DS-Tracer

I-V CURVE TRACER
User Manual

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This I-V curve tracer was built to Daystar, Inc. specifications by:

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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.

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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 .

NOMENCLATURE

A	Amperes or Amp
Hz	Hertz
I	Current
Ipk	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_{HIGH}	High voltage range < 600 Volts
V_{LOW}	Low voltage range < 150 Volts
V_{oc}	Open-Circuit Voltage: The maximum voltage a photovoltaic cell can generate with the output terminals open circuited
VPk	Voltage at peak power

1.0 INSTALLATION & QUICK START

Basic Description

The standard DS-100 Tracer has two current ranges (10 and 100 Amperes), two voltage ranges, two pyranometer and two temperature measurement inputs. Unless otherwise noted, this manual refers to DS-100 models.

A computer running the IVPC for Windows program controls the DS-Tracer. (See the IVPC Reference Manual) The computer connects to the DS-Tracer using one of its RS-232 serial ports—usually COM 1 or COM 2. Most of the operations of the DS-Tracer are actually done with the IVPC program. The basic steps to using the DS-Tracer are:

- Connect the DS-Tracer to the computer.
- Turn on the DS-Tracer power and connect DS-Tracer test leads to PV array.
- Connect pyranometers and thermocouples to DS-Tracer.
- Install and run IVPC for Windows. See your Windows Manual for installing programs.
- From File menu select New I-V Curve.
- Enter curve information and take curve.
- Save curve data.

To proceed with the Installation & Quick-Start, you will need the following:

- DS-Tracer I-V curve tracer and test leads.
- IVPC setup disk.
- PC computer running the Microsoft Windows® operating system.
- Serial cable to connect your computer to the DS-Tracer.

IVPC Installation

IVPC is written for use with Windows® 95 or newer which must be running to operate IVPC. To install IVPC, insert the IVPC CD-ROM (or floppy disk #1) in your computer. Note: The following description assumes the use of drive A:, but

you may designate another drive. Select Run from the File menu in the Windows program manager, enter **A:\SETUP**, and press OK as shown in Figure 1.

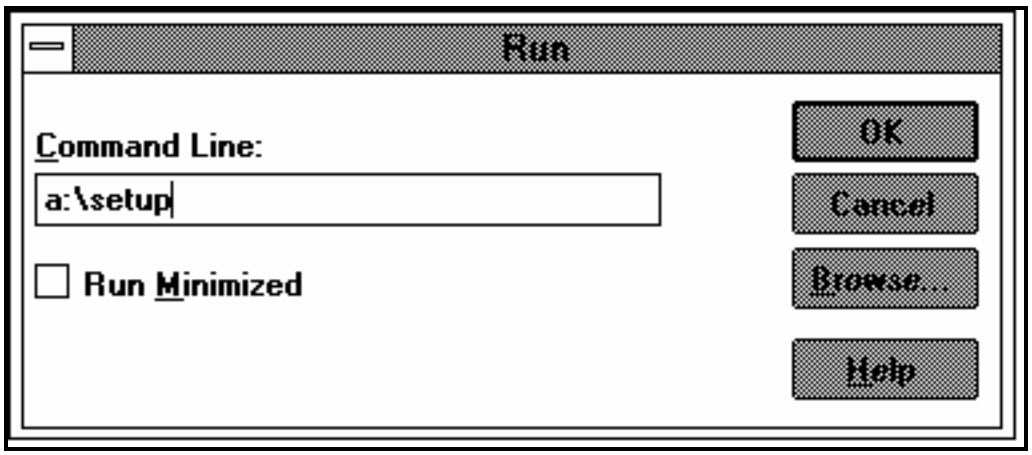


Figure 1. Running IVPC SETUP in Windows.

The setup program will prompt you for information on where you want to install IVPC. If you are unsure, use the defaults which create an IVPC sub-directory off of the root directory on drive C:. IVPC Setup automatically installs the necessary files in the IVPC directory and makes additions to your Windows system directory. Setup also creates a new program group icon in the Windows program manager window as shown in Figure 2.

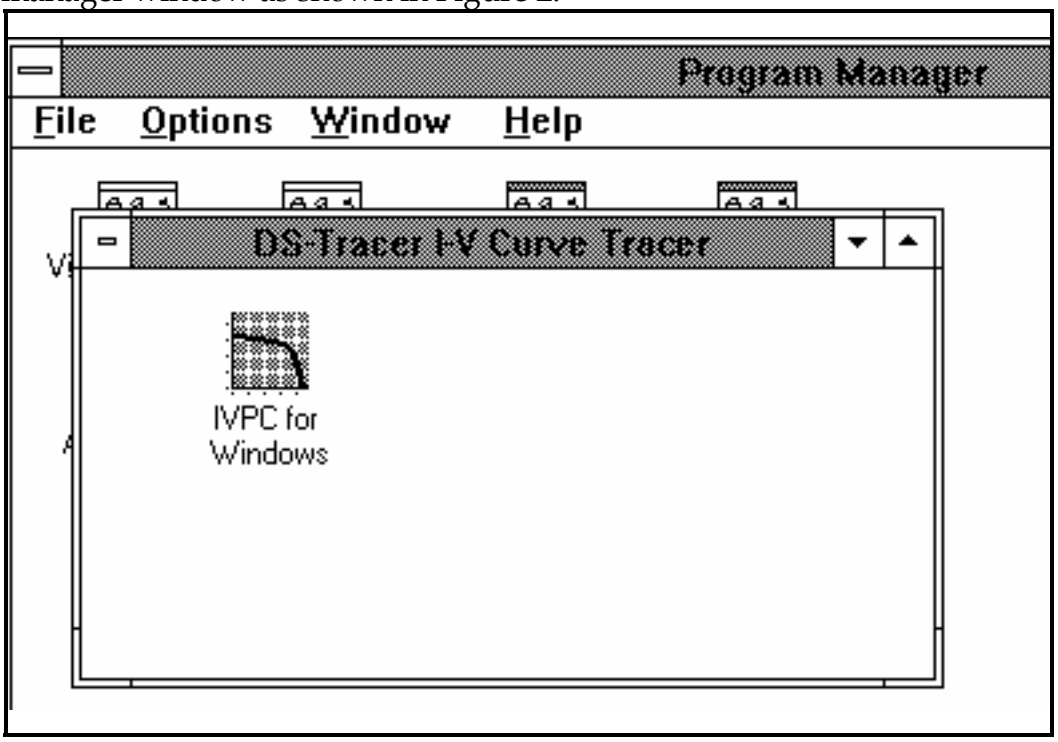


Figure 2. IVPC Program Group and icon.

CAUTIONS

There are several precautions to observe before using the DS-Tracer and IVPC to take I-V curves.

- The DS-Tracer battery should be fully charged. Unless otherwise noted in the packing instructions the AC charging circuit is set for 120 VAC, 60 Hz power.
- The DS-Tracer DISCONNECT switch should be in the OFF position and the DS-Tracer power should be turned on when making or breaking connections to a PV system or when changing the voltage range switch.
- The DS-Tracer should be connected 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 ensures that you can disconnect the DS-Tracer if a problem occurs. Refer to the DISCONNECT switch discussion in section 2.0 "Hardware Layout of The DS-Tracer" for details.

NOTE: The DS-Tracer DISCONNECT switch is not rated to interrupt high voltage systems producing more than five amps.

