement vs. Model section of the exported csv file**

Below Figure 55 shows the SolSensor Measurements section of the exported csv file, and the table that follows describes the contents. All of the values were recorded at the time the I-V measurement was made.

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

Figure 55. The SolSensor Measurements section of the exported csv file

Table 15. Description of the SolSensor Measurements section of the exported csv file

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

Figure 56 shows the Model Details section of the exported csv file, and Table 16 that follows explains the contents.

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

**Figure 56. Model Details section of the exported csv file**

**Table 16. Description of the Model Details section of the exported csv file**

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

Item	Description
Module Model	Model number of the PV module
# of Modules in String	Number of modules connected measured in series.
# of Strings in Parallel	Number of strings measured in parallel.
Inverter Mfr	Manufacturer of the inverter.
Inverter Model	Model number of the inverter.
Wire AWG	Wire gauge of the conductors between the point of measurement and the PV source.
Wire Length	Length (one-way, in ft) of the conductors between the point of measurement and the PV source.

Below Figure 57 shows the voltage, current, and power data saved from the measurement. The number of entries depends on the I-V curve resolution selected by the user for this particular measurement.

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

**Figure 57. The voltage, current, and power data from the I-V measurement**

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## Basis of PV Performance Predictions

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

### ***SolSensor Irradiance Calibration***

The SolSensor factory calibration process involves this sequence of steps:

- Calibration of the electronic tilt sensor.
- Calibration of the angular response of the irradiance sensor.
- Calibration of irradiance measurement at air mass 1.0-1.5 and normal incidence, relative to a pair of matched reference sensors
- The unique calibration coefficients are stored in SolSensor and are transmitted to the PC software on demand.

### ***Irradiance Measurement***

SolSensor measurement of irradiance involves these steps:

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

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

### ***Prediction of PV Performance***

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

- User creates a Project and inputs all of the required parameters, including selection of their PV module from the built-in equipment database.
- The model predicts  $I_{sc}$ ,  $I_{mp}$ ,  $V_{mp}$ , and  $V_{oc}$  for the current values of irradiance and temperature.
- Under low light conditions, the prediction is adjusted based on 200W/m<sup>2</sup> performance data in the database.
- The Performance Factor – the ratio of measured  $P_{max}$  to predicted  $P_{max}$  - is calculated and expressed in percent.

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

### ***Translation of Measured Values to STC***

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

### ***Measurement of $I_{sc}$***

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

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

# 4 Making Measurements

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## Introduction

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

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## Before you go to the field to make measurements

### ***Charge the equipment***

Before going to the field to make measurements, charge both the I-V Measurement Unit and SolSensor overnight. The equipment typically runs for 8 hours on a charge. Turn the equipment off when not in use.

### ***Check that you are using the latest PVA software***

Double click the PVA icon on your PC and the software will start. Click on About in the Help menu to make sure that you have selected the right version of software for the version of PVA hardware that you will be using. The PVA-1500 uses version 4.x software, and the PVA-1000 and PVA-600+ use version 3.x software. To check the latest available version number, visit <http://www.solmetric.com/downloads-pva.html>.

### ***Create a Project in the PVA software.***

See the earlier chapters in this User Guide for instructions.

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

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

### ***Make sure you have all your equipment***

#### Personal Protective Equipment

I-V Measurement Unit in its soft case, with a complete set of Solmetric-provided gear in its gear pouch. The pouch should contain PVA test leads, wireless USB adapter (not needed for PVA-1500S), PVA software on a flash drive, and PV connector tools.

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

### ***Assure adequate irradiance for your measurements***

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

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

---

## Making Measurements in the Field

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

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

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

### ***Connect the test leads to the PVA***

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

Connect the alligator clips to the ends of the test leads.

### ***Launch the PVA software***

Double click the PVA icon and the software will start. Make sure that you have selected the version of software that works with your version of the hardware. To check the software version, click About in the Help menu. The PVA-1500 uses version 4.x software, and the PVA-1000 and PVA-600+ use version 3.x software.

### ***Load your Project***

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

### ***Insert the wireless USB adapter (PVA-1000S and PVA-600+)***

Insert the USB adapter in a COM port

Make sure that COM port is the one that's selected in the Utility menu in the PVA software.

### ***Mount SolSensor***

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

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

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

### ***Attach SolSensor thermocouple***

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

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

Straighten the bare tip of the thermocouple lead. The tiny ball at the end is where temperature is measured.

Place the thermocouple tip in contact with the back of the module. Choose a location that is away from the cooler outer edges of the array.

## 4 Making Measurements

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

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

Press and release the pushbutton LED.

When the PVA-100S or PVA-600+ connects to the wireless USB adapter plugged into your PC, the Status indicator in the upper right corner of the PVA software displays Ready.

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

### ***Turn on SolSensor***

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

The original SolSensor connects to the wireless USB adapter plugged into your PC.

