User Training Webinar
Solmetric PVA-1000S
I-V Curve Tracer

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Recorded PVA Webinar Series

**Introduction**
Solmetric PVA-1000S I-V Curve Tracer

**User Training**
Solmetric PVA-1000S I-V Curve Tracer

**Data Analysis and Reporting**
Solmetric PVA-1000S I-V Curve Tracer

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Topics

- Introduction to I-V curves and the Solmetric PV Analyzer
- Equipment setup & measurement process
- Creating your ‘Project’ in the PVA software
- Using the PVA software
- Measuring irradiance & temperature
- Troubleshooting PV strings
- Data analysis and reporting (preview of separate webinar)
What is an I-V curve?
Basic concept (‘PV-101’)

1. Adjust the load
   (The load type can be resistive, capacitive, or electronic)

2. Measure current & voltage

3. Plot the point

- The PV modules can supply power at any of these operating points.
- The inverter’s job is to find and track the maximum power point, located at the knee of the curve.
- Any deviations from normal curve shape reduce the value of maximum power.
Deviations from normal I-V curve shape

- Reduces project risk by providing more performance information than any other method.
- Any deviation from normal shape reduces the value of Pmax available to the inverter.
- The deviations give us valuable troubleshooting clues (see the Troubleshooting Flowchart).
- Traditional measurements (Isc, Voc) cannot ‘see’ many of these deviations.
I-V curve tracing applications

- Commissioning and re-commissioning
- Performance troubleshooting
  - General use
  - In response to performance alarm (eg. a zone monitoring alarm)
- Performance auditing
  - Periodic performance assessment
  - In connection with bringing on an O&M contractor
  - Establishing value before system changes hands
  - Assessing the performance impact of storm damage
PVA1000S PV Analyzer
Overview

- Measurement range: 1000V, 20A or 30A
- Measured (red curve) vs. predicted (red dots)
- Large, clear displays & touch controls (your PC)
- Wireless interface, 300 foot range (line of sight)
PVA1000 PV Analyzer
Users include...

- EPC’s
- System Integrators
- Consultants & Commissioning Agents
- Training & Education
- O&M and Asset Management
- Electrical contractors
- Module Makers (Perf. Eng. & Warranty)
- Inverter Makers (O&M)
- PV Plane Insurers
- Field Reliability Research
- Laboratories NREL, TUV...

Solmetric
Solar I-V Curves
Interpreting Trace Deviations

Array Layout for Low-Slope Roofs
Designing Commercial Systems for Fire Code Compliance

String Inverter Specifications
140 Inverter Models for North American PV Installations

Projects
Fronius TRAC
Seattle Aquarium
St. Louis Science Center

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Interpreting I-V Curve Deviations
Paul Hernday
SolarPro, Aug/Sep 2014

See also:
Field Applications for I-V Curve Tracers
Paul Hernday
SolarPro, Aug/Sep 2011
PVA set up at a dc combiner box

Courtesy of Chevron Energy Solutions © 2011
SolSensor set up on PV module

- Mounts facing the same direction as the PV module, held in place with a specialized bar clamp.
- Irradiance sensor is the white ‘eye’ at left.
- Temperature sensor (K-type thermocouple) plugs in at right.
How the PVA works

Module electrical parameters (>50,000 modules)
# of modules in series & parallel
Array true azimuth
Irradiance
Module temperature
Array tilt
Latitude
Longitude
Date & time

Model Calculations

3 red dots predict I-V curve shape at operating conditions

I-V data

Wireless

Irradiance
Module temperature
Tilt

PV Source Circuit
‘Live’ demo of the measurement sequence
How the I-V measurement unit works

Simplified diagram

- The PV Analyzer uses a capacitive load for smooth and reliable operation.
- When you trigger the measurement is triggered, the capacitor connects to the PV source circuit.
- As the capacitor charges, the I-V curve is ‘traced’ from $I_{sc} \rightarrow V_{oc}$ in less than 1 second.
- Either 100 or 500 points (I,V pairs) are captured along the way.
Making a Measurement
Step 1: Press *Measure Now*
Making a Measurement
Steps 2 & 3: Click the array tree and save the data
Making a Measurement