- Do not connect the DS-Tracer to anything other than an open-circuited PV system.
- Do not connect the DS-Tracer to a PV system with an open-circuit voltage greater than 600 Volts.
- Do not connect the DS-Tracer to any PV system with a short-circuit current greater than maximum for your unit (100 Amperes for a DS-100).

Connecting Your Computer to the DS-Tracer

The DS-Tracer has a standard female, 9 pin connector in the upper right-hand corner. Connect this to your computer with a compatible mating cable. In most cases commonly available cables will work. However, a NULL modem cable may be used if your computer has a non-standard configuration.

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 and the DISCONNECT switch is in the OFF position. Plug the test lead into

the DS-Tracer being sure to match the red and black connectors. The Voltage Sense connector is keyed and can only be inserted in one way.

For safety, it is recommended that connection s be made to a circuit that can be isolated from the PV array with a system switch rated at full PV power. Refer to section 2.0 "Hardware Layout of The DS-Tracer" for details.

With the DS-Tracer DISCONNECT switch still OFF, attach the test leads to your PV module. By making connections with the PV system disconnect switch off, the chance of electric shock is avoided. After connecting the test leads, close the PV system switch. At this point, PV voltage should be present at the DS-Tracer. Turn the DS-Tracer DISCONNECT switch to ON. Note: The DS-Tracer DISCONNECT switch should always be the last switch closed and the first switch opened.

Starting IVPC (Refer to the IVPC Manual for Details)

IVPC will operate with Windows 95 or newer. IVPC opens to the Data Grid window shown in Figure 3. The Data Grid is a spread sheet that lists all of the I-V curve data files stored in the current directory. When starting IVPC for the first time the Data Grid may be empty if no I-V curves have been taken.

IVPC for Windows V 2.0 - [I-V Curve Data Grid]

File Edit View Options Normalize Window

	C	Date	File Name	Temp. #1	Time	Temp. #1	Voc
1	☐	11-11-91	ACME.IVA	40	11:11:11	40	62
2	☑	06-08-1995	AS.IVA	25	08:17:19	25	7.948
3	☐	06-08-1995	TEST1.IVA	45	08:14:04	45	11.968
4	☐	11-11-91	ACME_N.IVA	25	11:11:11	25	66.40451
5	☑	09-28-94	TESTN2.IVA	25	15:59:59	25	16.837
6	☐	06-08-1995	TEST2_N.IVA	0	08:17:19	0	0
7	☑	06-10-1994	TEST CUR.IVA	0	09:26:55	-2906.7	12.612
8	☐	06-08-1995	TEST2.IVA	30	08:17:19	30	11.968

Figure 3. IVPC Data Grid window.

The Data Grid can be thought of as a detailed directory of the I-V curves. However, in addition to file names you can display other curve data such as peak power or module ID. Refer to the IVPC Reference Manual for directions for changing the data displayed. Use the Data Grid to locate and display I-V curves that were taken previously and stored.

Taking an I-V Curve

Before taking a curve, the DS-Tracer should be turned on and connected to the PV system. Your computer should be connected to the DS-Tracer and running IVPC. From the IVPC File menu, shown in Figure 4, select New I-V Curve or press Ctrl-N (control and N keys at the same time).

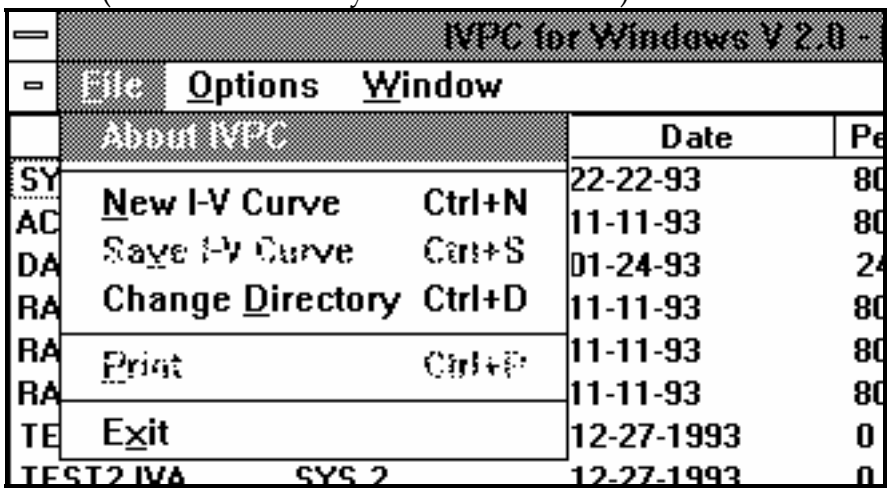


Figure 4. Select New Curve in the File menu to take an I-V curve.

Note: Some figures shown in this manual may not be exact because the software is updated from time-to-time and the information displayed may change slightly.

IVPC will open a new curve window as shown in Figure 5. This window provides areas to enter curve information identifying the I-V curve. The DS-Tracer takes 12 seconds to initialize the tracer hardware. Typically you will enter curve data during this delay. A status message indicating that the DS-Tracer is pre-charging is displayed in the area normally used to plot the curve.