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

### ***Prepare the PV source circuits for measurement***

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

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

### ***Connect the test leads to the PV equipment***

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

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

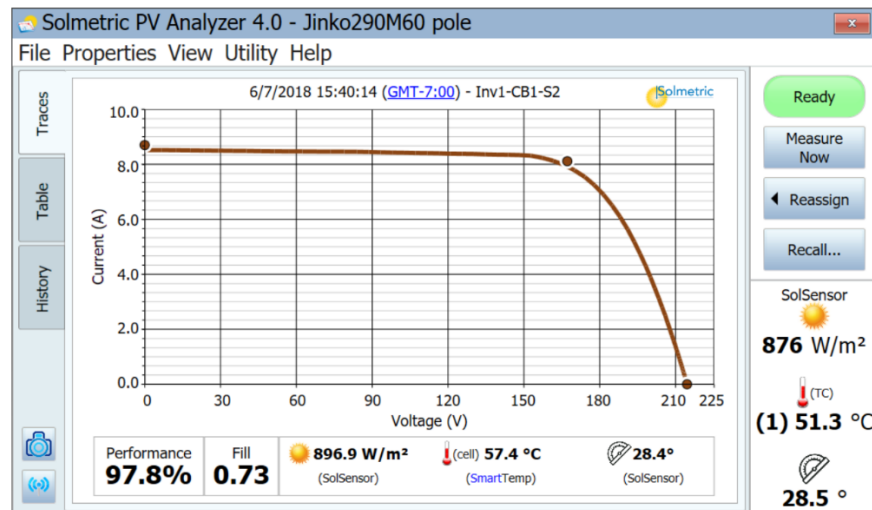
If measuring circuits in parallel (for example ‘harnessed’ strings), make sure the combined current is within the specified current range of the I-V Measurement Unit. Note that in some locations, the irradiance can greatly exceed 1000 watts per square meter. If that is the case and the modules are directly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

### **Select the first PV circuit to be measured**

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

### **Make your first measurement**

Refer to Figure 58



**Figure 58. Results of an I-V curve measurement**

Press the **Measure Now** button. The measured trace will typically appear in 5-20 seconds. The time is longer for the PVA-1000S, to allow for more self-cooling of the I-V Unit between measurements (higher voltage PV strings deliver more energy to the I-V Unit with each sweep than was the case with earlier, lower voltage versions of the PVA). The duration of the actual I-V data acquisition sweep is typically less than 1 second.

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

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

## 4 Making Measurements

with the predictions of the PV model, instead press the **Assign Only** button. The Array Tree closes and the I-V curve expands to its full width.

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

**NOTE:** Does the I-V curve end long before reaching down to the horizontal axis? Or does the I-V curve appear to be made up of several long straight lines? If so, just press Measure Now again and save just the newer I-V curve. This can happen on the first measurement of the session, or if the string under test has very different electrical behavior from the ones you measured before it. It is a side effect of a feature in which the PV Analyzer keeps improving its performance by learning from the previous measurements.

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

### ***Select the next PV circuit and take another measurement***

Lift the previous fuse and insert the next one.

Repeat the above steps to make and save your measurement.

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

### ***View the consistency of your data before moving on***

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

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

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

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

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

***From time to time, back up your data***

The PVA software will remind you to back up your data. Always do this. It is possible for PVA Project files to become corrupted. Also create a backup when you are finished measuring a PV installation. Select Backup Project... from the File menu.

## 4 Making Measurements

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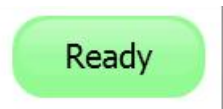
## 5 Troubleshooting PVA Operation

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

---

### Troubleshooting Using Status Messages

Your main tool for troubleshooting PVA operation is the Status indicator, shown in Figure 59 and discussed in this chapter.



**Figure 59. Status indicator**

---

**WARNING**

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

---

#### *"Ready" message*

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

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

#### *"Initializing" message*

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

### *"Measuring" message*

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

### *"Disabled" message*

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

- Wireless USB version is incompatible

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

- I-V Measurement Unit battery voltage is too low

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

- Current in excess of xxA was detected

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

- Excess voltage was detected

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

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

- I-V Measurement Unit is too hot

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

- Current overload pulse

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

### ***"Paused" message***

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

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

### ***"No USB Wireless" message***

This means that the PC cannot find the wireless USB adapter used to communicate with the I-V Measurement Unit and SolSensor. Plug the USB adapter into an open USB port. You may need to go to the Utilities menu, select Settings, and follow the instructions to locate the USB adapter. Be aware that each I-V Measurement Unit is matched with the USB adapter it was shipped with; mixing them up will make communications impossible. Matching USB adapters to I-V Measurement Units allows multiple PV analyzers to be used on large projects without disturbing each other's wireless links. The PVA-1500S does not require a wireless USB adapter.

### ***"No I-V Measurement Unit" message***

In this case, the PC has found the wireless USB adapter, but cannot communicate with the I-V Measurement Unit. If the I-V Measurement Unit is switched off, turn it ON. If the LED is blinking quickly, the I-V Measurement 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 Measurement Unit are within wireless range of one another. The PVA-1500S does not require a wireless USB adapter.