Step 4: Review the results

- Performance: 101.0%
- Fill: 0.74
- Power: 622.5 W/m²
- (cell) 47.8 °C
- (SolSensor) 17.4 °C

SolSensor: 611 W/m²
(TC) 47.9 °C
17.4 °C
Performance Factor
The key performance metric

Performance Factor = \frac{P_{\text{max (measured)}}}{P_{\text{max (predicted)}}}

- If measured and predicted Pmax agree, Performance Factor is 100%.
- Even in a new array with healthy modules, not all readings will be 100%. PV modules are not all identical, irradiance and temperature are not exact measurements, cell temperature is not uniform across the modules, and the electrical measurements have slight errors. A newly constructed array should have Performance Factor values in the 90-100% range.
Fill Factor
Key metric for comparing I-V curve shapes

Fill factor is a measure of the square-ness of the I-V curve. A squarer curve (less rounded) means higher output power (and higher module efficiency).

At high irradiance, the value of the fill factor is not strongly influenced by irradiance, making it a great metric for comparing string shapes.

Fill factor is determined entirely by the measured values of Imp, Vmp, Isc, and Voc (see equations). No PV model is required.

Fill factor is easy to understand graphically. Just divide the area of the green rectangle (defined by the max power point) by the area of the blue rectangle (defined by Isc and Voc).

Fill Factor = \( \frac{\text{Imp} \times \text{Vmp} \text{ (watts)}}{\text{Isc} \times \text{Voc} \text{ (watts)}} \)

For the red curve: \( \text{FF} = \frac{7\text{A} \times 39\text{V}}{8\text{A} \times 45\text{V}} = 0.76 \)
Exporting Your Data

The image shows a software interface for exporting data. The menu includes options such as:
- New Project...
- Browse Project...
- Recent Projects
- Export Trace for Active Measurement...
- Export Traces for Entire System...
- Export Meg Test Data...
- Exit

The graph displays voltage (V) on the x-axis and another variable (presumably temperature, T) on the y-axis. The data includes:

- PF: 95.8%
- FF: 0.70
- 1031 W/m²
- (cell) 55.6 °C
- T tilt: 36.4°
The PVA software automatically creates this folder tree on your hard drive (you select the location).

Each string folder contains a data file of a string measurement (csv format).

If you also measured the individual modules that make up the string, there are module-level folders below the string folders.

The free Solmetric I-V Data Analysis Tool (DAT) imports the data from these folders, displays charts and graphs, and generates reports.
Example of the report generated by the Data Analysis Tool
PV module database
Contains approximately 60,000 PV modules

New version of Equipment Module Database available. Do you want to install it?

Yes  No
User Guide
Built-in & hyperlinked, for easy use in the field

1 Introduction
   Overview
   Computer Minimum System Requirements
   PVA-600 Equipment

2 Getting Started
   Precautions
   Understanding the PVA-600
   Installation Procedure
   Special XP Operating System Instructions
   Installing Drivers for the Optional Solmetric Wireless Sensor Kit
   Charging the Battery

3 Using the PVA-600
4 Using the PVA-600 Software
5 Interpreting Measured I-V Curves
6 Measuring Environmental Conditions
7 Translation of I-V Data to Standard Test Conditions
Topics

• Introduction to I-V curves and the Solmetric PV Analyzer
• Equipment setup & measurement process
• Creating your ‘Project’ in the PVA software
• Using the PVA software
• Measuring irradiance & temperature
• Troubleshooting PV strings
• Data analysis and reporting
  (preview of separate webinar)
Measurement Process
Measuring strings at a combiner box

**Setup:**
1. Mount SolSensor
2. Attach thermocouple
3. Open combiner dc disco
4. Lift the string fuses
5. Clip PVA to bus bars

**Measurement:**
1. Insert a string fuse
2. Press “Measure”
3. View and save results
4. Lift the fuse and insert the next fuse

Cycle time is 10-20s per string, including flipping the fuses
Test Process
Example: Measuring strings at a combiner box

**Hardware setup** (do once at each combiner box)

1. Mount SolSensor to PV module and attach thermocouple*
2. Open the combiner DC disconnect
3. Lift the string fuses
4. Clip PVA test leads to the combiner buss bars

**Electrical measurement** (repeat for each string)

1. Insert a string fuse
2. Press “Measure”
3. View and save results
4. Lift the fuse

- This takes 10-15 seconds/string
- Typically, moving between combiner boxes takes more time than the actual testing.