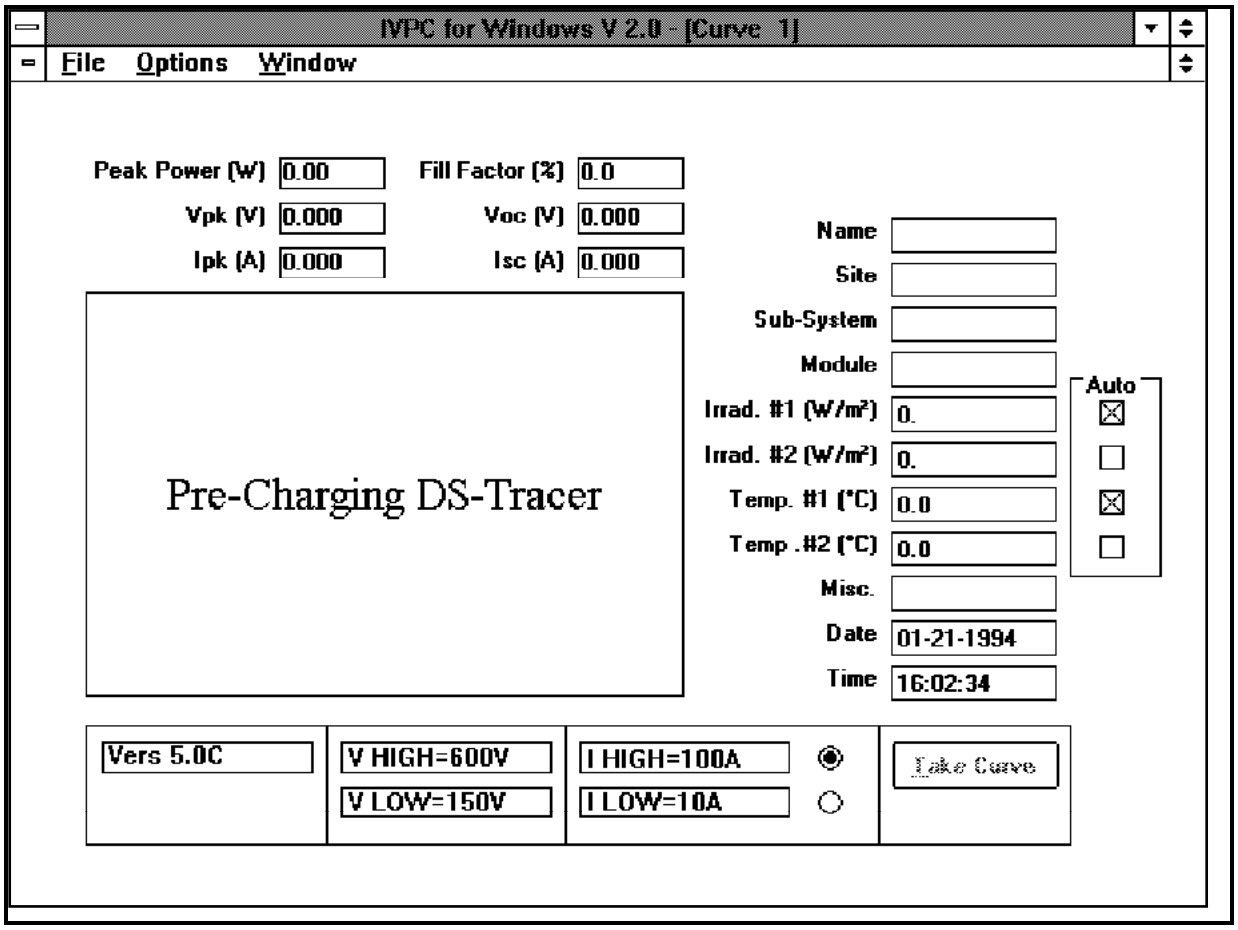


Figure 5. New Curve screen while DS-Tracer is pre-charging.

After initialization, the status message changes and the Take Curve button is enabled as shown in Figure 6. The status message indicates that a curve can be taken by using the mouse to press the Take Curve button or by pressing Alt-T.

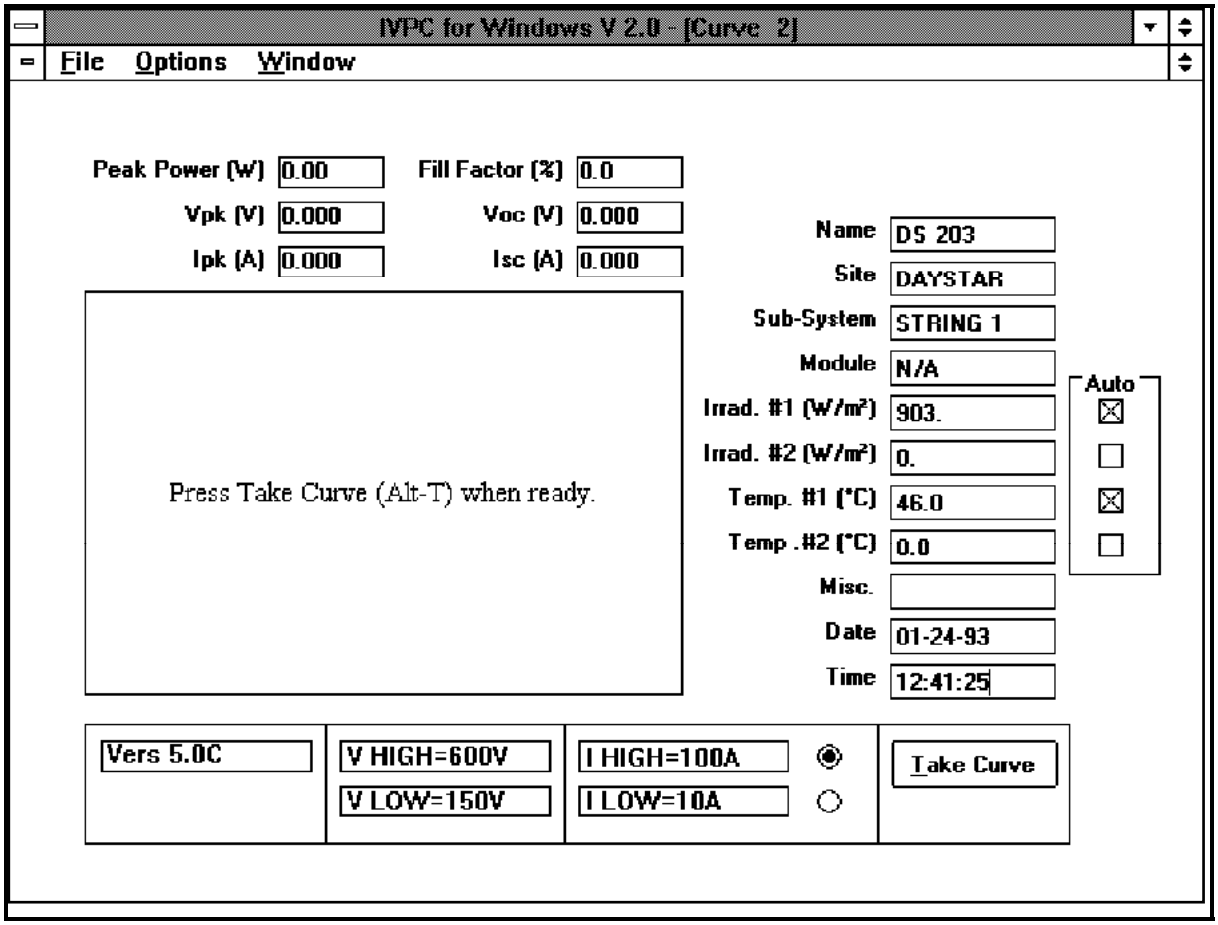


Figure 6. DS-Tracer is pre-charged and ready to immediately take the curve.

After pressing Take Curve, the DS-Tracer takes approximately 6 seconds to take the curve and plot the data as shown in Figure 7. You may save this data by selecting Save I-V Curve from the File menu. The curve is stored in the current directory and the Data Grid is updated.

