



DS-1000 I-V CURVE TRACER User Manual



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WARNINGS

THE IMPROPER USE OF THIS INSTRUMENT CAN PRESENT AN ELECTRICAL SHOCK HAZARD THAT CAN CAUSE DEATH OR SERIOUS INJURY.

THIS INSTRUMENT SHOULD ONLY BE USED AS DESCRIBED IN THIS OPERATIONS MANUAL.



WARNING THIS INSTRUMENT MAY PRESENT AN ELECTRICAL SHOCK HAZARD WHICH CAN RESULT IN DEATH OR SERIOUS INJURY IF THE FOLLOWING PRECAUTIONS ARE NOT FOLLOWED:

- THIS INSTRUMENT MUST ONLY BE USED FOR TAKING ELECTRICAL CURRENT AND VOLTAGE (I-V) CURVES OF PHOTOVOLTAIC (PV) SOLAR MODULES.
 - THIS INSTRUMENT MUST NOT BE USED BEYOND ITS OPERATING RANGE.
 - THIS INSTRUMENT MUST NOT BE USED BY PERSONNEL WHO DO NOT HAVE EXPERIENCE HANDLING HIGH VOLTAGE DC AND PHOTOVOLTAIC MODULES.
 - THIS INSTRUMENT MUST NOT BE USED DURING RAIN, SNOW, SLEET, OR IN ANY AREA OF HIGH MOISTURE SUCH AS AREAS WITH STANDING WATER OR MUD.
 - THIS INSTRUMENT MUST NOT BE USED IF IT IS NOT FUNCTIONING AS DESCRIBED IN THIS USER MANUAL .
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NOMENCLATURE

A	Amperes or Amp
Hz	Hertz
I	Current
I_{pk}	Current at peak power
I_{sc}	Short-Circuit Current: The maximum current a photovoltaic cell can generate with the output terminals shorted
I-V	Current-Voltage
PV	Photovoltaic
V	Voltage
V_{oc}	Open-Circuit Voltage: The maximum voltage a photovoltaic cell can generate with the output terminals open circuited
V_{pk}	Voltage at peak power

1.0 Installation & Taking I-V Curves

Basic Description

The standard DS-1000 Tracer has three user selectable current ranges (1, 10 and 100 Amperes), three automatically selected voltage ranges (10, 100, and 1000 Volts), two irradiance and two temperature measurement inputs. Unless otherwise noted, this manual refers to standard DS-1000 models.

A computer running the IVPC for Windows program controls the DS-Tracer. The computer running the IVPC application may be connected to the DS-Tracer by RS-232 serial or USB.

Most DS-Tracer operations are performed with the IVPC program. Refer to the IVPC help system for details on operating the DS-1000 I-V Tracer. However, the basic steps for using the DS-Tracer are:

- Install and run IVPC for Windows.
- Connect the DS-Tracer to the computer (either RS-232 or USB).
- Connect pyranometers and thermocouples to DS-Tracer.
- Turn on the tracer power and connect DS-Tracer test leads to PV array.
- From the “Curve” menu, select New I-V Curve or press the “New Curve” button on the toolbar.
- Enter curve information.
- Press the “Take Curve” button when ready to sweep the I-V curve.
- IVPC automatically displays the I-V curve and adds it to the IVPC worksheet.

To proceed with the Installation & Quick-Start, the following are needed:

- DS-Tracer I-V curve tracer and test leads.
 - IVPC CD-ROM or IVPC download from www.daystarpv.com
 - PC computer running the Microsoft Windows® operating system (XP through 8).
 - Serial or USB cable to connect a computer to the DS-Tracer.
-

IVPC Installation

IVPC is written for use with Windows® XP through 8 which must be running to operate IVPC. To install IVPC, insert the IVPC CD-ROM in the computer. Open the IVPC CD-ROM (or alternately IVPC files downloaded from www.daystarpv.com) and run the “setup.exe” program.

The setup program prompts for information on where to install IVPC. If unsure, use the defaults, which create an IVPC sub-directory within the Windows programs folder. IVPC Setup automatically installs the necessary files in the IVPC directory and makes additions to the Windows system directory.

Precautions

There are several precautions to observe before using the DS-Tracer.

- Keep the DS-Tracer battery charged. The DS-1000 has a universal power supply that works with AC line voltages from 85 V_{ac} to 264 V_{ac} 50/60 Hz.
- Turn the DS-Tracer power on when making or breaking connections to a PV system.
- Connect the DS-Tracer to the PV array through a PV system disconnect switch capable of interrupting the short-circuit current of the array at peak-power voltage. This allows disconnecting the DS-Tracer from the PV system if a problem occurs.
- Do not connect the DS-Tracer to anything other than an open-circuit, PV system. Be sure the PV array is electrically isolated from power conditioning equipment such as charge controllers or inverters.
- Do not connect the DS-1000 Tracer to a PV system with an open-circuit voltage greater than 1000 Volts.
- Do not connect the DS-Tracer to any PV system with a short-circuit current greater than maximum 100 Amperes for a standard DS-1000.



The DS-Tracer RS-232 and USB ports, irradiance inputs, temperature inputs, auxiliary analog inputs, and auxiliary charge inputs are all referenced to the same electrical common inside the tracer. Therefore these devices must be either electrically floating or referenced to the same electrical common.

Note: All of these connections are electrically isolated from the PV inputs.

Connecting a Computer to the DS-Tracer

The DS-1000 I-V Tracer provides two interfaces; an RS-232 and USB port. The RS-232 interface uses a standard female, 9 pin connector located on the DS-Tracer front panel. The standard USB connection is labeled “Main USB.” Use either of these connections depending on the configuration of the computer running the IVPC program. However, only one of these ports should be connected at a time.

Note: Special USB drivers must be installed on the computer in order to use the USB port. See the section “Appendix B DS-1000 USB Drivers” for details on installing these drivers.

Connecting a PV Module to the DS-Tracer

The DS-Tracer is connected to the PV array or module with the test leads provided. Before connecting a PV module, be sure the DS-Tracer power switch is ON. The test lead is designed to remain connected to the DS-Tracer at all times. It is typically unnecessary to remove this from the tracer.



For safety, the test lead should never be disconnected from the tracer while the other end is connected to a PV system. Doing so could present an electric shock hazard.