### ***Searching for I-V Unit***

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

### ***Searching for SolSensor***

This message appears in the SolSensor data display area when SolSensor 300 has not yet established its WiFi link to the PVA-1500S I-V Unit. Make sure the SolSensor 300 is

turned on and that it is within wireless range. Obstructions in the line-of-sight can also reduce wireless range. Also make sure that you are using the SolSensor 300 that was shipped from Solmetric with that particular I-V Unit; they are permanently paired at the factory.

---

## Troubleshooting by Symptom

### ***"No I-V Measurement Unit" message***

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

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

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

### ***SolSensor parameter values are not displayed***

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

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

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

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

This may occur with the PVA-1000S or PVA-600+ when the I-V Unit or SolSensor or both are being physically relocated. The communication path from the PC to each of the instruments may be direct or indirect (one instrument relays the signal to the other).

Indirect links allow operation at greater distances from the PC, but the network may be unavailable for 10-20 seconds during the switch between direct and indirect.

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

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

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

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

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

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

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

***I-V trace consists of straight line segments***

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

***Trace is noisy***

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

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

This can occur if there is a noisy connection in the PV circuit being measured. This is not a problem with the I-V Measurement Unit.

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

Verify that the irradiance sensor is mounted in the plane of the array. Check for array soiling.

***Unstable voltage message***

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

***I-V Measurement Unit cannot be turned on***

Check that the Unit has been charged.

***Thermal fuse***

The I-V Measurement Unit contains a thermal fuse set to trip 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](mailto:support@solmetric.com)

# 6 Measuring Irradiance, Temperature, and Tilt

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## Introduction

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

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

Measuring irradiance presents a number of requirements and challenges:

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

Each of these topics is discussed in this chapter.

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

- The PV cell is embedded in other materials, so a surface temperature measurement is not possible.

## 6 Measuring Irradiance, Temperature, and Tilt

- The materials in which the PV cell is embedded have poor thermal conductivity, so there can be substantial temperature drop between the cells and the module's outer surfaces.
- Temperature offset between PV cell and module backsheet depends on racking configuration and ventilation.
- Temperature is not uniform across a PV module or array, due to variations in racking configuration and ventilation.
- Temperature at a given location may vary with time, even at constant irradiance, due to convection currents and wind.
- An air gap between a backside temperature sensor and the actual backside surface results in significant temperature error.
- Massive temperature sensors, particularly bulky RTD devices, do not track rapid changes in module temperature.
- Surface and material issues limit the accuracy of infrared temperature measurements.

These topics are all discussed in this chapter.

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

**Table 17. Sensor Choices**

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

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

---

## Measuring Irradiance with SolSensor

### ***SolSensor irradiance sensor***

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

### ***Preliminary Irradiance***

SolSensor irradiance measurement is further calibrated according to the PV model parameters for the selected PV module. If a Project and model have not yet been created, SolSensor values do not receive this further calibration, and are considered 'preliminary irradiance' values. In this situation, the irradiance value is displayed in italics. Once the Project and model are created, the irradiance is displayed in normal font. Expect to see slight differences between preliminary and final irradiance.

### ***SolSensor Precautions***

#### ***Covering the Irradiance Sensor***

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

---

**WARNING**

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

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#### ***Cleaning the Irradiance Sensor***

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

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**WARNING**

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

---

### ***Orienting and mounting the irradiance sensor***

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

See Setting Up SolSensor for details on mounting SolSensor on the module frame.

---

**NOTE**

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

---

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

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

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

### ***Albedo effects***

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

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

### ***Diffuse light***

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

SolSensor irradiance sensor is corrected for angular effects. One of the benefits of this correction is better performance under diffuse light conditions.

---

## Determining Irradiance from the Measured I-V Curve

When you select the From I-V option, the PVA software calculates irradiance from the measured I-V curve. This option has several benefits and limitations. The limitations are due to the fact that because the resulting irradiance value is an input to the PV model, the dot locating the predicted value of  $I_{sc}$  is forced to agree with the measured value of  $I_{sc}$ .

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

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

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

- Uniform soiling is interpreted as reduced irradiance and thus does not cause a deviation between the measured and predicted I-V curves. You can mitigate this risk by inspecting the array before measuring, and cleaning it if needed.
- Similarly, uniform degradation of module  $I_{sc}$  is also interpreted as reduced irradiance, and thus is not detected. The From I-V temperature option provides several benefits:

### ***Entering Irradiance Manually***

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

- It is often difficult to accurately orient hand-held irradiance sensors in the plane of the array.

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

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## Measuring PV Module Backside Temperature with a Thermocouple

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

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

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

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

- The model by which temperature is determined from  $V_{oc}$  is valid only at relatively high irradiance. At low irradiance, there is substantial error in the derivation of temperature.
- Shorted bypass diodes are interpreted as lower cell temperature. You can mitigate this risk by comparing  $V_{oc}$  values between strings or modules under test. Values should be fairly consistent. If a single string shows a deviation of more than about 10-12 volts, a bypass diode may be turned on or shorted.