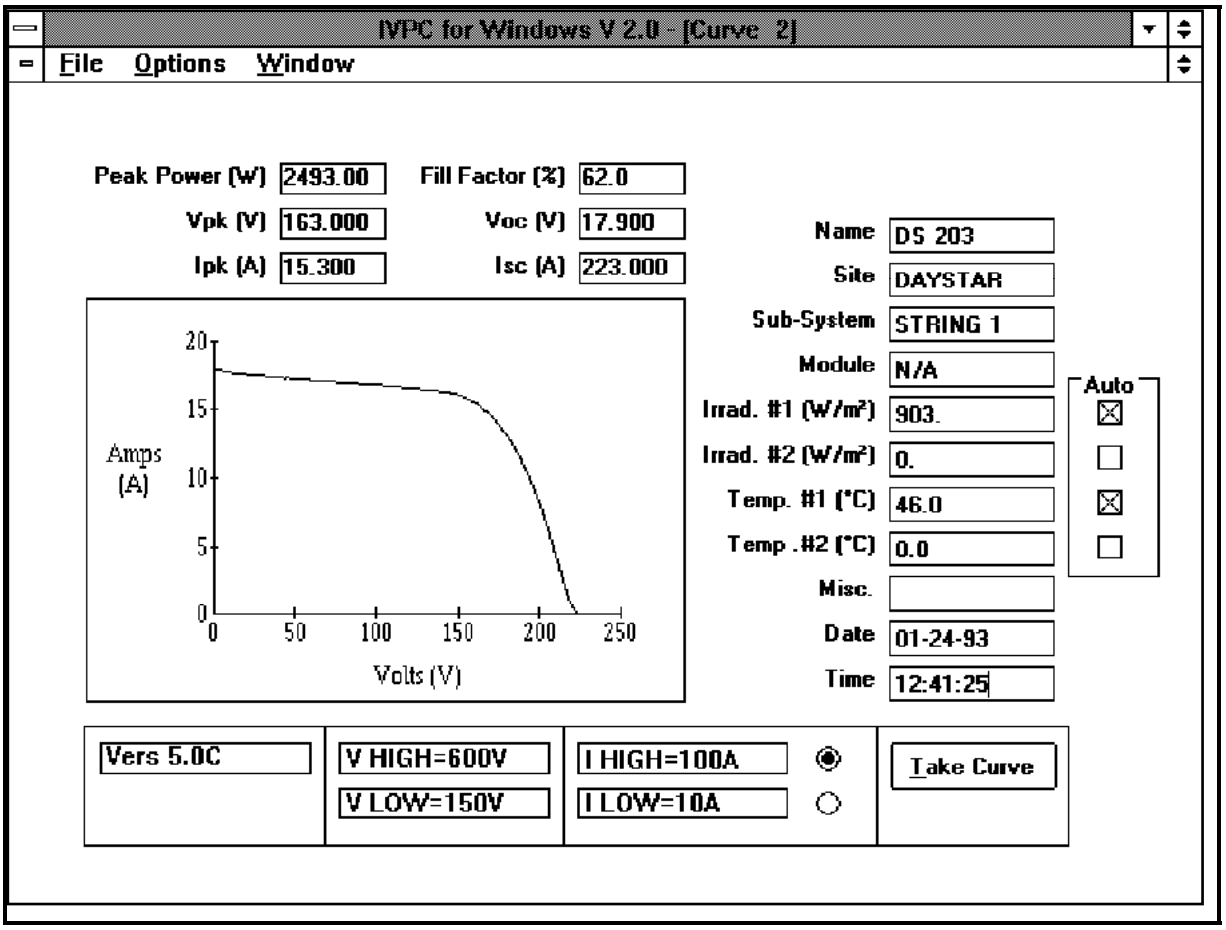


Figure 7. Example of I-V curve.

You can return to the Data Grid without closing the curve window by using the Window menu shown in Figure 8.

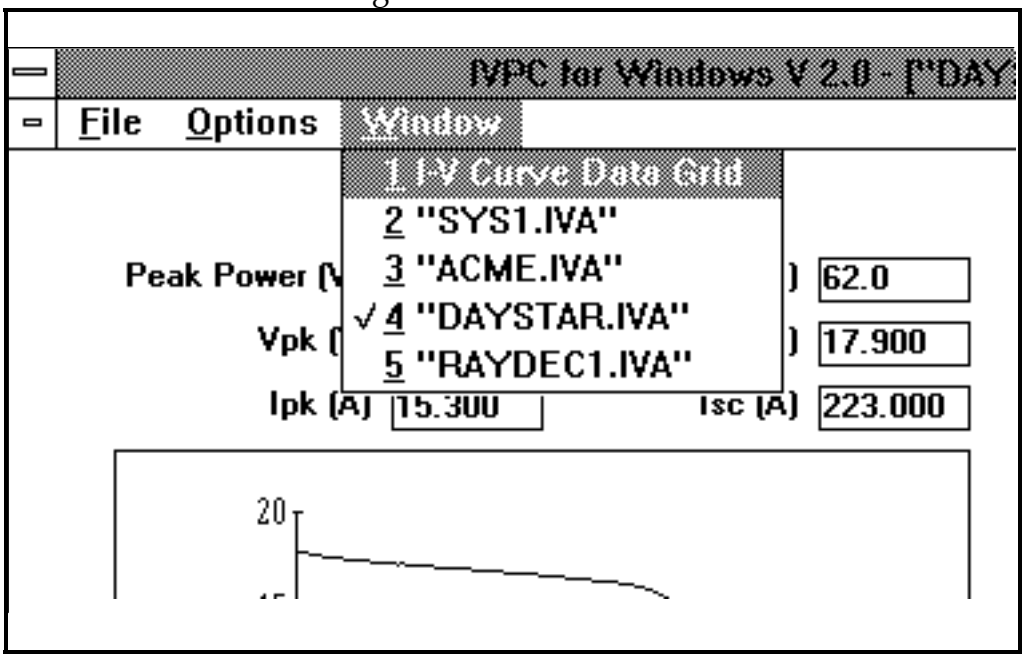


Figure 8. Moving to the Data Grid with the Window menu.

Close the I-V curve window with the window control box shown in Figure 9. This will also return you to the Data Grid window.

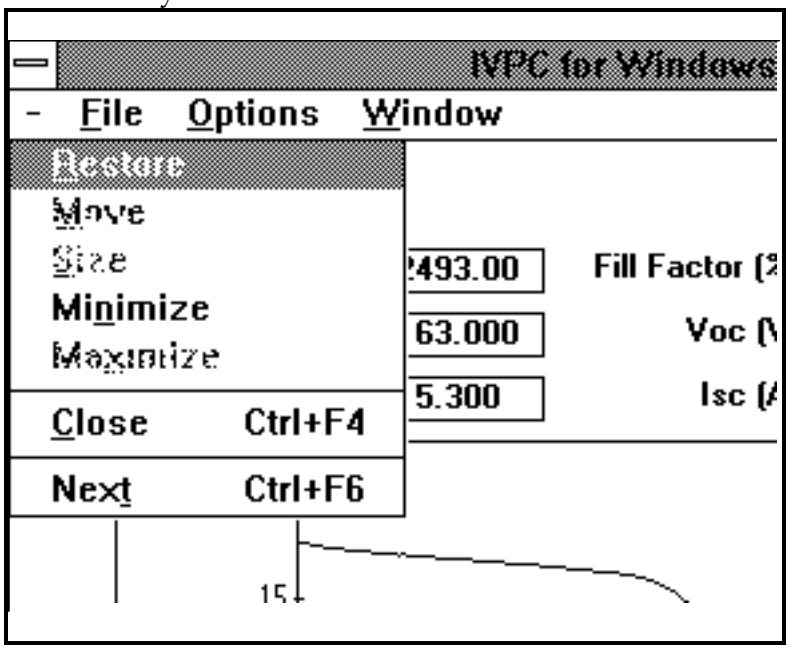


Figure 9. Closing a curve window.

If You Get an Error

There are several error messages you may see when taking a curve. The DS-Tracer automatically turns itself off when it does not receive a command for 15 minutes. This features 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 you will receive an error indicating that the DS-Tracer does not respond. Simply turn the DS-Tracer switch off, wait several seconds, and turn it back on. Press Yes to 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. Simply follow the IVPC directions given when the error occurs. Most errors happen as soon as you chose New I-V Curve from the File menu. Most often you can correct the problem and continue without having to restart.

Displaying Saved Curves

I-V curves that are stored are selected from the Data Grid. Be sure to set the current working directory to the sub-directory where the curves are stored. Use the Change Directory command in the File menu to select a new directory as shown in Figure 10. To display a curve shown on the Data Grid, double click anywhere on the row for that curve. A window very similar to the one used to take a curve is displayed. More than one curve window can be open at the same time. Use the Window menu to return to the Data Grid and select another curve. The Window menu is also used to switch between curve windows.