*You may prefer to move SolSensor only needed to maintain wireless connection.
Application Examples
Measuring strings at a combiner box

Photos courtesy of
West Coast Solar Energy
and...

Multi-Contact US HQ
Windsor CA

Charles Shultz Museum
Santa Rosa, CA
Selecting a String to Test
Insert one fuse at a time
Accessing a source circuit means both isolating it and connecting to it.
For a particular system layout, choose the safest and most convenient point of access.
Shut down inverter and open the dc disconnect before accessing PV source circuits.
Access Challenges
Dead-front terminal blocks

- Dead-front terminal blocks make it more difficult to connect the I-V curve tracer.
- Fuse clips can be used as a test point for the ungrounded conductor.
- To create a test point for the grounded conductor, insert a short piece of home-run wire in a spare terminal slot.
- Another approach is to use test probes (for example Fluke FTP-1) in place of one or both alligator clips.
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Creating your ‘Project’ in the PVA software

- The ‘Project’ is a file that contains a description of your PV system and all of your measurement results.
- The Project file concept allows you to conveniently email your results within your company, to your client, or to Solmetric for applications support.
- The recipient sees just what the technician saw in the field.
Creating your ‘Project’
Wizard screen #1 – Site Info

New Project Wizard - Site Info

Acquire Site Info using the online Roof Azimuth Tool or select a city from the list.

Latitude: 38.55°N
Longitude: 122°W
Array Type: Fixed
Array Azimuth (True): 180°

Project's Time Zone:
(UTC-08:00) Pacific Time (US & Canada)

⚠️ IMPORTANT: Your computer time is set to:
5:22 PM (Pacific Daylight Time)
Your local time and time zone need to be correct for accurate performance modeling.
Special settings
for horizontal single axis trackers

For **horizontal single axis trackers**, you have the options of:
1. Parking the array and measuring all strings at the same tilt and azimuth, or
2. Measuring while the tracker is running.

To do #2:
1) Toggle the **Array Type** box to “Horizontal 1-axis”
2) Enter the morning azimuth of the array

At solar noon, the PVA software will automatically flip the azimuth 180-degrees. The tilt of the array is wirelessly reported by SolSensor with each measurement. SolSensor is attached to a module frame or to the torque tube.
Time and Date
Set to local coordinates before making measurements

- The date, time, latitude, longitude, tilt and azimuth are all used to calculate the Performance Factor. The predictive model needs this information.
- Before measuring, be sure your PC is set to the correct local date, time, time zone, and daylight savings status.

<table>
<thead>
<tr>
<th>UTC/GMT Offset (hours)</th>
<th>Pacific time</th>
<th>Mountain time</th>
<th>Central time</th>
<th>Eastern time</th>
</tr>
</thead>
<tbody>
<tr>
<td>DST off</td>
<td>-8</td>
<td>-7</td>
<td>-6</td>
<td>-5</td>
</tr>
<tr>
<td>DST on</td>
<td>-7</td>
<td>-6</td>
<td>-5</td>
<td>-4</td>
</tr>
</tbody>
</table>

www.timetemperature.com
Creating your ‘Project’
Wizard screen #2 – PV Module

New Project Wizard - PV Module

Search

- All
- Favorites
- Recent
- Custom

Select Manufacturer:

- 1Soltech
- 3e environment energy economy s.r.l.
- 3S Swiss Solar Systems AG
- 3SUN Company Limited
- 54Solar Inc.
- 833 Solar Pangea Systems S.A.
- A.C. Solar Inc.