### ***Selecting a thermocouple wire gauge***

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

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

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

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

### ***Selecting a thermocouple tip***

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

### ***Selecting a tape for thermocouple attachment***

A good tape for this application will:

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

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

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

### ***Attaching the thermocouple to the module backside***

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

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

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

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

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

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

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

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

## Measuring PV module temperature with an infrared thermometer

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

Since the IR thermometer determines temperature by sensing radiant energy emitted by the object being measured, the accuracy of the temperature measurement depends on how closely the emissivity control setting of the instrument matches the actual emissivity of the object. The emissivity of a material is a measure of its relative ability to emit energy through radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature. A true black body would have an  $\epsilon = 1$  while any real object would have  $\epsilon < 1$ . In general, the duller and blacker a material is, the closer its emissivity is to 1. The more reflective a material is, the lower its emissivity. Highly polished silver has an emissivity of about 0.02.

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

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

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

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

## Determining Cell Temperature from the Measured I-V Curve

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

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

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

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

- The model by which temperature is determined from  $V_{oc}$  is valid only at relatively high irradiance. At low irradiance, there is substantial error in the derivation of temperature.
- Shorted or conducting bypass diodes are interpreted as lower cell temperature. You can mitigate this risk by comparing  $V_{oc}$  values between strings or modules under test. Values should be fairly consistent. If a single string shows a deviation of more than about 10-12 volts, a bypass diode may be turned on or shorted.

## Using SmartTemp to Measure Cell Temperature

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

- At irradiance values lower than 400W/m<sup>2</sup>, temperature is obtained from the backside thermocouple.
- At irradiance values greater than 800W/m<sup>2</sup>, temperature is calculated using the **From I-V** method.
- At irradiance values between 400 and 800W/m<sup>2</sup>, the PVA software progressively shifts between the thermocouple and From I-V methods.

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

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

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# 7 Interpreting Measured I-V Curves

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## Introduction

A PV module, string, or array has a characteristic curve of current versus voltage; the “I-V curve”. The I-V curve represents the entire family of current and voltage pairs at which the PV circuit can be operated or loaded. The PV analyzer’s mathematical models predict the shape for this curve for thousands of different PV modules and configurations. Occasionally the shape of the measured I-V curve will deviate substantially from the shape predicted by the model. These substantial deviations from the predicted I-V curve shape contain information about the performance of the PV System. This section describes the most common patterns of deviation and identifies possible causes for these deviations.

---

## Inputs to the PV Model

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

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

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

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## I-V Curve Terminology

These abbreviations will be used in the following discussion:

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

### ***Performance Factor***

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

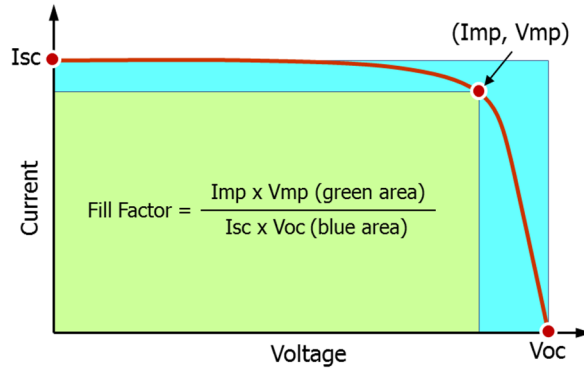
The predicted maximum power value is determined by the PV model, which takes into account the current values of irradiance and temperature. This means that Performance Factor values taken at different irradiances and temperatures can be directly compared. Like most array performance measurements, the comparison is more accurate if the irradiance levels are high. Performance measurements taken at less than 400W/m<sup>2</sup> irradiance are not good predictors of how the string will perform at high irradiance.

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

### ***Fill Factor***

The Fill Factor is a valuable measure of the square-ness of the I-V curve. It is defined by three points on the I-V curve, as shown in Figure 60. The Fill Factor range is 0 to 1.0, and the closer the Fill Factor is to 1.0, the more square is the shape of the I-V curve. Each PV

technology has its own nominal range of fill factor values, and each module model number typically has an even narrower nominal range.