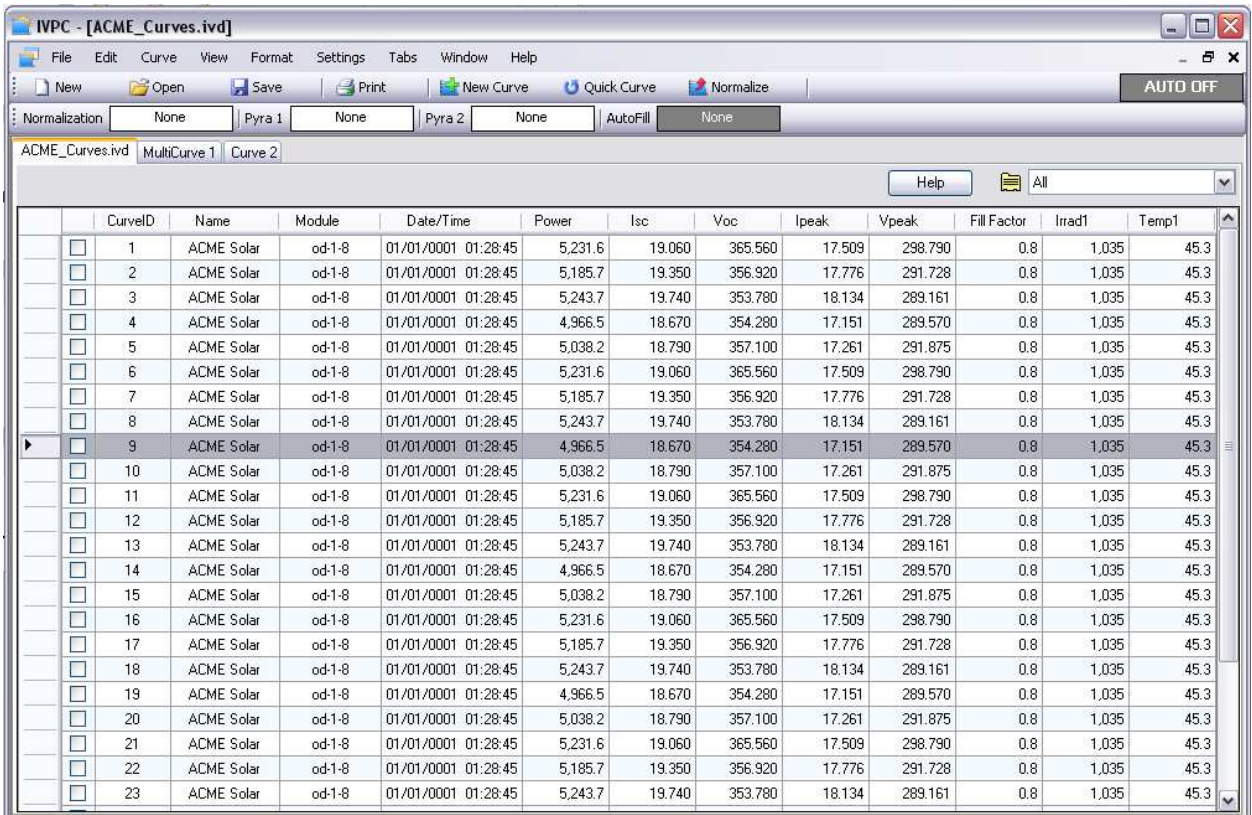


For safety, it is recommended that connections be made to the PV array through a system disconnect switch rated at full PV power.

With the test lead attached to the DS-Tracer, connect the test leads to the PV system.

Starting IVPC

The following description assumes the use of IVPC 3. IVPC opens to the Data Grid window shown in Figure 1. IVPC Data Grid window.. The Data Grid is a spread sheet that lists all of the I-V curve data files stored in the I-V curve worksheet. When starting IVPC for the first time, the Data Grid may be empty if no I-V curves have been taken.



The screenshot shows the IVPC Data Grid window with a menu bar (File, Edit, Curve, View, Format, Settings, Tabs, Window, Help) and a toolbar (New, Open, Save, Print, New Curve, Quick Curve, Normalize, AUTO OFF). Below the toolbar are normalization settings for Pyra 1 and Pyra 2, and an AutoFill button. The main area contains a table with the following data:

CurveID	Name	Module	Date/Time	Power	Isc	Voc	Ipeak	Vpeak	Fill Factor	Irrad1	Temp1	
<input type="checkbox"/>	1	ACME Solar	od-1-8	01/01/0001 01:28:45	5,231.6	19.060	365.560	17.509	298.790	0.8	1,035	45.3
<input type="checkbox"/>	2	ACME Solar	od-1-8	01/01/0001 01:28:45	5,185.7	19.350	356.920	17.776	291.728	0.8	1,035	45.3
<input type="checkbox"/>	3	ACME Solar	od-1-8	01/01/0001 01:28:45	5,243.7	19.740	353.780	18.134	289.161	0.8	1,035	45.3
<input type="checkbox"/>	4	ACME Solar	od-1-8	01/01/0001 01:28:45	4,966.5	18.670	354.280	17.151	289.570	0.8	1,035	45.3
<input type="checkbox"/>	5	ACME Solar	od-1-8	01/01/0001 01:28:45	5,038.2	18.790	357.100	17.261	291.875	0.8	1,035	45.3
<input type="checkbox"/>	6	ACME Solar	od-1-8	01/01/0001 01:28:45	5,231.6	19.060	365.560	17.509	298.790	0.8	1,035	45.3
<input type="checkbox"/>	7	ACME Solar	od-1-8	01/01/0001 01:28:45	5,185.7	19.350	356.920	17.776	291.728	0.8	1,035	45.3
<input type="checkbox"/>	8	ACME Solar	od-1-8	01/01/0001 01:28:45	5,243.7	19.740	353.780	18.134	289.161	0.8	1,035	45.3
<input checked="" type="checkbox"/>	9	ACME Solar	od-1-8	01/01/0001 01:28:45	4,966.5	18.670	354.280	17.151	289.570	0.8	1,035	45.3
<input type="checkbox"/>	10	ACME Solar	od-1-8	01/01/0001 01:28:45	5,038.2	18.790	357.100	17.261	291.875	0.8	1,035	45.3
<input type="checkbox"/>	11	ACME Solar	od-1-8	01/01/0001 01:28:45	5,231.6	19.060	365.560	17.509	298.790	0.8	1,035	45.3
<input type="checkbox"/>	12	ACME Solar	od-1-8	01/01/0001 01:28:45	5,185.7	19.350	356.920	17.776	291.728	0.8	1,035	45.3
<input type="checkbox"/>	13	ACME Solar	od-1-8	01/01/0001 01:28:45	5,243.7	19.740	353.780	18.134	289.161	0.8	1,035	45.3
<input type="checkbox"/>	14	ACME Solar	od-1-8	01/01/0001 01:28:45	4,966.5	18.670	354.280	17.151	289.570	0.8	1,035	45.3
<input type="checkbox"/>	15	ACME Solar	od-1-8	01/01/0001 01:28:45	5,038.2	18.790	357.100	17.261	291.875	0.8	1,035	45.3
<input type="checkbox"/>	16	ACME Solar	od-1-8	01/01/0001 01:28:45	5,231.6	19.060	365.560	17.509	298.790	0.8	1,035	45.3
<input type="checkbox"/>	17	ACME Solar	od-1-8	01/01/0001 01:28:45	5,185.7	19.350	356.920	17.776	291.728	0.8	1,035	45.3
<input type="checkbox"/>	18	ACME Solar	od-1-8	01/01/0001 01:28:45	5,243.7	19.740	353.780	18.134	289.161	0.8	1,035	45.3
<input type="checkbox"/>	19	ACME Solar	od-1-8	01/01/0001 01:28:45	4,966.5	18.670	354.280	17.151	289.570	0.8	1,035	45.3
<input type="checkbox"/>	20	ACME Solar	od-1-8	01/01/0001 01:28:45	5,038.2	18.790	357.100	17.261	291.875	0.8	1,035	45.3
<input type="checkbox"/>	21	ACME Solar	od-1-8	01/01/0001 01:28:45	5,231.6	19.060	365.560	17.509	298.790	0.8	1,035	45.3
<input type="checkbox"/>	22	ACME Solar	od-1-8	01/01/0001 01:28:45	5,185.7	19.350	356.920	17.776	291.728	0.8	1,035	45.3
<input type="checkbox"/>	23	ACME Solar	od-1-8	01/01/0001 01:28:45	5,243.7	19.740	353.780	18.134	289.161	0.8	1,035	45.3

Figure 1. IVPC Data Grid window.

The Data Grid is as a detailed list of the I-V curves. In addition to curve names, the data grid displays other curve data such as peak-power or module ID. Refer to the IVPC Help system for details.

Taking an I-V Curve

Before taking a curve, turn on the DS-Tracer and connect it to the PV system. Connect the computer running IVPC to the DS-Tracer. From the “Curve” menu, shown in Figure 2, select “New Curve” or press Ctrl-T.