Import   New Custom...  Cancel   Previous   Next   Finish
Selecting the module manufacturer

1) Begin typing the maker’s name to bring up possible hits.

2) Click on your manufacturer’s name when you see it (for example, SunPower).
Selecting the model number

1) Begin typing any part of the model number to bring up possible hits.

2) Click on your model number when you see it (for example, SPR-E20-245-B-AC).

**TIP** Click the Favorites or Recent radio buttons for quick access to modules you have used in previous projects.
View parameters of selected module and edit if needed

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Power</td>
<td>245 Wp</td>
</tr>
<tr>
<td>Max Power Voltage (Vmp)</td>
<td>40.5 V</td>
</tr>
<tr>
<td>Max Power Current (Imp)</td>
<td>6.05 A</td>
</tr>
<tr>
<td>Open Circuit Voltage (Voc)</td>
<td>48.8 V</td>
</tr>
<tr>
<td>Short Circuit Current (Isc)</td>
<td>6.43 A</td>
</tr>
<tr>
<td>Temp. Coeff. of Voc</td>
<td>-0.254 %/K</td>
</tr>
</tbody>
</table>

Values can be edited

Note: Changing a module parameter will create a new custom module.
Full list of PV Module Parameters

The built-in PV module database contains approximately 60,000 module types.

All 17 of the PV model parameters can be edited. Editing allows you to:

- Create modules that are not yet in the database
- Adjust values to match datasheet values, if necessary
- Multiply the values of nominal power and current by the number of strings you are testing in parallel (harnessed strings).

There are two methods for setting up the project for harnessed (parallel) strings.
1. Multiply Pnom, Isc, Imp, and Imp(w00W/m2) by the number of strings in parallel, or
2. Build your harness into the Array Navigator ‘tree’
There are two methods for setting up the project for harnessed (parallel) strings.

1. Multiply Pnom, Isc, Imp, and Imp(w00W/m2) by the number of strings in parallel, or
2. Build your harness into the Array Navigator ‘tree’
Creating your ‘Project’
Wizard screen #3 – Create your ‘tree’

Use this tool to create the repeating, symmetrical architecture of your PV field.
Example ‘tree’

In this example, the system has 2 skids, each with 4 inverters, each with 4 combiners, each with 6 harnesses, each with 4 parallel strings, each with 14 modules.

To add a layer click Add Layer Below. All white fields in a layer are editable.

If there are non-symmetries in your system, ignore them for now and customize the tree in the next (Array Navigator) window.

**TIP** Your first time, write out the names and quantities beforehand to ‘debug’ it.
‘Array Navigator’ screen
Use it to customize your ‘tree’

The choices below apply to everything at or below the level you highlight.

# Modules per String:
14

Wire Length (per string, one way):
30.0 ft

Wire Gauge:
10 (AWG)
Editing tools
Use these to customize your ‘tree’

Replaces the highlighted branch of the tree, and all layers below it, with a new structure (also opens the Symmetrical Tree Builder for you to build the new structure).

Adds an inverter below the selected layer.

Adds a combiner below the selected layer.

Adds a string below the selected layer.

Adds a ‘group’ below the selected layer.

Shifts the selected layer (and everything below it) up or down in the tree.

Why would you want to edit your tree?
1) Rename layers
2) Customize for bipolar system to separately represent the positive and negative strings in the combiner box
3) Expand the system
4) Etc.

TIP You can also copy, cut, paste, rename and delete any layer or item in the tree.
Topics

• Introduction to I-V curves and the Solmetric PV Analyzer
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• Data analysis and reporting (preview of separate webinar)
‘Live’ Demo of the PVA Software

This is an actual demonstration of the software, except that for indoor teaching purposes we use previously stored measurements.
Topics

- Introduction to I-V curves and the Solmetric PV Analyzer
- Equipment setup & measurement process
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- Using the PVA software
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Maximizing wireless range

- To optimize wireless range, mount SolSensor in a location that has a clear line of sight to your PC.