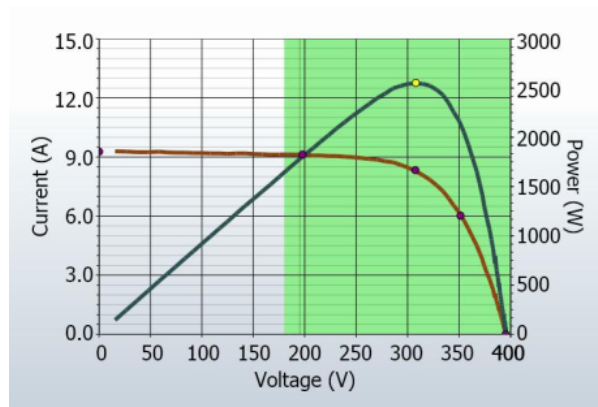


**Figure 60. Definition of the Fill Factor.**

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

## The Shape of a Normal I-V Curve

Figure 61 below shows a normal I-V curve (red line), as a starting point for the discussion. The predicted I-V curve shape, determined by the PVA built-in PV model, is shown by the three dots. The power versus voltage curve is also displayed (blue line). Like the I-V curve itself, the P-V curve represents the entire family of points at which the PV circuit could be operated or loaded. The P-V curve is generated by multiplying  $I \times V$  for at every point on the I-V curve.



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

## 7 Interpreting Measured I-V Curves

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

1. A slightly sloped region above 0 V (the horizontal leg of the curve)
2. A steeply sloped region below  $V_{oc}$  (the downward leg of the curve)
3. A bend or 'knee' in the curve between these two regions

In a normal curve, the three regions are smooth and continuous. The shape and location of the knee depends on cell technology and manufacturer. Crystalline silicon cells have sharper knees; thin film modules usually have more gradual knees.

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

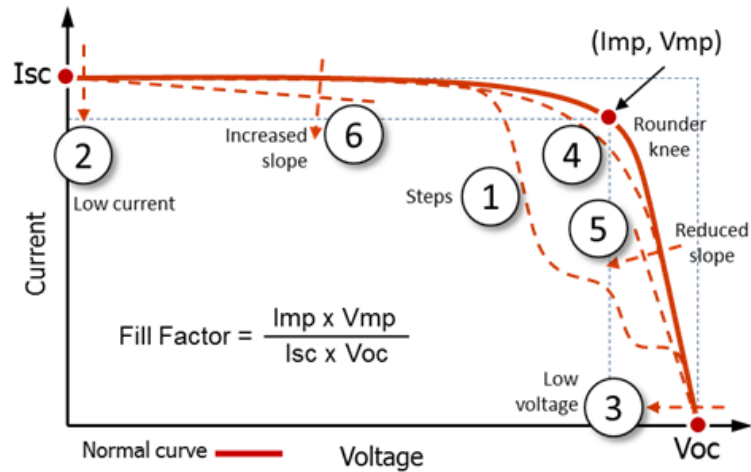
- SC – First point, at the predicted short circuit current  $I_{sc}$
- MP – Second point, the predicted maximum power point  $I_{mp}$ ,  $V_{mp}$
- OC – Third point, at the predicted open circuit voltage  $V_{oc}$

---

## Interpreting I-V Curves

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

1. Notches or steps
2. Low Current
3. Low voltage
4. Rounder knee
5. Steeper slope in horizontal leg
6. Less steep slope in vertical leg



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

It would be convenient if each of the I-V curve deviations illustrated in Figure 62 corresponded to a unique physical cause. In fact, there are multiple possible causes for each.

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**NOTE**

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

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

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

## 1. Notches or steps

Examples of this type of deviation are shown in Figure 63, Figure 64, and Figure 65.