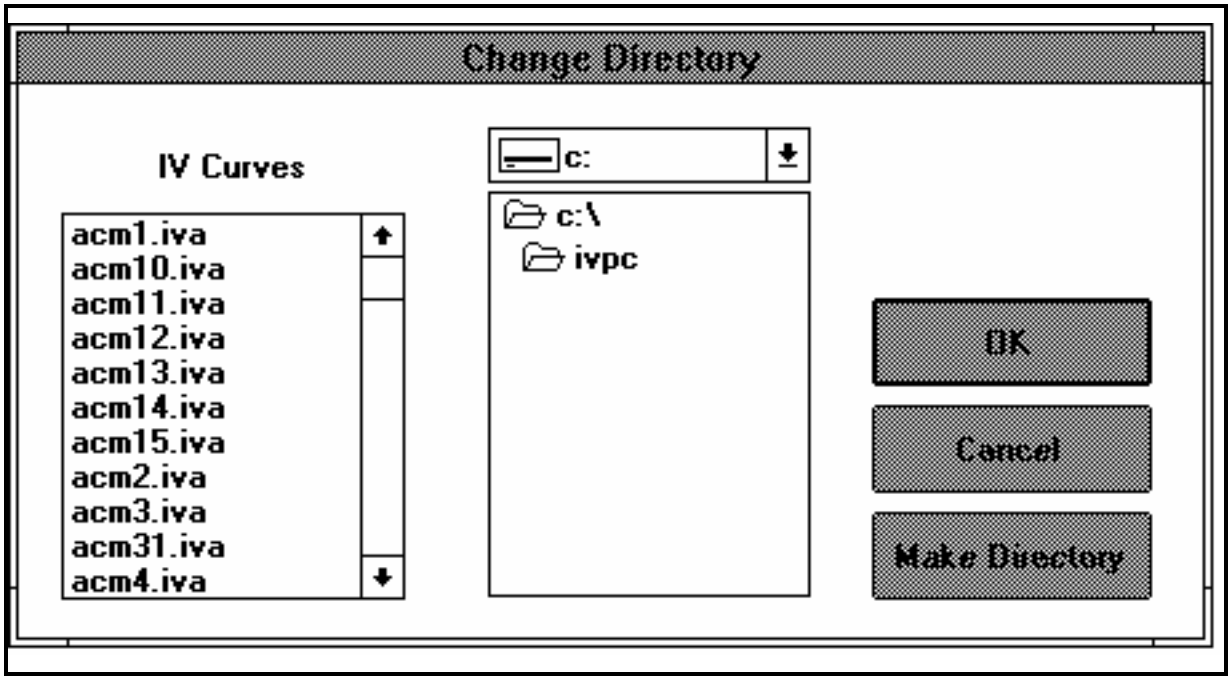
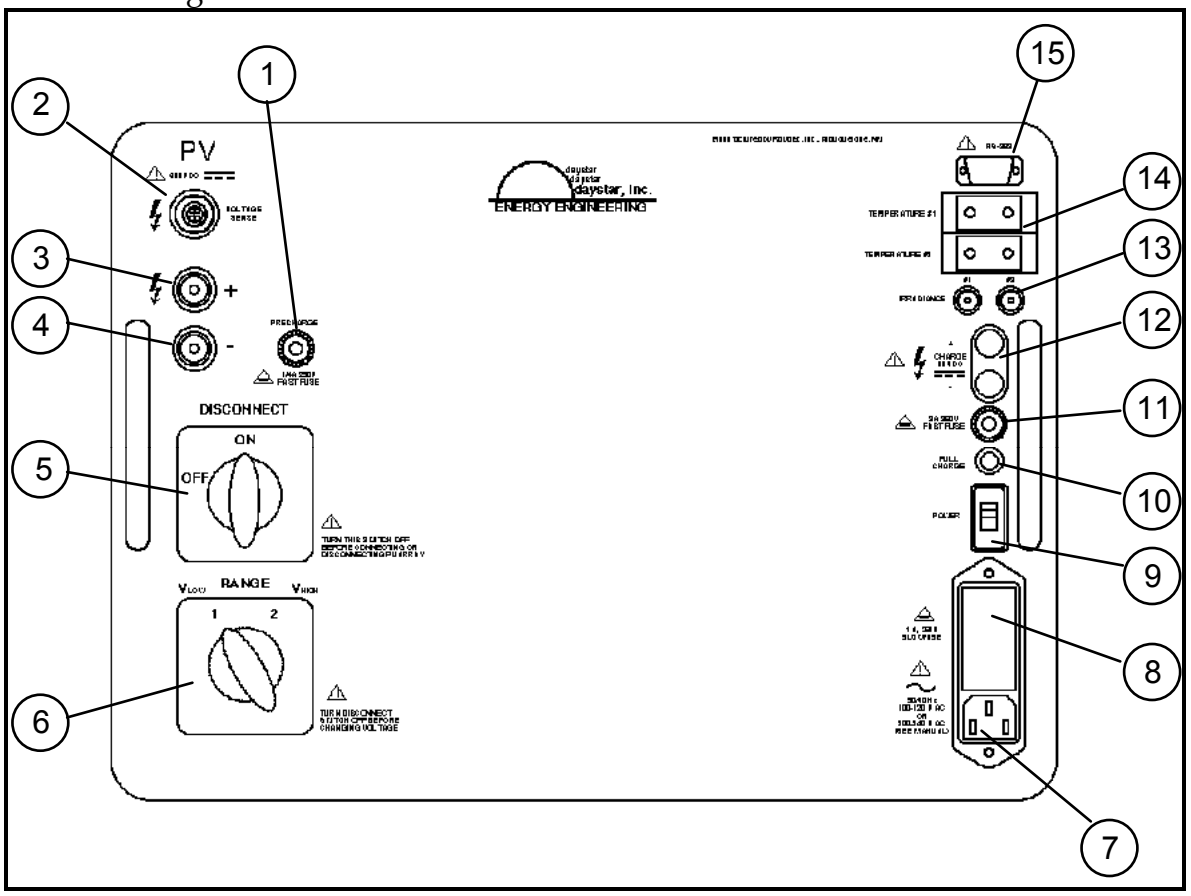


Figure 10. Change Directory dialog box.

2.0 Hardware Layout of The DS-Tracer

This section describes the DS-Tracer 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 11 shows the front panel layout of the DS-Tracer. Each of the key components is described in detail in the following section.



1. Pre-Charge Fuse
2. Voltage Sense Connector
3. Positive PV System Connector
4. Negative PV System Connector
5. Disconnect Switch
6. Voltage Range Switch
7. AC Supply Input
8. AC Voltage Select & Fuse
9. Power Switch
10. Full Charge Indicator
11. DC Supply Input Fuse
12. DC Supply Input
13. Pyranometer Inputs (DS-100 Only)
14. Thermocouple Inputs (DS-100 Only)
15. RS-232 Serial Port Connector

Figure 11. Face plate of the DS-Tracer .

Pre-Charge Fuse

The DS-Tracer uses a pre-charge circuit to apply a negative voltage to the DS-Tracer load capacitors before taking a curve. The pre-charge fuse protects the pre-charge circuit if it is inadvertently active while the DS-Tracer load capacitors are sweeping an I-V curve. Typically this fuse blows if the DS-Tracer DISCONNECT switch is turned on or off during the pre-charge cycle. Replace the fuse with a 1/4 A Fast 3AG fuse. Refer to the section Pre-Charge Precautions for more details and information on the potential damage the pre-charge can do to thin-film PV modules.