- In fixed tilt arrays, mount SolSensor on an upper edge or on an end where it can see your PC as you move between combiner boxes.

- Avoid placing the transmitter or the receiver on metal surfaces. This will dramatically reduce the wireless range.

- Mounting SolSensor on a tripod is another option. SolSensor has camera mount threads on its backside. Be sure to orient SolSensor to the tilt and azimuth of the array.
Why measure irradiance & temperature? Important factors determining PV output

- As shown by these graphs, irradiance and temperature have a big effect on PV output power.
- For crystalline silicon modules, the maximum power rises with increasing irradiance and drops with increasing temperature.
- In order to predict what our measured I-V curve SHOULD look like, we need to know the irradiance and module temperature were at the time of the I-V curve measurement.
When our sensor measurements are not accurate, it’s an apples-to-oranges comparison! It can lead us to believe a healthy string of modules is underperforming, or an underperforming string is healthy. It’s just not a fair or useful comparison.

When our expected I-V curve shape (3 red dots) is based on accurate irradiance and temperature data, comparing it to our measured curve is an apples-to-apples comparison.

**Why Measure irradiance & temperature?**

Important factors determining PV output.
What is irradiance?
Irradiance components

Irradiance is defined as the solar power incident on a flat surface divided by the area of the surface. The units of irradiance are watts per square meter (W/m²). The irradiance incident on a PV array has three components:

**Direct light** – light arriving in a straight line from the sun

**Diffuse light** – light scattered to array modules by clouds or particles in the atmosphere

**Albedo** – light reflected off objects or surfaces within view of the array

It’s important that our irradiance sensor have the same ‘view’ of these different components as the array that is being tested.
As shown in this day-long recording, when the diffuse light increases, the direct light decreases.

When does this happen?

- Clouds near or blocking the sun
- Overcast
- Heavy haze or smog

Notice that there is still some diffuse light even in the early morning when the blue curve is smooth. This is expected. Even a clear sky has some water vapor that scatters a small fraction of the light.
It’s an overcast, hazy day. This tree is slightly to the north of our horizontal (zero tilt) array. Is the tree blocking some of our sunlight?

Perhaps you think ‘NO’ because it is not in the direct path of the sun’s rays.

The answer is ‘YES’ because under these diffuse light conditions, the light is arriving nearly equally from all directions in the sky.

If we mount our irradiance sensor near this tree, it will see less light than the modules in our array (assuming a large array).

Try to mount SolSensor in a location that has the same view of the whole sky as the array itself.
Recommended weather conditions
For *performance* measurement

- **High and stable irradiance**
  - Ideally >800 W/m², not lower than 400 W/m².
  - The I-V curve of cSi changes shape at low light, especially below 400, making it a less useful predictor of performance at high irradiance.
  - Stable irradiance means less irradiance & temperature error due to time delay between I-V and irradiance measurements, and less distortion of the I-V curve due to irradiance variation during data acquisition.

- **4-5 hour window centered on solar noon**
  - For good irradiance level and reduced angle of incidence effects
  - [http://www.esrl.noaa.gov/gmd/grad/solcalc/](http://www.esrl.noaa.gov/gmd/grad/solcalc/)

- **Little or no wind**
  - To reduce temperature-related performance variation
  - Higher cell temperature $\rightarrow$ lower Voc
Why **stable** conditions?

Instability → measurement error

- If there is any time delay between the I-V and irradiance measurements, irradiance variations during that time interval cause **irradiance errors that are random in both magnitude and direction**.

- The greater the time delay, or the steeper the irradiance ramp, the greater the irradiance error.

- There is no way to correct or 'back out' these random errors during data analysis.

- The same type of error affects temperature measurement, but to lesser degree because temperature ramping is slower, and the dependence of performance on temperature is less profound.

In the PVA, the I-V and sensor measurements are wirelessly triggered **simultaneously**.
Selecting sensor methods

The PVA provides several methods for determining irradiance and several for module temperature. Click this menu item and the options will appear in drop boxes below the I-V graph.
Irradiance measurement options

Overview

**SolSensor** is the default method. It uses SolSensor’s built-in silicon photodiode sensor.

The **From I-V** method calculates the irradiance from the measured I-V curve, relying primarily on Isc but also involving Voc.