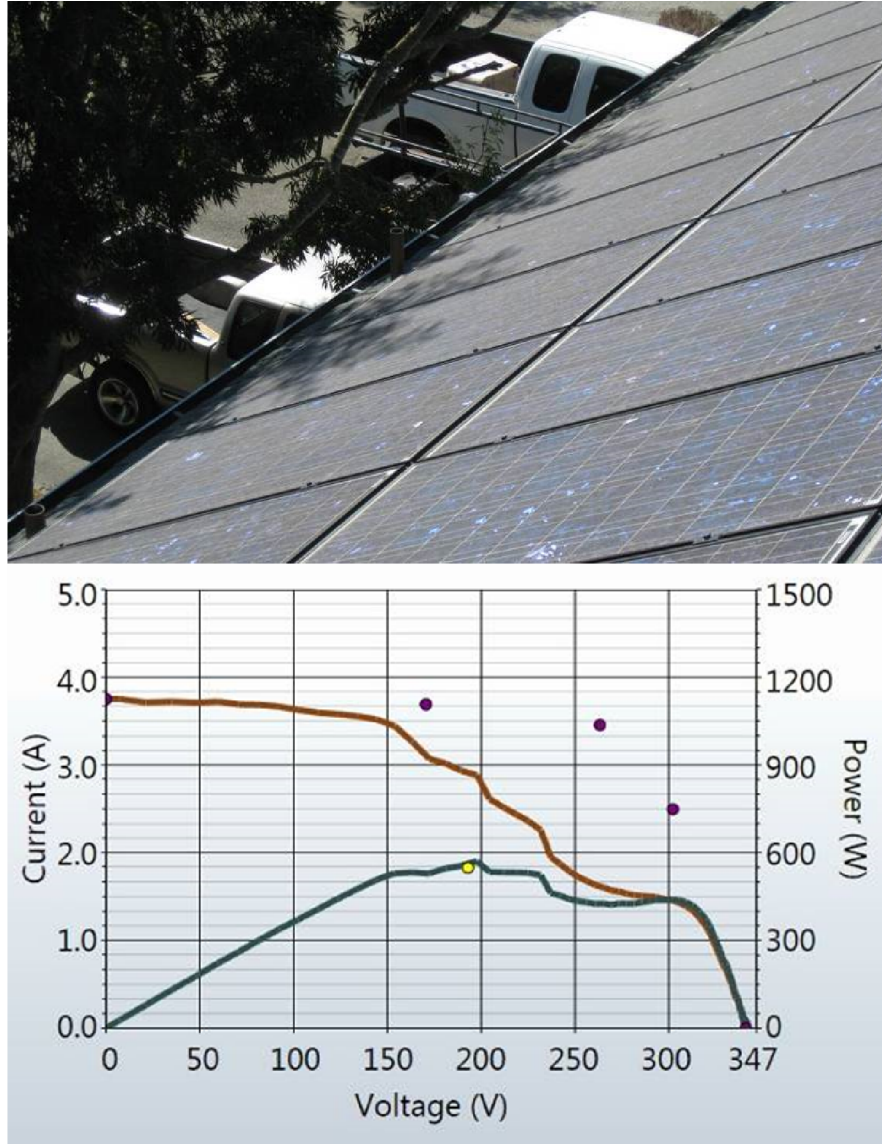
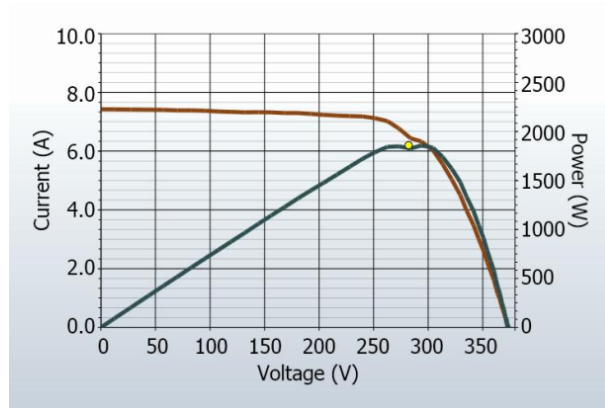
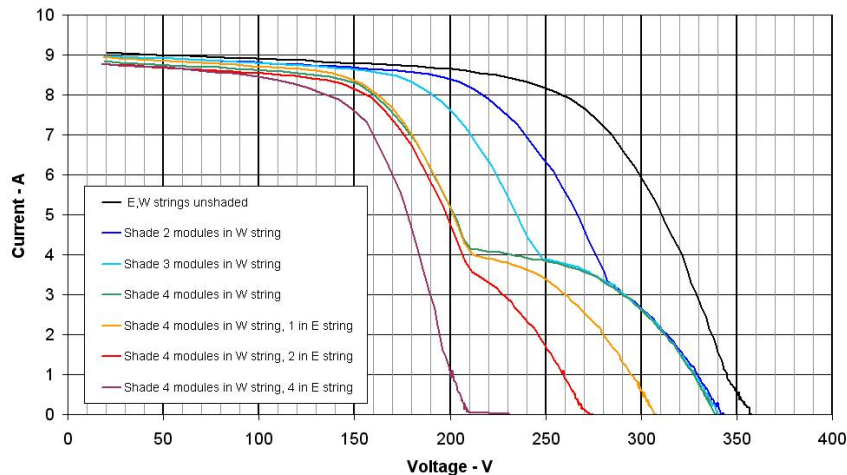


Figure 63. The effect of partial shading on a string I-V curve.



**Figure 64. The shading impact of placing a business card on a single cell in a string of fifteen 180-watt modules**



**Figure 65. The effect of intentionally shading entire modules in different combinations, in two parallel-connected strings**

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**NOTE**

The graphic shown in Figure 65 is an overlay of several I-V curve measurements.

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

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

Potential causes located in the array include:

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

- Bypass diode is short-circuited

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

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

### ***PV Cells Are Damaged***

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

### ***Cell String Conductor Is Short Circuited***

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

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## 2. Low Current

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

Potential causes located in the array include:

- Uniform soiling
- Strip shade
- Dirt dam

- Module degradation

Potential causes associated with the model settings include:

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

Potential causes associated with irradiance or temperature measurements include:

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

### ***Uniform soiling***

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

### ***Strip shade***

### ***Dirt dam***

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

### ***Module Degradation***

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

### ***Incorrect PV Module Is Selected for the PV Model***

PV modules with similar PV model numbers may have different  $I_{sc}$  specifications. Check that the module you selected from the on-board module list matches the nameplate on the

back of the PV modules. If the array is known to have a mix of PV modules of different types, this can also contribute to changes in  $I_{sc}$ . Mixed modules can also cause a mismatch effect, another class of deviation discussed later.

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

The measured value of  $I_{sc}$  scales directly with the number of strings in parallel. Check that the correct value is entered into the model.