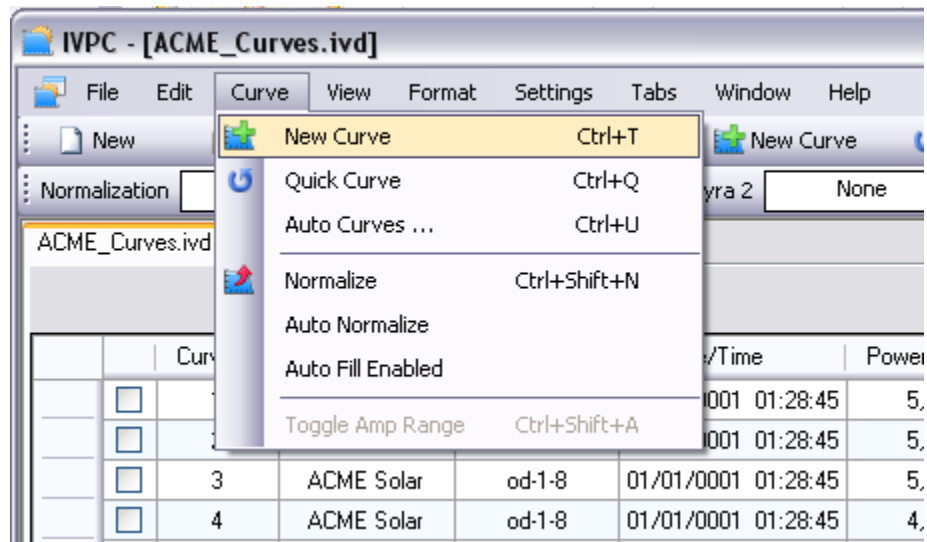


Figure 2. Select “New Curve” in the “Curve” menu to take an I-V curve.



Note: Some figures shown in this manual may vary. Please refer to the IVPC manual for the most up-to-date information on using IVPC.

After starting a new curve, IVPC opens a new curve window as shown in Figure 3. This window provides areas to enter curve information identifying the I-V curve. The DS-Tracer may take several seconds to initialize the tracer hardware. A status message indicating that the DS-Tracer is pre-charging is displayed in the area normally used to plot the curve.

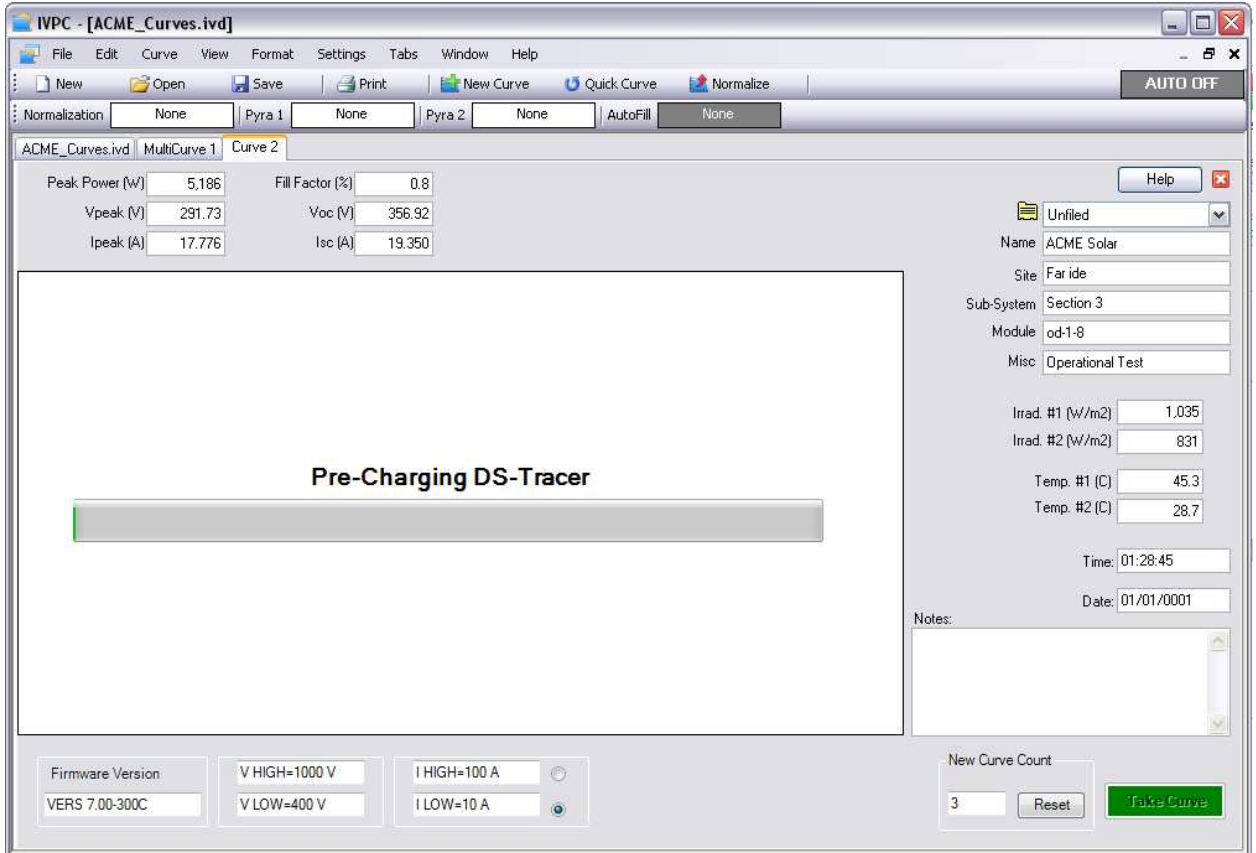


Figure 3. New Curve screen while DS-Tracer is pre-charging.

After initialization, the status message changes and the “Take Curve” button is enabled as shown in Figure 4. This status message indicates that a curve can be taken by pressing the “Take Curve” button or by pressing Alt-T.

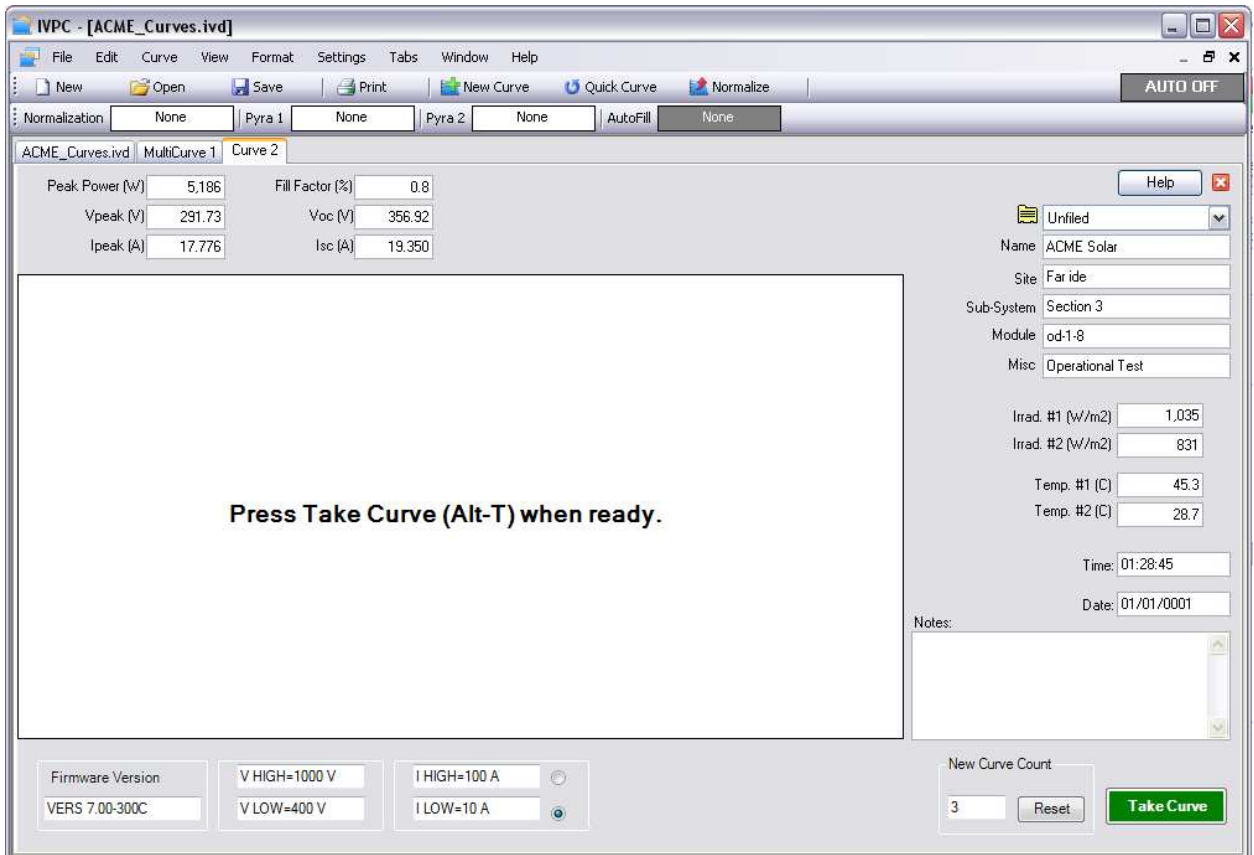


Figure 4. DS-Tracer is pre-charged and ready to immediately take the curve.