The **Manual** method enables the user to manually enter irradiance values that are obtained from another source when SolSensor is not available.
Irradiance measurement options
Strengths and limitations of the options

The **SolSensor** option uses SolSensor’s built-in silicon photodiode sensor. It’s spectral response is similar to crystalline silicon solar cells, and software-based spectral corrections adapt it to other common solar cell technologies. The sensor is also corrected for angular effects and is temperature compensated. **Use this method for all serious performance measurements.**

The **From I-V** method calculates the irradiance from the measured I-V curve, relying primarily on $I_{sc}$ but also involving $V_{oc}$. This option eliminates the need for the hardware based measurement of irradiance, but is not accurate if the array is soiled or significantly degraded.

The **Manual** method enables the user to manually enter irradiance values that are obtained from another source when SolSensor is not available. It saves deploying the irradiance sensor, but takes much more time for manual data entry. Also, under unstable irradiance conditions, the time delay between I-V curve and irradiance measurements translates into irradiance error.
Temperature measurement options

Overview

**SmartTemp** is the default method. It is a blend of the thermocouple (TC) and **From I-V** methods. When irradiance is above 800W/m² **SmartTemp** uses only **From I-V**, and below 400W/m² it uses only the thermocouple data. Between those irradiance levels, **From I-V** and thermocouple values are blended in changing proportion. Use this or the **TC** method for serious performance measurements.

**TC1, TC2, Avg(TC1, TC2)** are thermocouple methods. SolSensor provides two thermocouple inputs, labeled TC1 and TC2. In most commissioning and O&M work, just a single thermocouple is used. Use this or the **SmartTemp** method for serious performance measurements.

The **From I-V** method calculates the average cell temperature from the measured I-V curve, relying primarily on Voc but also involving Isc.

The **Manual** method enables the user to manually enter temperature values that are obtained from another source when SolSensor is not available.
Temperature measurement options
SmartTemp method

SmartTemp is the default method. It is a blend of the thermocouple (TC) and From I-V methods. When irradiance is above 800W/m$^2$ SmartTemp uses only From I-V, and when irradiance is below 400W/m$^2$ it uses only the thermocouple data. Between those irradiance levels, the From I-V and thermocouple values are blended in changing proportion.
SmartTemp uses the From I-V and TC methods where they are strongest, as shown below:

<table>
<thead>
<tr>
<th>Irradiance</th>
<th>From I-V</th>
<th>Thermocouple</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>(+) Little affected by irradiance variations</td>
<td>(-) Greater temperature offset between backside and cells</td>
</tr>
<tr>
<td>Low</td>
<td>(-) Strongly affected by irradiance variations</td>
<td>(+) Smaller temperature offset between backside and cells</td>
</tr>
</tbody>
</table>

If you plan on measuring a system again and again as the system ages and degrades, the thermocouple option has the advantage over From I-V and SmartTemp that it is not influenced by aging of Voc.
The thermocouple (TC) method determines module temperature from a thermocouple attached to the back of a module. SolSensor provides two thermocouple sockets and you can choose to use one or the other, or both. If Avg(TC1, TC2) is selected, the software uses the average of the two thermocouple values.

Backside surface temperature sensors have a long history in PV array performance measurements, but there are two significant limitations:

1. Temperature is not uniform across PV arrays, so the temperature reported by the thermocouple depends upon where it is attached.

2. The temperature of interest to the PV model is the temperature of the PV cells themselves, not the module backside temperature. Research has shown that cell temperature is typically 3°C warmer than the back surface under high light conditions. For the purposes of the PV model, the PVA software adds 3°C to the thermocouple temperature at 1000 W/m², and scales down the temperature offset at lower irradiance values.