Note: Only replace this or any other fuse with the DS-Tracer completely disconnected from the PV array.

PV & Voltage Sense Connectors

When an I-V curve is taken, the load current flows through the test lead into the large red and black PV connectors. The red and black connectors go to PV array positive and negative terminals respectively. The PV array voltage is measured separately to avoid measurement errors caused by voltage drops in the power leads. The test leads incorporate voltage sense wires that run between the Voltage Sense connector and the ends of the test leads.

DISCONNECT Switch

The DISCONNECT switch is used to isolate the DS-Tracer from the PV array when connecting or disconnecting the test leads between the tracer and PV system. Having this switch in the OFF position ensures that no significant current can flow into the DS-Tracer while making or breaking connections. This feature prevents the possibility of an electrical arc and protects the user from possible injury. Although the DISCONNECT switch should always be OFF when connecting or disconnecting the test leads, it becomes more important at higher PV voltages.

Note: the DS-Tracer DISCONNECT switch is not rated to break the electrical current at the full voltage and current rating of the DS-Tracer.

The DS-Tracer should always be connected through a PV system disconnect rated at the PV system Voc and Isc values as shown in Figure 12. A system switch provides a way to break a circuit should the DS-Tracer have a major internal failure.

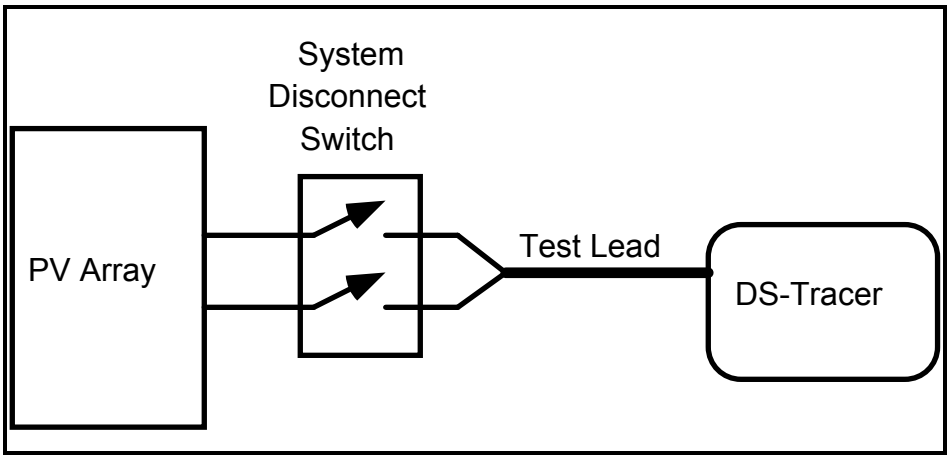


Figure 12. Use of PV system disconnect switch.

Voltage Range Switch

The voltage range switch changes the electrical configuration of the capacitors that form the load for the PV array. It will not affect the measurement range of the I-V curve, but it does affect how quickly an I-V curve is taken. In the low voltage setting, the DS-Tracer has more load capacitance and therefore a curve is swept slower. Note: This affects how quickly the PV array goes from Isc to Voc. It does not affect how long it takes a curve to plot in IVPC. All curves take about 6 seconds to take with IVPC regardless of the RANGE switch position.

The higher Isc and the lower Voc the more quickly a curve is taken. If curve are swept too fast, the dynamic characteristics of the PV array can become significant and affect the accuracy of an I-V curve. Under most circumstances, the DS-Tracer can be left in the V_{HIGH} range. However, the low voltage range will give a better curve of low voltage, high current PV systems (for example 60 Amps, 12 Volts). Refer to section 4.0 "Theory of Operation" for more details on DS-Tracer capacitance.

NOTE: Leave the voltage range switch on the DS-Tracer in the HIGH position unless taking a high current, low voltage I-V curve.

AC Power Entry & Fuse

The DS-Tracer battery is recharged by connecting the DS-Tracer to an AC power source with the cord provided. It is not necessary for the tracer to be on. In fact, the battery will charge faster if the DS-Tracer is turned off. Refer to section 5.0 " Maintenance" for details of battery charging.

DS-Tracer Power Switch

This switch turns on the DS-Tracer power. This switch should be on before connections are made to a PV array. It makes no difference if it is on or off while connecting to the control computer. Of course, it must be on to take an I-V curve. 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 you suspect that the DS-Tracer has turned itself off, simply 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. Sometimes this LED will turn on for several seconds if the AC power cord is unplugged before the battery is fully charged. This occurrence does not indicate a fully charged battery.

Auxiliary DC Power & Fuse

The DC Power connector is a standard banana jack connector used to recharge the battery from a DC power source such as a PV module. Do not exceed the input voltage and current rating. A fuse protects the Tracer from excess current.

Pyranometer Inputs

The model DS-100 has two inputs for measuring pyranometers. Refer to the IVPC Manual and Appendix C "DS-Tracer Technical Specifications" for details.

Note: These inputs are not electrically isolated from each other or the thermocouple circuits. Therefore they should always be electrically isolated when connected. The pyranometer inputs are isolated from the PV test inputs.

Thermocouple Inputs (DS-100 Only)

The standard model DS-100 is configured with two type "T" thermocouple inputs for measuring PV array module temperatures. Refer to section 8.0 "IVPC Software Reference" and Appendix C "DS-Tracer Technical Specifications" for details.

Note: These thermocouples are not electrically isolated from each other or the Pyranometer circuits . Therefore they should always be electrically

isolated when connected. The thermocouple inputs are isolated from the PV test inputs.

RS-232 Serial Port

All DS-Tracer operations are controlled with commands sent to the DS-Tracer through this serial 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 you can create your own software using the DS-Tracer command codes described in section 7.0 "DS-100 Tracer Capabilities".

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

9600 Baud
No parity
8 data bits
1 stop bit
Transmits on pin 2
Receives on pin 3
Pulls CTS, DSR and CD High at all times.
GND on pin 5

The DS-Tracer RS-232 port is optically isolated from all other DS-Tracer circuitry—PV array, temperature, and irradiance.

3.0 Using The DS-Tracer to Take I-V Curves

Connecting Your Computer to the DS-Tracer

The DS-Tracer has a standard, female 9 pin connector in the upper right-hand corner. Connect this to your computer with the appropriate cable. For example, if your computer has a male 9 pin serial port use a Male-Female 9 pin cable. Your computer may have a female connector or even a 25 pin connector so select the correct cable. In most cases these common cables will work fine. Use a NULL modem cable if your computer is configured as a DCE rather than a DTE.

Connecting a PV Module to the DS-Tracer

The DS-Tracer is connected to the PV system with the test leads provided. Before connecting a PV module, be sure the DS-Tracer power switch is ON and the DISCONNECT switch on the tracer front panel is in the OFF position. Plug the test lead into the DS-Tracer being sure to match the red and black connectors. The Voltage Sense connector is keyed and can only be inserted in one way. With the DISCONNECT switch still OFF, attach the test leads to your PV module.