After pressing the “Take Curve” button, the DS-Tracer takes approximately 2 to 10 seconds to take the curve and plot the data as shown in Figure 5. The new curve data is automatically added to the worksheet. However, the worksheet is not automatically saved to disk.

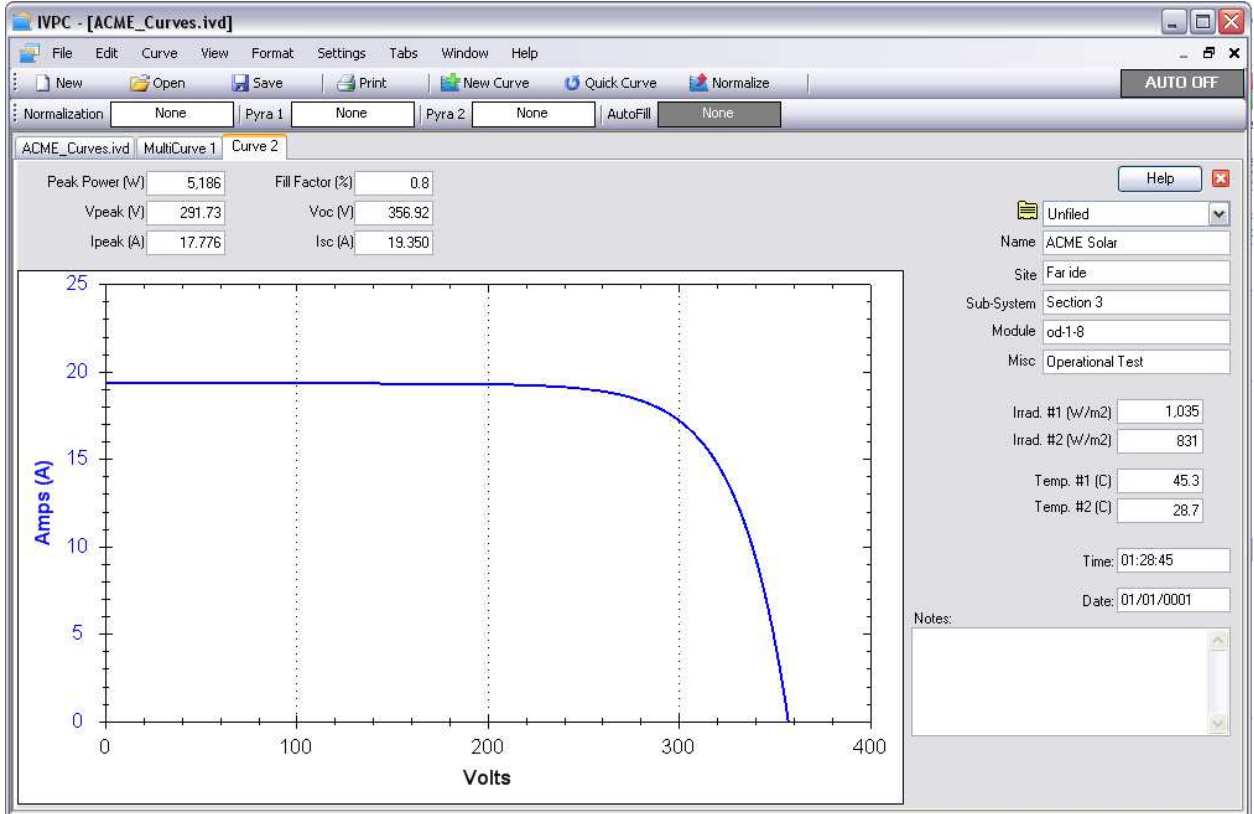


Figure 5. Example of I-V curve.

It's possible to return to the Data Grid, without closing the curve window, by clicking on the data grid tab (far left tab) as shown in Figure 6. Closing the I-V curve window also opens the Data Grid tab.

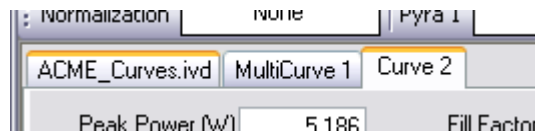


Figure 6. Moving to the Data Grid using tabs.

If There Is an Error

There are several error messages IVPC may display when taking a curve. The DS-Tracer automatically turns off when it does not receive a command for 15 minutes. This feature helps to protect the DS-Tracer battery. If the DS-Tracer has been on for more than 15 minutes without taking a curve it will power down and IVPC generates an error indicating that the DS-Tracer does not respond. Turn the DS-Tracer power switch off, wait several seconds, and turn it back on. Allow the tracer approximately 10 seconds to initialize. Then retry as indicated on the error dialog box.

Other errors occur if the PV array voltage is too high or if it is zero or negative. Follow the IVPC directions given when the error occurs. Most errors occur immediately after selecting “New Curve” from the “Curve” menu.

The most common problem results from a communication error. Incorrect COM port settings in IVPC may cause this problem. The COM port settings must match the actual COM port on the computer. Note: If the COM port is a “virtual” COM port, such as those created by USB to serial adapters or by the DS-1000 USB drivers, it is possible that this COM port number has been inadvertently changed.

Use the Windows device manager to confirm the current COM port setting of the virtual COM port. The COM port number set for this virtual port must match the COM port number set in IVPC.

Displaying I-V Curves

From the Data Grid, double click a curve to display it.

Use the “Multi-plot” feature, under the “View” menu, to display multiple curves on one plot. Several options exist for displaying I-V curves. Refer to the IVPC Help system for details.