If you plan on measuring a system again and again as the system ages and degrades, the thermocouple option has an advantage over From I-V and SmartTemp in that it is not influenced by aging of Voc.
**Temperature measurement options**

**From I-V method - strengths**

<table>
<thead>
<tr>
<th>From I-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Temp (default)</td>
</tr>
<tr>
<td>TC 1</td>
</tr>
<tr>
<td>TC 2</td>
</tr>
<tr>
<td>Avg(TC1, TC2)</td>
</tr>
<tr>
<td>From I-V</td>
</tr>
<tr>
<td>Manual</td>
</tr>
</tbody>
</table>

The PV model needs to know the PV cell temperature in order to accurately predict the expected I-V curve shape and calculate the Performance Factor. The **From I-V** method provides an indirect measure of the *average cell temperature* of the PV module or string under test.

The **From I-V** method has several advantages:

1. Average cell temperature is the best input to the PV model because it accounts for the unpredictable variation in temperature across any PV array.

2. The temperature determination is simultaneous with measurement of the I-V curve. This eliminates temperature errors related to time delays, which can be a problem under gusty wind conditions or rapidly ramping irradiance.

3. Since the **From I-V** method does not involve a thermocouple, there is no error related to where on the modules the thermocouple is mounted, or temp. drop from cell to backside.

4. In Building Integrated PV applications, it is often not practical to mount a thermocouple on the backside of a PV module. The **From I-V** method eliminates that need.

**IEC 60904-5:2011 describes the preferred method for determining the equivalent cell temperature (ECT) of PV devices (cells, modules and arrays of one type of module), for the purposes of comparing their thermal characteristics, determining NOCT (nominal operating cell temperature) and translating measured I-V characteristics to other temperatures.**

**Solmetric**
The From I-V method has several limitations.

1. Calculation of cell temperature from Voc is reliable at high irradiance levels, but at lower irradiance levels Voc varies increasingly with irradiance, thus introducing a temperature error.

2. The From I-V method calculates temperature using the temperature coefficient of Voc as found on the PV module datasheet. If the PV modules are damaged or degraded in ways that reduce Voc, the calculated temperature will be too hot. Fortunately, in the crystalline silicon technology, Voc has the lowest aging rate of all the PV module parameters.

3. Shorted bypass diodes significantly reduce Voc, resulting in an overly high temperature value.

If you are using the From I-V measurement and you notice a particularly high temperature value, it is good practice to check the measured Voc. If Voc is significantly low compared to the rest of the population of strings, the Voc issue may require troubleshooting.
Temperature measurement options

Manual entry method

The **Manual** method allows the user to enter temperature values obtained from other instruments, such as:

- Hand-held surface temperature meter
- Infrared thermometer or imager
- Monitoring system connected to the PV plant

The manual method has some limitations:

1. It takes time to read and enter the temperature values. Under conditions where irradiance is ramping or the wind is gusting, a time delay between temperature and I-V measurements translates into a temperature error which in turn affects the shape of the predicted I-V curve and the value of the Performance Factor.

2. Other temperature methods may be less accurate or precise than SolSensor’s methods.

3. The time required to manually enter temperature values greatly reduces the number of strings that can be measured in a day’s time. Over a few projects, increased labor costs can add up to more than the purchase cost of SolSensor.
Thermocouple mounting
Choosing your TC mounting location

Avoid mounting your TC at the cooler edges of the array.

In large arrays you may need to move SolSensor from time to stay in wireless range.

When you move SolSensor to a new subarray, mount it in the same relative location.

Why?

Temperature is not uniform across PV arrays, and using a consistent mounting location avoids introducing more variation than necessary into the TC data.

This photo is not the best example because this system is so small that you would not need to move SolSensor to remain in wireless range.
When testing single modules, mount the thermocouple ~2/3 of the way between the corner and center of the module.

Press tape and thermocouple into firm contact with module backside.

For all thermocouple mounting applications, use high-temperature tape (e.g., 1-3/4 inch green Kapton dots**). Electrical tape and cheap big box store duct tape sag at high temperatures, allowing the tip of the thermocouple to break contact with the backside of the module. Even a tiny airgap can cause temperature measurement error.