### ***Irradiance Changed Between Irradiance and I-V Measurements***

The time delay between the irradiance measurement and the I-V measurement can translate into measurement error. The error is greatest when the sky conditions are not stable (for example, partially cloudy) and a manual irradiance sensor is being used. The process of orienting the manual sensor, noting the value, and entering the value into the PVA software takes much more time than the automated process used by SolSensor.

### ***Irradiance Sensor Is Not Oriented in the Plane of Array***

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

### ***Albedo Effects (reflection) Contribute Additional Irradiance***

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

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

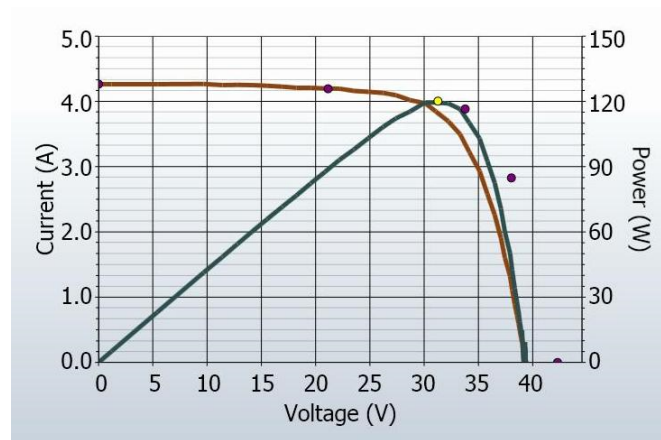
Most PV modules exhibit changes in the shape of their I-V curves under low light conditions. This effect tends to set in below  $600 \text{ W/m}^2$  and becomes quite significant below  $400 \text{ W/m}^2$ . Also, if sunlight is hitting the module surfaces at a glancing angle - early or late in the day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

### ***Manual Irradiance Sensor Is Not Accurate***

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

## 3. Low voltage

An example of this type of deviation is shown in below.



**Figure 66. Measurement with less steep than predicted slope in the vertical leg of the I-V curve.**

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

Potential causes located in the array include:

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

### ***PV Cell Temperature Is Hotter than the Measured Temperature***

The module  $V_{oc}$  is dependent on the temperature of the solar cells, with higher temperatures resulting in a lower  $V_{oc}$ . It is possible that a poor thermal connection exists between the temperature measurement device and the back of the module. Also, if the temperature measurement is taken on the front side of the module, direct sunlight on the temperature sensor could result in erroneous temperature readings. It is also possible that

the PV module under test has a poor thermal connection between the back of the module and the actual PV junction.

### ***One or More Cells or Modules Are Completely Shaded***

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

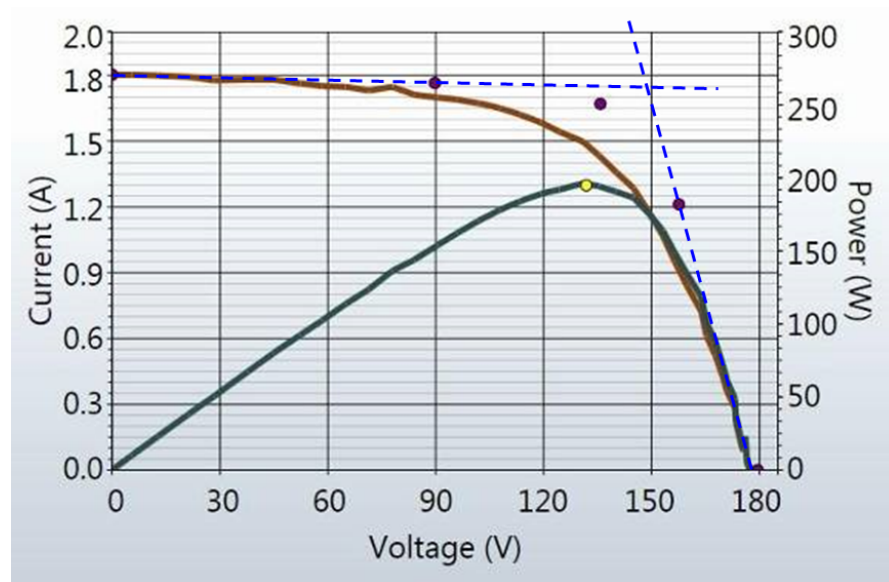
### ***One or More Bypass Diodes Are Conducting or Shorted***

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

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## 4. Rounder knee

An example of this type of deviation is shown below.