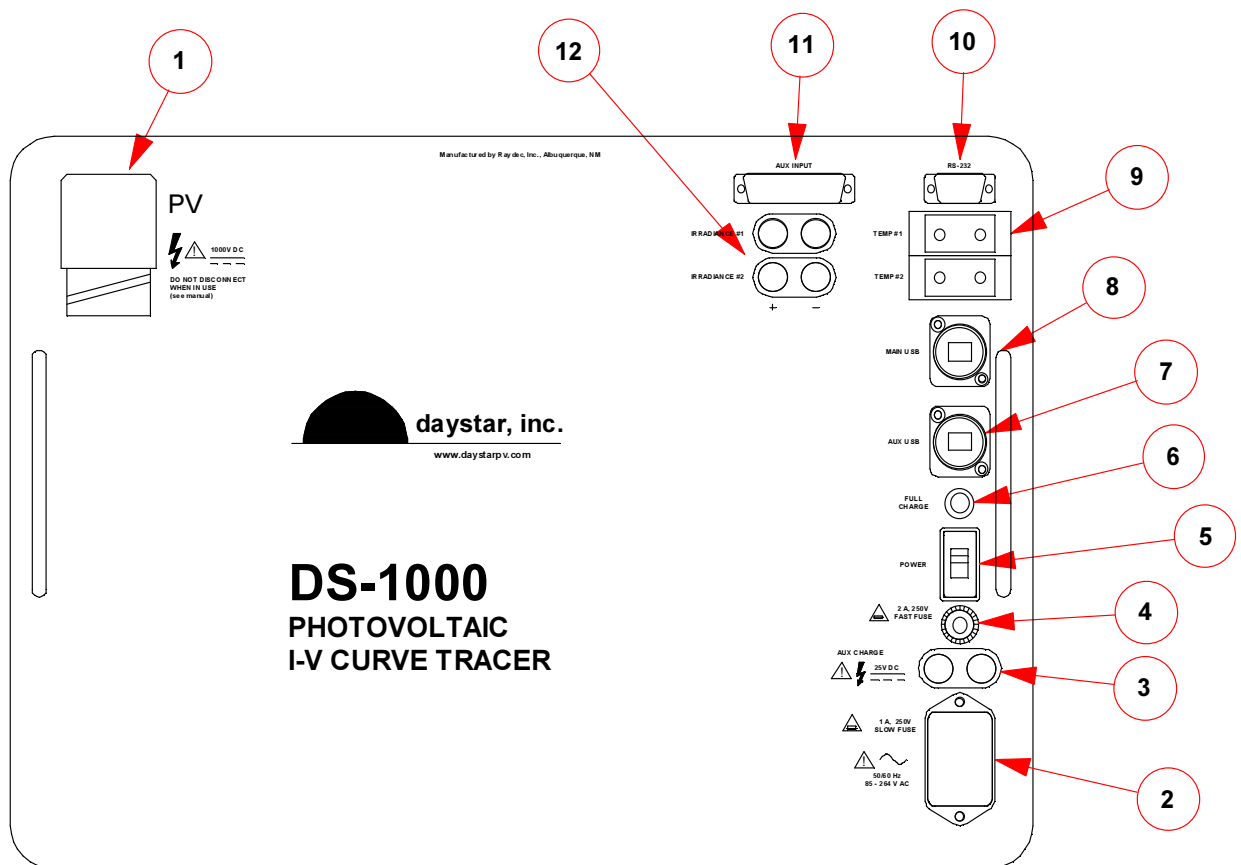
Summary of Steps for Taking I-V Curves

1. Connect the computer to the DS-Tracer and start IVPC. Turn the DS-Tracer power switch ON.
2. Connect pyranometers to the DS-1000. If pyranometers are connected, enter pyranometer constants in IVPC. Refer to the IVPC help system for details. Note: Pyranometers do not need to be used to sweep an I-V curve.
3. Connect thermocouples to the DS-1000. Refer to the IVPC help system for details. Thermocouples are not required to sweep an I-V curve.
4. Connect the DS-Tracer test lead to the DS-Tracer before connecting the test lead to the PV system. Connect the red clip to PV positive and the black clip to PV negative. Be sure to connect the tracer to the PV system through a system disconnect switch rated for I_{sc} and V_{oc} . The DS-Tracer is now ready to take I-V curves.
5. From the "Curve" menu in IVPC select "New Curve".
6. Edit I-V curve information such as name and site as needed.
7. When ready, press the "Take Curve" button to begin the I-V sweep. The I-V curve is displayed as soon as the curve sweep is complete.
8. To take another I-V curve of the same PV system, repeat step 5-7.

To test another PV subsystem, open the PV system disconnect switch. Remove the cables and repeat steps 4 and 7.
9. When finished taking curves, open the PV system disconnect switch. Disconnect the DS-Tracer from the PV system.
10. Switch off the power to the DS-Tracer.

2.0 Panel Layout

This section describes the DS-1000 photovoltaic I-V curve tracer in more detail. The DS-Tracer generates a complete current-voltage (I-V) curve that characterizes the photovoltaic system under test. Figure 7 shows the front panel layout of the DS-1000. Each of the key components is described in detail in the following section.



- | | |
|--------------------------|----------------------------------|
| 1. PV System Connector | 7. AUX USB Port |
| 2. AC Power Entry & Fuse | 8. Main USB Port |
| 3. DC Supply Input | 9. Thermocouple Inputs |
| 4. DC Supply Input Fuse | 10. RS-232 Serial Port Connector |
| 5. On-Off Switch | 11. AUX Analog Inputs |
| 6. Full-Charge Indicator | 12. Irradiance Inputs |

Figure 7. Face plate of the DS-Tracer.

PV Test Lead Connector

When an I-V curve is taken, the load current flows through the test lead into DS-Tracer. The red and black test clips go to PV array positive and negative terminals respectively. The test cable contains separate voltage sense wires to measure the PV voltage at the test clips. This 4-wire measurement technique avoids measurement errors caused by voltage drops in the test leads.

For maximum safety, the DS-Tracer should be connected through a PV system disconnect rated at the PV system V_{OC} and I_{SC} values. See Figure 8. A system disconnect switch provides a way to break the electrical connection should the DS-Tracer have a major internal failure.

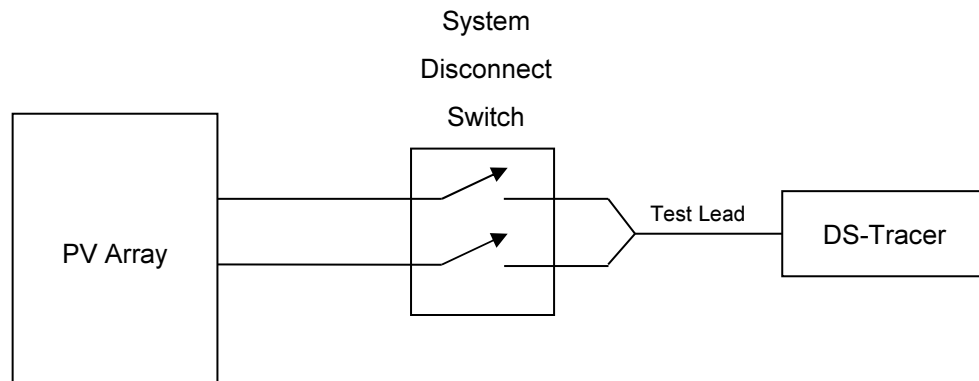


Figure 8. Use of PV system disconnect switch.

AC Power Entry & Fuse

Connecting the DS-Tracer to an AC power source recharges the DS-Tracer battery. It is not necessary for the tracer to be on. Refer to section “Battery Charging and Care” in section “4.0 Maintenance” for details of battery charging.

DC Supply Input & Fuse

The DS-Tracer may be powered or recharged from an external DC power source. This source could be a PV module. Refer to section “Battery Charging and Care” in section “4.0 Maintenance” for details of battery charging.

ON-Off Switch

This switch turns on the DS-Tracer power. Turn this switch on before connections are made to a PV array. The curve tracer takes approximately 10 seconds to initialize after it is turned on.

The DS-Tracer automatically turns itself off if a curve has not be taken for 15 minutes. This feature protects the DS-Tracer battery. If the DS-Tracer has turned itself off, switch the power switch off, wait several seconds, and turn the switch back on.

Full Charge Indicator

When this LED lights, its indicates that the DS-Tracer battery is fully charged. When fully charged, this indicator remains on while the DS-Tracer is plugged into AC power. Sometimes this LED will turn on briefly if the AC power cord is unplugged before the battery is fully charged. This occurrence does not indicate a fully charged battery.

Aux USB Port

This port supports auxiliary DS-1000 operations This port is a standard USB Type-A port. This port is not used to control the DS-1000 I-V tracer. It is used to update the I-V curve tracer internal firmware. In the event that an update is needed, the proper use of this port will be described at that time. This port may also be used for advanced features in future releases of DS-1000 firmware or IVPC.

Main USB Port

All DS-Tracer operations are controlled with commands sent to the DS-Tracer through this USB port or the RS-232 port. This port is a standard USB Type-B port. Normally the DS-Tracer functions are controlled with the IVPC software, but custom software can control the DS-Tracer using the DS-Tracer command codes. Refer to the “DS-1000 Command Reference” manual for details.

Thermocouple Inputs

The standard model DS-1000 is configured with two Type “T” thermocouple inputs for measuring PV array module temperatures. Refer to the IVPC Help system for details on making temperature measurements and “Appendix C - DS-1000 Technical Specifications”.

RS-232 Serial Port

All DS-Tracer operations are controlled with commands sent to the DS-Tracer through this serial port or the USB port. This port is a standard 9 pin RS-232 port. This port is configured as a DCE device. Normally the DS-Tracer functions are controlled with the IVPC software, but custom software can control the DS-Tracer using the DS-Tracer command codes. Refer to the “DS-1000 Command Reference” manual for details.