** MOCAP MCD-PE 1.75” green Kapton poly dots
$80 for a roll of 1000 dots
customerservice@mocap.com
Topics

• Introduction to I-V curves and the Solmetric PV Analyzer
• Equipment setup & measurement process
• Creating your ‘Project’ in the PVA software
• Using the PVA software
• Measuring irradiance & temperature
• Troubleshooting PV strings
• Data analysis and reporting (preview of separate webinar)
Selective Shading Troubleshooting Method

Overview

I-V curve of a problem string of 10 modules.

**Example:** The step in the I-V curve is reducing max power voltage by approximately 12v. Which module causes the step?

**Principle:**
Electrically ‘remove’ one module at a time to see which module has the problem.

To ‘remove’ a module, force it’s bypass diodes on by applying shade.

**Process:**
1. Shade 3 rows of the first module and measure the string’s I-V curve.
2. Repeat with shade moved to each of the other modules.
3. Compare the I-V curves. The curve without the step is from the bad module.
The same method can also be used to identify a bad cell string in a single module, by applying shade to one cell string at a time.
Infrared Imaging
Companion tool to I-V curve tracing

Demo example: Middle cell group is hotter because it is not exporting electrical power. Bypass diodes were forced ‘on’ by covering a cell with cardboard.

Thermal processes are an important piece of the PV system performance. Infrared imaging helps us find:

- Poor electrical connections that cause power loss and eventually arcs and fires
- Open-circuited PV strings and bypassed cell groups performance issue that disrupts thermal balance can be located with infrared imaging.
- PV cell hot spots

IR imagers are a great companion tool with I-V curve tracing:

<table>
<thead>
<tr>
<th></th>
<th>I-V</th>
<th>IR</th>
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<tr>
<td>Detect issue</td>
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<td>Measure performance</td>
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<tr>
<td>impact</td>
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<td></td>
</tr>
<tr>
<td>Find bad module</td>
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<td>✓</td>
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Infrared Imaging
Aerial imaging of large arrays

Image courtesy of Portland Habilitation Center, Oregon Infrared, and Dynalectric
Topics

• Introduction to I-V curves and the Solmetric PV Analyzer
• Equipment setup & measurement process
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• Data analysis and reporting (preview of separate webinar)
What clouds our understanding of actual string performance?

**Shading**
- Vegetation
- Buildings
- Rooftop equipment
- Other PV modules

**Weather**
- Low irradiance
- Unstable irradiance
- Wind

**Soiling & Debris**
- Uniform soiling
- Dirt dams
- Leaves & branches
- Frisbees

**Measurement Issues**
- Irradiance sensor not in POA
- Thermocouple not attached
- Thermocouple location
- Resistive losses
Types of I-V curve deviations
From normal, expected shape

- Each of the six deviations has multiple causes.
- Classifying the deviations by shape narrows the causes and speeds troubleshooting (see the Solmetric PV Array Troubleshooting Flowchart)
- Earlier measurement methods miss much of this information.
Overview of data analysis process
Data display, interpretation, and reporting

1. Export data from PVA software
2. Use the Data Analysis Tool (Excel with macros) to display the data in tables, I-V graphs, and histograms. The DAT is a free Solmetric PVA accessory.
3. Review and interpret data
4. Generate a punch list if needed
5. After repairs and re-testing are finished, re-run the DAT
6. Generate the DAT report for your client
7. Prepare a brief, high-level summary of the findings of the DAT report. Often clients find this helpful.
Tables & graphs generated by the DAT

Table

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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I-V Curves

Histories

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Recorded PVA Webinar Series

Introduction
Solmetric PVA-1000S I-V Curve Tracer

User Training
Solmetric PVA-1000S I-V Curve Tracer

Data Analysis and Reporting
Solmetric PVA-1000S I-V Curve Tracer

Instructor:
Paul Hernday
Senior Applications Engineer
paul@solmetric.com
User Training Webinar
Solmetric PVA-1000S
I-V Curve Tracer

October 1, 2015

Instructor:
Paul Hernday
Senior Applications Engineer
paul@solmetric.com