For maximum safety, it is recommended that connection s be made to a circuit that can be isolated from the PV array with a system switch rated at full PV power. Refer to the DISCONNECT switch discussion in section 2.0 "Hardware Layout of The DS-Tracer".

By making connections with the PV system switch open, the chance of electric shock is avoided. After connecting the test leads, close the PV system switch. At this point, PV voltage should be present at the DS-Tracer. Turn the DS-Tracer DISCONNECT switch to ON. Note: The DS-Tracer DISCONNECT switch should always be the last switch closed and the first switch opened.

Taking an I-V Curve

1. Connect your computer to the DS-Tracer as described above and start IVPC for Windows as describe in section 8.0 "IVPC Software Reference". Turn the power switch of the DS-Tracer on.

2. Check the clock time of the notebook computer. This clock is used to record the time for I-V curves.

3. If you have a DS-100 TRACER, you can connect one or two pyranometers directly to the DS-Tracer. If pyranometers are connected you must enter

correct pyranometer constant in IVPC. See section 8.0 "IVPC Software Reference" on automatic operation.

4. If you purchased a DS-100 TRACER, you may connect one or two thermocouples directly to the DS-Tracer. See section 8.0 "IVPC Software Reference" on automatic operation.

5. Open the PV array system switch to isolate the PV array under test. NEVER try to take a curve of a PV array connected to a battery or inverter.

6. With the DS-Tracer DISCONNECT switch in the OFF position, connect the PV system to the DS-Tracer front panel using the leads provided. (Red is positive, black is negative.) Plug the red and black leads and the voltage sense plug into the mating connectors on the DS-Tracer; then connect the negative lead to the PV array followed by the positive red lead. Be sure to connect the tracer to the PV system through a system disconnect switch rated for Isc and Voc. Refer to the discussion of the DISCONNECT switch in the section 2.0 "Hardware Layout of The DS-Tracer".

7. Set the voltage range switch to the desired setting, V_{LOW} or V_{HIGH}. Leave the voltage range switch in the V_{HIGH} position unless taking a curve of a high current (> 50 Amperes), low voltage (< 24 Volts) PV array.

8. Turn the DS-Tracer DISCONNECT switch to the ON position. The DS-Tracer is now ready to take I-V curves.

9. From the File menu in IVPC select "New I-V Curve". Refer to New I-V Curve in the IVPC Software Reference section 8.0 for details on using IVPC to take a curve.

10. To take another I-V curve of the same PV system, repeat step 9.

    To test another PV subsystem, turn the DS-Tracer DISCONNECT switch to OFF and open the PV system disconnect switch. Remove the cables and repeat steps 5 through 9.

WARNING: Disconnecting cables when the array disconnect switch is ON may result in electrical arcing and may damage the DS-Tracer and/or injure the operator.

11. When finished taking curves, turn the DS-Tracer DISCONNECT switch to the OFF position and open the PV system disconnect switch. Disconnect the DS-Tracer from the PV system. Remove the positive, red lead first followed by the negative lead.

12. Switch off the power to the DS-Tracer.

4.0 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.

The DS-Tracer employs two high speed, analog-to-digital converters to sample the current and voltage. One converter digitizes the array voltage while the other digitizes the array current. The DS-Tracer analyzes the digitized values, saves those that show significant change, and transfers the data set to the control computer. The data set includes the I-V curve data plus 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, temperature, and array identification may be added to each data set. The irradiance and temperature data are either entered by the operator using IVPC or sampled by the DS-100 TRACER. The DS-75 does not have the capability to sample irradiance and temperature.

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 or short circuit value, the voltage and current are sampled by high speed analog to digital converters. These data points define the I-V curve.

Before acquiring data, the DS-Tracer reverse charges its capacitive load by approximately -25 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 Isc is reached. This method allows a true short circuit current reading to be made. The DS-Tracer allows 5 seconds for a curve to reach open circuit voltage. At this point the circuitry discharges the capacitors through a resistive load.

The complete cycle actually begins with a 5 second discharge of any voltage on the capacitors. This discharge is followed by 7 seconds of pre-charge, 5 seconds to take the curve, and finally another 5 seconds for discharge. The initial discharge cycle is not normally needed. However, if the DS-Tracer connection

sequence is not performed correctly, these capacitors might accidentally be charged. This will not harm the DS-Tracer , but if these capacitors are not discharged before the pre-charge cycle, the pre-charge fuse will blow.

The DS-Tracer uses an SCR to close the circuit between the PV system and the load capacitors. SCRs are susceptible to false triggering (turn on) if the voltage across them is increased too rapidly. The DS-Tracer DISCONNECT switch uses two 1MΩ resistors (one each for the positive and negative leads) across the switch contacts. These resistors allow the SCR to "see" the PV system voltage before the DISCONNECT switch is closed; thereby preventing the SCR from false triggering when the disconnect switch is closed. This switch should always be the last switch closed and the first switch opened when making PV system connections.

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 (Isc) and dividing it by the DS-Tracer load capacitance in Farads. Refer to Appendix C "DS-Tracer Technical Specifications" for the values of load capacitance which changes with position of the voltage RANGE switch. For example, if using a load capacitance value of 0.005 f, and a PV system with an Isc of 20A the rate would be:

Rate = 20A/0.005f=4000 V/S.

When comparing this value to the PV system, it is best to normalize this rate to an individual PV cell. This can be 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 4000 V/S÷ 50=80 V/S. 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.

5.0 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 Hawker Energy.) 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 eliminates the possibility of completely discharging the battery if the DS-Tracer power is accidentally left on.

The DS-Tracer battery may be charged in two ways–AC line power or a DC source such as a PV module. To charge the battery from AC line power, connect the tracer to a 120 V or 240 V 50/60 Hz AC outlet using the AC power cord included with the DS-Tracer.

You can switch the DS-Tracer from 120 V AC to 240 V AC by changing the voltage selector (only two positions are connected) . The voltage selector card and AC line fuse are located within the AC input receptacle. Voltage selection is made by rotating the card to the desired position. **The DS-Tracer is shipped in the 120 V position.**

NOTE: Because of potential ground loops, do not attempt to take an I-V curve with the AC power cord plugged into an AC voltage source.

In addition to using AC power, you can connect a DC supply such as a PV module to the DC input connector. This feature is useful when working in remote locations without AC power. Connect a DC V 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 1.25 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. If you connect a supply that produces less than 1.25 A, 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.

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 light comes on. You do not need to turn the DS-Tracer on to recharge the battery, In fact, it will recharge more quickly if the DS-Tracer is off.

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.

Exterior Cleaning

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

Transportation

Treat the DS-Tracer as you would a notebook computer. The DS-Tracer is mounted in a heavy duty case but 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. The DS-Tracer can be carried on board airline flights and fits under most airline seats. A shipping container with foam packing may be ordered from Daystar, Inc.

DS-Tracer Fuses

The DS-Tracer has three externally accessible fuses. The first of the external fuses is located in the AC input power receptacle. Power line surges or internal faults can 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 user accessible fuse is located on the front panel and is labeled “PRE-CHARGE” fuse. This 1/4 Amp, fast-blow fuse protects the DS-Tracer pre-charge circuitry. See section 6.0 “Pre-Charge Precautions” for more details. This fuse may blow if the DS-Tracer connection and disconnection sequences are not followed exactly.

A third 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.

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. Contact DAYSTAR INCORPORATED if you suspect that this fuse has blown.