The DS-Tracer uses the following default RS-232 format:

9600 Baud
No parity
8 data bits
1 stop bit

Aux Analog Inputs

There are 8 auxiliary (Aux) inputs. These have similar functionality to the irradiance inputs, with the exception that there is no internal resistor referencing the inputs to the DS-Tracer common. Refer to the IVPC Help system for details on using this feature. Refer to “Aux Input Connections” in section “6.0 DS-1000 Additional Capabilities” for details on connecting to these inputs.

Irradiance Inputs

The model DS-1000 has two irradiance inputs for measuring pyranometers. These inputs measure DC voltages only. In order to use a reference cell, the cell must have a shunt resistor attached to convert the cell current to a voltage. Refer to the IVPC Help system for details on making temperature measurements and “Appendix C - DS-1000 Technical Specifications”.

These inputs are differential, but there is a 10 K resistor from the negative (black) input and the internal circuit common. Therefore the pyranometer can be either electrically referenced to the same common as the other DS-Tracer inputs such as the computer, or it can be electrically floating.

3.0 Theory of Operation

The DS-Tracer obtains an I-V curve by varying the electrical impedance connected across the PV array output terminals. Varying the impedance from zero to infinity causes the array operating point to change from I_{sc} to V_{oc} .

The DS-Tracer accomplishes this impedance change by connecting the array to a capacitive load. As the capacitor charges, the array moves through its operating range and presents a set of current and voltage values that form the I-V curve. When the capacitor load reaches V_{oc} data sampling stops.



NOTE: The DS-1000 uses a sophisticated switching technique that actively controls the start of the sweep. Although this controlled switching is designed to detect fault conditions and take appropriate action to protect the DS-1000, the user is encouraged to ensure the DS-Tracer is always used with PV systems within its voltage and current rating and that auxiliary equipment such as inverters, power conditions, and charge controls are not connected to the PV system while sweeping I-V curves.

Data Sampling

The DS-Tracer employs two high-speed, analog-to-digital converters to sample the current and voltage simultaneously. One converter digitizes the array voltage while the other digitizes the array current. The DS-Tracer typically collects tens of thousands of data points and reduces this to 1000 points (typically).

In addition to the I-V data points, the I-V curve includes the values of open-circuit voltage, V_{oc} , and short-circuit current, I_{sc} . Peak-power, voltage at peak-power V_{pk} , current at peak-power I_{pk} , and fill factor are calculated and displayed with the curve.

Irradiance and temperature data, and array identification may be added to each I-V curve. The irradiance and temperature data are either entered by the operator using IVPC or sampled by the DS-1000.

Curve Sweep

The DS-Tracer sweeps an I-V curve by switching the PV system to a bank of capacitors. As these capacitors charge, the PV system voltage increases until open circuit voltage is reached. While the voltage is increasing, and the current to the capacitors is decreasing from its maximum, short-circuit value, the voltage and current are sampled by high-speed analog-to-digital converters. These data points define the I-V curve.

Pre-Charge

Before acquiring data, the DS-1000 reverse charges its capacitive load to approximately -15 V. This negative pre-charge is used to offset any voltage drops created by the test leads and to allow any switching transients to settle before I_{sc} is reached. This method allows a true short circuit current reading to be made. After the capacitive load charges to V_{oc} , the curve sweep is complete. At this point the circuitry discharges the capacitors through a resistive load.

Sweep Speed

Curve sweep time varies with PV system current and voltage. The sweep is typically less than one second, but can be as long as 10 seconds.

The complete cycle actually begins with a discharge of any residual voltage on the capacitors and a pre-charge to -15 V, curve sweep, and finally another discharge/pre-charge period to ready for the next I-V curve sweep.

Some PV systems are sensitive to how quickly an I-V curve is taken. The speed of a curve is most easily expressed in volts per second by taking the PV short circuit current in Amps (I_{sc}) and dividing it by the DS-Tracer load capacitance in Farads. The DS-1000 load capacitance varies depending on PV system voltage and current range selection. There are four possible load capacitance values from approximately 2,500 uF to 11,600 uF.

For example, for a load capacitance value of 2,500 μF , and a PV system with an I_{sc} of 20A the rate would be:

$$\text{Rate} = 20\text{A}/0.0025 \text{ F} = 8000 \text{ V/S.}$$

When comparing this value to the PV system, it is best to normalize this rate to an individual PV cell. This is done by dividing the rate by the number of PV cells in series.

If the previous example had fifty cells in series, the rate of each cell would be $8000 \text{ V/S} \div 50 \text{ cells} = 160 \text{ V/S-cell}$. Different PV technologies vary in their sensitivity to the charge rate. It is left to the user to determine if there is reason for concern. Often the PV module manufacturer can provide information concerning how quickly an I-V curve can be swept on their modules. Daystar, Inc. will also provide any assistance possible.

4.0 Maintenance

Battery Charging and Care

The DS-Tracer contains a 12-Volt sealed, maintenance-free, lead-acid battery. (A 5 AH Cyclon brand, #0809-0012 manufactured by EnerSys.) The battery is designed for 400 cycles of a 50 percent discharge. Using the DS-Tracer for 6 hours continuously discharges the battery 50 percent. If the DS-Tracer were used for 6 hours every day, the battery should have a minimum life of 13 months (one discharge/charge cycle a day). Fully charging the DS-Tracer after every use increases battery life. The DS-Tracer is programmed to turn itself off after 15 minutes without a command. This reduces the possibility of completely discharging the battery.

The DS-Tracer battery may be charged in two ways—AC line power or a DC source such as a PV module. The DS-1000 has a universal AC power supply and therefore will work with single phase, AC line voltages from 85 V_{ac} to 264 V_{ac} 50/60Hz. To charge the battery from AC line power, connect the tracer to the AC source (with the AC power cord provided). The tracer will immediately start charging the battery

Battery charging is independent of using the DS-1000 tracer. Therefore the tracer may be used to take curves using AC power. The battery will continue to charge while the tracer is used.

A DC supply, such as a PV module, can also recharge and power the DS-Tracer. This feature is useful when working in remote locations without AC power. Connect a DC Voltage source within the range specified on the DS-Tracer front panel to the DC Power connector. This is a standard banana jack connector. Connect the DC positive and negative to the red and black jacks respectively.

The charge circuit uses a maximum of 1 A and requires a minimum of 16 V. If using a PV module for recharging, the open circuit voltage of this module should

not exceed the maximum rating shown on the DS-Tracer front panel. When connected to a supply that produces less than 1A, the DS-Tracer simply takes longer to recharge. The internal charging circuitry limits the DC charging current. Therefore power sources with current capabilities greater than 2 A can be used. For example, a 5 A PV module could be used. The DS-Tracer will only draw the current it needs for charging. Unlike charging from an AC power source, when using a DC source, such as a PV module, DS-Tracer operating power may reduce the available charge current and slow battery charging.

The automatic charging system maintains the battery at its peak charge level and will not overcharge the battery. When the battery is fully charged, the full-charge indicator comes on. The DS-Tracer can be either on or off when recharging the battery.

It will not harm the battery to leave the DS-Tracer connected to the power source after the battery is fully charged. Note: The full charge indicator may come on for a short time if the charging power is removed before the DS-Tracer is fully charged. This occurrence does not indicate that the battery is fully charged.

During charging, the front panel of the DS-1000 near the irradiance connectors may get slightly warm.

Exterior Cleaning

The exterior surface of the DS-Tracer may be cleaned with a soft cloth dampened with water or a mild soap only. Do not use detergents, abrasive cleansers, or other solvents.

Transportation

Treat the DS-Tracer similar to a notebook computer or other electronics. While the DS-Tracer is mounted in a heavy-duty case, this is **NOT** adequate to ship the unit as freight without using a shipping container. Because of its weight, it will likely be damaged if it is dropped or tossed. Due to airline security, Daystar does not recommend attempting to carry the tracer on board a commercial airplane as

carry-on baggage. A shipping container with foam packing is supplied as standard equipment with all DS-1000 curve tracers. Daystar strongly recommends using this case anytime the DS-1000 is shipped.