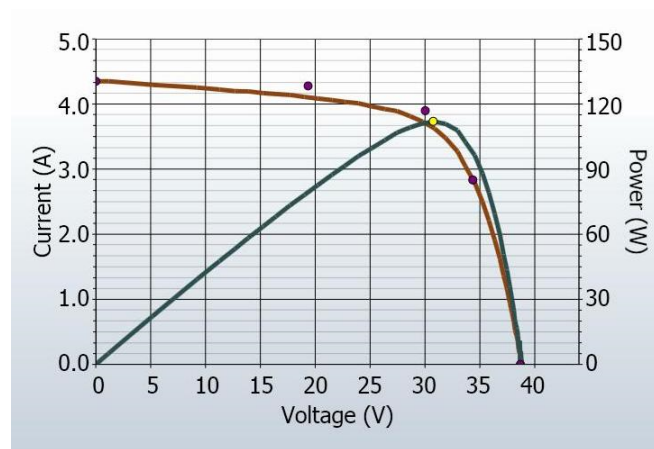


**Figure 67. I-V curve measurement showing rounder knee than predicted by the PV model.**

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

## 5. Steeper slope in horizontal leg

An example of this deviation is shown below.



**Figure 68.** An I-V curve showing steeper slope in the horizontal leg of the I-V curve.

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

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

Potential causes located in the array include:

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

### ***Shunt Paths Exist in PV Cells or Modules***

Shunt current is current that bypasses the solar cell junction without producing power, short circuiting a part of a cell or module. Some amount of shunt current within a solar cell is normal, although higher quality cells will have a higher shunt resistance and hence lower shunt current. Shunt current can lead to cell heating and hotspots appearing in the

## 7 Interpreting Measured I-V Curves

module encapsulant material. Shunt current is typically associated with highly localized defects within the solar cell, or at cell interconnections. Infrared imaging of the PV module can usually identify minor shunt current hot spots since a temperature rise of 20 °C or more is common.

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

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

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

### ***Module $I_{sc}$ Mismatch***

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

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

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

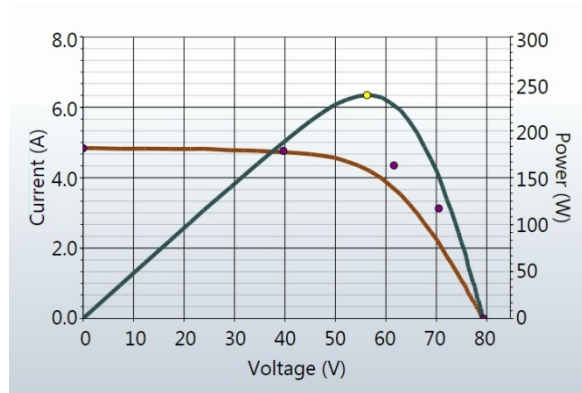
***Tapered shade or dirt dam***

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

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## 6. Less steep slope in vertical leg

An example of this type of deviation is shown below.



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

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

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

Potential causes located in the array include:

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

***PV Wiring Has Excess Resistance or Is Insufficiently Sized***

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

## 7 Interpreting Measured I-V Curves

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

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

### ***Electrical Interconnections in the Array Are Resistive***

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

### ***Series Resistance of PV Modules Has Increased***

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

## 8 Translation of I-V Data to Standard Test Conditions

The PVA PC software provides a feature for translating the displayed I-V curve to Standard Test Conditions (STC) of  $1000\text{W}/\text{m}^2$  and  $25\text{ }^\circ\text{C}$ . The software also translates the key performance parameters in the Table view (tab).

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

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

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### Parameter definitions

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

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

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

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

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

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

$\alpha_{I_{sc}}$  = Normalized temperature coefficient for  $I_{sc}$ , ( $\%/^\circ\text{C}$ ). This parameter is ‘normalized’ by dividing the temperature dependence ( $\text{A}/^\circ\text{C}$ ) measured for a particular standard solar spectrum and irradiance level by the module short-circuit current at the standard

## 8 Translation of I-V Data to Standard Test Conditions

reference condition,  $I_{sc}$ . Using these (%/°C) units makes the same value applicable for both individual modules and for parallel strings of modules.

$\alpha_{I_{mp}}$  = Normalized temperature coefficient for  $I_{mp}$ , (%/°C). Normalized in the same manner as  $\alpha_{I_{sc}}$ .

$\beta_{V_{oc}}$ , (%/°C) = Temperature coefficient for module open-circuit-voltage.

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

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

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## Definition of the translation process

The basic translation model used here makes the following approximations:

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

In light of these approximations we make these assumptions:

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

$V_{oc}$  varies linearly with temperature according to  $\beta_{V_{oc}}$ .

$P_{mp}$  scales with E and varies with temperature according to  $\gamma_{mpp}$

$V_{mp}$  changes with temperature depending on  $\gamma_{mpp}$  only, since  $\alpha_{I_{mp}}$  is much smaller than  $\alpha_{I_{sc}}$  and is assumed to be zero.

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

$$V_{oc\,trans} = V_{oc\,m} / \{1 + \beta_{V_{oc}} / 100 * (T_m - T_{trans})\}$$

$$I_{sc\,trans} = I_{sc\,m} * [E_{trans} / E_m] / \{1 + \alpha_{I_{sc}} / 100 * (T_m - T_{trans})\}$$

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

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

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