DS-Tracer Fuses

The DS-Tracer has two externally accessible fuses. The first of the external fuses is located in the AC input power receptacle. Power line surges or internal faults could cause this fuse to fail. Return the DS-Tracer for repairs if this fuse blows repeatedly. Replace this fuse with the type indicated on the DS-Tracer panel.

A second user replaceable fuse is the 2 Amp, fast-blow DC charging fuse. This fuse should only blow if a DC source voltage exceeds the rating on the DS-Tracer panel. Replace only with a 2 Amp, fast-blow DC charging fuse.

There is an internal fuse on the power supply board battery circuit. This fuse is installed as protection when the DS-Tracer is removed from its case during repairs.

5.0 Pre-Charge Precautions

In order to compensate for voltage drops across the test lead, the DS-Tracer pre-charges the capacitive load to approximately -15 V. When an I-V curve is taken, the PV module voltage starts at -15 V and increase to V_{oc} . Most PV modules (single crystal silicon for example) easily withstand this negative pre-charge voltage. However, this pre-charge voltage can damage some thin-film modules—particularly those with very low V_{oc} values. Higher voltage modules have more cells in series and therefore the pre-charge voltage is spread across more cells. Only individual low-voltage, thin-film modules are affected. It is not a concern for systems with many modules in series.

Avoid damage to a thin-film module by inserting a by-pass diode across the module terminals as shown in Figure 9. This diode limits the reverse voltage to approximately -1 V maximum. Locating the diode at the PV module terminals still allows the pre-charge to offset voltage drops across the test leads.

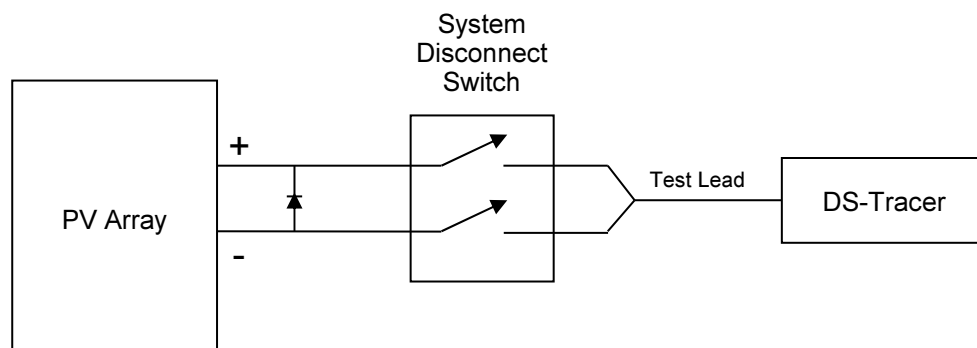


Figure 9. Use of by-pass diode to protect thin-film PV modules.

The by-pass diode should be rated to handle the instantaneous peak current created by shorting the pre-charge capacitor through the by-pass diode. The DS-1000 design ensures this current will not exceed 150 A and lasts less than 2 ms. The diode reverse voltage rating must be greater than module V_{oc} . A Motorola MR750 series rectifier or similar is recommend. This rectifier has a reverse voltage rating of 50 V and can handle peak currents over 300 A.

6.0 DS-1000 Additional Capabilities

The DS-1000 tracer has auxiliary capabilities. These include analog circuits for reading external temperatures and irradiances.

Temperature & Irradiance Inputs

The DS-1000 has two thermocouple temperature inputs and two dual, 5-way binding posts for connecting pyranometers. Using these inputs is optional and they are not needed to take I-V curves. The temperature and irradiance inputs are enabled using the AUTO feature of IVPC. When a curve is taken, the temperature and irradiance inputs are sampled immediately before the DS-1000 sweeps a curve. Refer to the IVPC help for details on using these inputs when taking I-V curves.

Temperature Connections

Two standard thermocouple connectors are available on the front of the DS-1000. A standard DS-1000 comes with Type- "T" thermocouple connectors. In order to accurately acquire temperature data, only matching thermocouple types should be used. The thermocouple inputs are electrically isolated from the PV system, but not isolated from other analog circuits or the computer connections. Therefore, it is necessary that the thermocouple be electrically insulated when bonded to a surface.

Irradiance Connections

There are two dual, 5-way binding posts for pyranometer inputs located on the front panel of the DS-1000. These inputs can accommodate ± 5 V signals and accurately measure millivolt signals. These inputs can be used for any analog voltage measurement within the range of the DS-1000. Refer to the "Appendix C - DS-1000 Technical Specifications" for details on measurement ranges.

Aux Input Connections

There is a single 25-pin connector for measuring auxiliary (Aux) inputs signals. These inputs accommodate ± 5 V signals and accurately measure millivolt signals. These inputs can be used for any analog voltage measurement within the range of the DS-1000. Refer to “Appendix C - DS-1000 Technical Specifications” for details on measurement ranges.

Note: These inputs are fully differential, and the applied signal must be referenced to circuit common (COM). For example, jumper the negative input to COM.

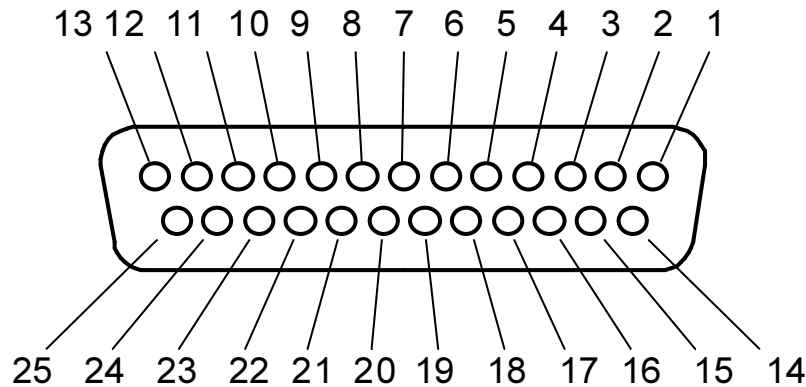


Figure 10. Aux Input Connector.

Aux Chan	Aux (+)	Aux (-)
1	Pin 1	Pin 14
2	Pin 3	Pin 16
3	Pin 4	Pin 17
4	Pin 6	Pin 19
5	Pin 7	Pin 20
6	Pin 9	Pin 22
7	Pin 10	Pin 23
8	Pin 12	Pin 24
COM	2,5,8,11,15,18,21,24	
N.C	13	

Multiple Current Ranges

The standard DS-1000 includes three current ranges, 1, 10 and 100 Amperes. Before an I-V curve is taken, select one of these three ranges using IVPC. Inadvertently selecting a low range, when the high range is required, will not damage the DS-1000. However, the displayed I-V curve will not include current values higher than the selected range.

External Command Set

Typically the IVPC program controls the DS-1000, however users may want to write software to perform custom tracer operations or integrate the DS-1000 into a larger data acquisition system. This is possible using commands sent to the DS-1000 through its RS-232 serial or USB control ports.

Refer to the “DS-1000 Command Reference” manual for details.

The DS-1000 uses a significantly different command set than previous Daystar I-V tracers. Daystar strongly recommends using the latest command set. However, the DS-1000 has legacy support for the older command set, should the user need to use the DS-1000 in a system already using the older commands.

7.0 Troubleshooting

- **Data is not plotted after taking an I-V curve.**
 - Proper connection has not been made to PV system.

- **I-V curve is flat.**
 - PV short circuit current exceeds selected current range (check current range setting). Check for bad connections to PV module or array.

- **I-V looks abnormal.**
 - PV system is malfunctioning.
 - PV system is NOT isolated from power conditioning or other equipment.
 - Voltage sense wires on test lead are broken near clips.

- **DS-Tracer Stops Working (Locks Up)**
 - Battery out of power (charge battery).
 - Unknown Reasons (reset DS-Tracer by recycling power).

- **Cannot establish connection of external computer to DS-Tracer.**
 - DS-Tracer is not turned on or has turned itself off.
 - DS-Tracer RS-232 or USB port is not connected to computer.
 - IVPC is set to wrong COM port.

- **DS-Tracer will not accept external command.**
 - Parameters are not properly formatted.

- **Irradiance readings are incorrect.**
 - Pyranometer coefficients are incorrect.
 - Supplied signal is not a DC voltage.

- **Aux input readings are incorrect.**
 - Supplied signal is not a DC voltage.
 - Differential input signals is not referenced to input common.

Appendix A DS-Tracer ERROR CODES

ERROR 10 "I/O ERROR"

RS-232 serial communications error. Baud rate, parity, number of data bits, or number of stop bits is incorrect. DS-Tracer uses 9600 baud, no parity, 8 data bits, and 1 stop bit.

ERROR 13 "UNKNOWN COMMAND"

Command is not recognized by the DS-Tracer . This may be due to a syntax error.

ERROR 14 "BUFFER OVERFLOW"

Internal command line buffer overflow. Total number of characters in command line cannot exceed 255.

ERROR 15 "COMMAND LINE OVERFLOW"

A command has been sent to the DS-Tracer before the previous command has finished. Wait for return prompt.

ERROR 16 "PARAMETER TOO LONG"

The maximum length of any command line parameter is 15 characters.

ERROR 17 "TOO MANY PARAMETERS"

A maximum of 16 parameters (including command code) are allowed.

ERROR 30 "OVER MAXIMUM VOLTAGE"

The take I-V curve command cannot continue because the PV system voltage exceeds the maximum voltage range (this PV system cannot be tested with the DS-Tracer).

ERROR 32 "INPUT LESS THAN OR EQUAL ZERO VOLTS"

The take I-V curve command cannot continue because the PV system voltage is less than or equal to 0 V. Check PV system and DS-Tracer disconnect switches. This error can also be caused by a reverse polarity on the DS-Tracer to PV system connection.

ERROR 50 “INVALID NUMERIC PARAMETER”

Parameter must represent valid numeric value.

ERROR “UNKNOWN ERROR”

Some type of unknown error has occurred. Check parameters for proper syntax.

Appendix B DS-1000 USB Drivers

In order to use the DS-1000 USB port for tracer control, the DS-1000 USB drivers must be installed on the computer running IVPC.

Two drivers will be installed. The primary driver will be a USB device driver labeled “DS-1000 I-V Tracer”. The second driver will be a virtual COM port also labeled “DS-1000 I-V Tracer”. This virtual COM port will function as a conventional COM port.

While normally, there is no reason to use the virtual COM port when using IVPC 3, in some cases, it may be useful to avoid problems when using the USB port directly. Note: This does not affect how the tracer is connected, only how the Windows operating system “sees” the tracer. Either directly as a USB device or indirectly through a COM port.

IVPC 3 supports COM ports 1 through 16. Therefore after being created, the virtual COM port must be assigned a COM port number in this range. It is possible for the operating system to assign a COM port number outside this range, even if a COM port number from 1 to 16 is not in use.

Use the Windows device manager to change the COM port number assigned to this virtual COM port to a value from 1 to 16. Often Windows will warn that a COM port is in use, even when the port is known to be unused at the time. If the port is known to be available, reassign it to the necessary value from 1 to 16.

Consult the Microsoft documentation and help system for details on using the device manager.

Note: If a conventional RS-232 COM port is available, there is no advantage to using the DS-1000 USB port and it is not necessary to install these USB drivers. However, many notebook computers do not have COM ports, and therefore it is necessary to install these DS-1000 USB drivers.

The DS-1000 USB drivers are located on the IVPC CD-ROM supplied with the tracer in the DS-1000 USB Drivers folder. This folder contains detailed instructions on how to install the drivers.

Note: These instructions are not specific to the DS-1000 and were provided by the USB hardware manufacturer. Therefore these instructions will not refer to the DS-1000 driver by name.

When first connecting the DS-1000 to a computer using the USB connection, Windows recognizes that new hardware has been connected and begins the process of installing the driver. The instructions on the CD-ROM provide much more detail, but in general, have Windows use the drivers in the driver folder on the IVPC CD-ROM using the “Have Disk” or “Browse” option.

Follow the steps as outlined in the driver installation instructions. If using a virtual COM port, confirm that the assigned COM port number is appropriate and if necessary change it to a number from 1 to 16 as described above. Also, be sure to set the COM port number in IVPC to match this setting.

Appendix C - DS-1000 Technical Specifications

Measurement Accuracy

PV Voltage Accuracy

Range	Error @ 25 C	Error 0-50 C	Resolution
1000 V	$\pm 0.4 \text{ V} (.4 \text{ V}) \pm 0.01\% (0.1\%)$	$\pm 0.4 \text{ V} (.4 \text{ V}) \pm 0.05\% (0.2\%)$	30 mV
100 V	$\pm 40 \text{ mV} (50 \text{ mV}) \pm 0.01\% (0.1\%)$	$\pm 40 \text{ mV} (80 \text{ mV}) \pm 0.05\% (0.2\%)$	3 mV
10 V	$\pm 4 \text{ mV} (17 \text{ mV}) \pm 0.01\% (0.1\%)$	$\pm 7 \text{ mV} (50 \text{ mV}) \pm 0.15\% (0.4\%)$	300 μV

PV Current Accuracy

Range	Error @ 25 C	Error 0-50 C	Resolution
100 A	$\pm 50 \text{ mA} (50 \text{ mA}) \pm 0.05\% (0.2\%)$	$\pm 50 \text{ mA} (50 \text{ mA}) \pm 0.1\% (0.2\%)$	3 mA
10 A	$\pm 5 \text{ mA} (5 \text{ mA}) \pm 0.05\% (0.2\%)$	$\pm 5 \text{ mA} (50 \text{ mA}) \pm 0.2\% (0.4\%)$	300 μA
1 A	$\pm 0.5 \text{ mA} (0.5 \text{ mA}) \pm 0.07\% (0.2\%)$	$\pm 0.5 \text{ mA} (0.5 \text{ mA}) \pm 0.35\% (0.9\%)$	30 μA

Irradiance and Aux Input Accuracy

Range	Error @ 25 C	Error 0-50 C	Resolution
5 V	$\pm 500 \text{ uV} (550 \text{ uV}) \pm 0.01\% (0.015\%)$	$\pm 500 \text{ uV} (800 \text{ uV}) \pm 0.05\% (0.1\%)$	150 μV
500 mV	$\pm 50 \text{ uV} (60 \text{ uV}) \pm 0.01\% (0.02\%)$	$\pm 50 \text{ uV} (120 \text{ uV}) \pm 0.05\% (0.1\%)$	15 μV
50 mV	$\pm 5 \text{ uV} (10 \text{ uV}) \pm 0.01\% (0.02\%)$	$\pm 5 \text{ uV} (70 \text{ uV}) \pm 0.05\% (0.1\%)$	1.5 μV
5 mV	$\pm 0.5 \text{ uV} (5 \text{ uV}) \pm 0.03\% (0.05\%)$	$\pm 1.1 \text{ uV} (60 \text{ uV}) \pm 0.05\% (0.1\%)$	0.15 μV

Temperature Accuracy

Error @ 25 C	Error 0-50 C
$\pm 1 \text{ C max}^*$	$\pm 2.5 \text{ C max}^*$

*Does not include error of attached thermocouple.

Accuracy = \pm typ. absolute error (max. abs. error) \pm typ. % of reading error (max. % error)

General Specifications

Power	85 Vac to 264 Vac 50/60 Hz
Battery	5 A-Hr, sealed lead acid (EnerSys #0809-0020)
Hours of Use	Up to 12 Hrs on full battery charge
Charge Time	Less than 8 hours
Size	46 cm x 36 cm x 20 cm (18" x 14" x 8")
Weight	14.4 kg (31.8 lbs)