6.0 Pre-Charge Precautions

In order to compensate for voltage drops across the test leads, the DS-Tracer pre-charges the capacitive load to -25 V. When an I-V curve is taken, the PV module voltage will start at -25 V and increase to 0 V (Isc) and continue to Voc. Most PV modules (single crystal silicon for example) can easily withstand this negative pre-charge voltage. However, this pre-charge voltage can damage some thin film modules—particularly those with very low Voc values. Higher voltage modules have more cells in series and therefore the pre-charge voltage is spread across more cells. This problem has only been noted during measurements of individual low voltage, thin-film modules. It is not a concern for systems with many modules in series.

You can avoid damage to a thin film module by inserting a by-pass diode across the module terminals as shown in Figure 13. This diode limits the reverse voltage to approximately -1 V maximum. Locating the diode at the PV module terminals rather than at the DS-Tracer allows the pre-charge to still offset voltage drops across the test leads.

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. Due to circuit resistances, this current will not exceed 250 A and can last less than 2 ms. The diode reverse voltage rating must be greater than module Voc. A Motorola MR750 series rectifier is recommend. This rectifier has a reverse voltage rating of 50 V and can handle peak currents over 300 A.

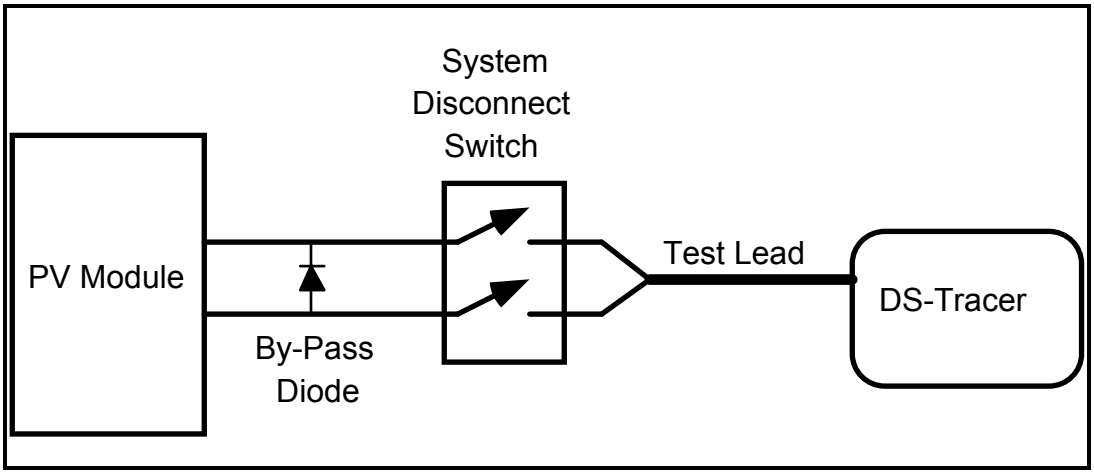


Figure 13. Use of by-pass diode to protect thin-film PV modules.

7.0 DS-100 Tracer Capabilities

The DS-100 TRACER has additional capabilities over the DS-75 TRACER. These include analog circuits for reading external temperatures and irradiances, a second PV current range, and external operation and control. Each of these additions is discussed separately.

Temperature & Irradiance Inputs

The DS-100 has two type "T" thermocouple temperature inputs and two BNC inputs for connecting pyranometers. You do not need to use these inputs to take I-V curves. The temperature and pyranometer inputs are enabled using the AUTO feature of IVPC. When a curve is taken, the temperature and pyranometer inputs are sampled immediately before the DS-100 takes a curve. Refer to the section on IVPC for details on using these inputs when taking I-V curves.

Temperature Connections

Two standard type "T" thermocouple connectors are available on the front of the DS-100. The thermocouple inputs are electrically isolated from the PV system, but not isolated from other analog circuits. Therefore, it is necessary that the thermocouple be electrically insulated when bonded to a surface.

Pyranometer Connections

There are two BNC connectors for pyranometer inputs located on the front panel of the DS-100. These programmable inputs can accommodate ± 3 V signals and accurately measure mV signals. These inputs can be used for any analog voltage measurement within the range of the DS-100. Refer to the Appendix C "DS-Tracer Technical Specifications" for details on measurement ranges.

Multiple Current Ranges

The DS-100 includes two current ranges; 10 Amperes and 100 Amperes. Use IVPC before the I-V curve is taken to select of one of these two ranges. You will not damage the DS-100 by inadvertently selecting the low range when the high range is required. However, the displayed I-V curve will not include current values higher than 10 Amperes.

External Command Set

Typically the IVPC program controls the DS-100, however you can write your own program if necessary. Some users may want to write software to perform custom tracer operations. This is possible using the following commands sent to the DS-100 through its RS-232 serial port.

The DS-100 sends a prompt character ">" when it is ready to receive a command line. Commands should only be sent to the DS-Tracer after receiving this prompt. Each command has a unique one character start code, indicating the type of command, followed by comma-delineated parameters as required.

After receiving a command line, the DS-Tracer attempts to perform the requested operation. If the command and its parameters can be decoded properly, the DS-Tracer sends a "*" followed by a carriage return (ASCII 0DH) to indicate that the command was accepted. If the command was not accepted, the DS-Tracer will return an error line in place of the "*" line . It is this return line that should be checked following all commands. Refer to Appendix B "DS-Tracer Error Codes" for a list of error messages. Each command of the DS-Tracer is described below with an example of a proper command line and responses from the DS-Tracer.

Read I & V "B"

This command reads the DS-100 array current and voltage A/D converters, and repeatedly outputs their 12 bit integer values until another character is received. Typically it is used to calibrate the DS-Tracer. Note: The values return have not been zeroed—i.e. 0 V won't give a 0 integer value.

Format

```
"B,n1,n2"      n1 = Voltage gain code 0,1,2, or 3.
               n2 = Current gain code 0,1,2, or 3.

Gain Codes
0 = 1
1 = 10
2 = 100
3 = 1000
```

Example

```
command  "B,0,1"
response "*"
response "3045"Voltage A/D Output.
response "2839"Current A/D Output.
delay
response "3046"
response "2838"
```

Continues until a character is received.

Pre-Curve "E"

This command initiates the pre-curve sequence. The sequence is a 5 second discharge of the tracer load capacitors followed by a 7 second pre-charge.

Format

```
"E"          Start pre-curve sequence.
```

Example

```
command  "E"
response "*"
12 second delay
response ">"
```

Read Analog Input "R"

The read-analog command has a form for reading a specified analog input channel and a form for auto-calibrating the gain of the analog circuits.

Format

Option 1

```
"R,n1,n2"    Read input n1 (0-13).
             n2 = Pyranometer constant in W/m2 / volt.
                  Only needed if n1 = 2 or 3.
```

Option 2

```
"R,C,a"      Calibrate and set average constant.
```

Option 1 reads one of 14 possible analog inputs. It returns a fixed point numeric value for the channel.

"n"	Description
0	Temperature #1
1	Temperature #2
2	Irradiance #1
3	Irradiance #2
4	N/A
5	2.5 V Reference
6	0V Reference for 3.0 V scale
7	0.25 V Reference
8	0V Reference for 0.30 V scale
9	25 mV Reference
0	0V Reference for 30 mV scale
11	2.5 mV Reference
12	0V Reference for 3.0 mV scale
13	Thermocouple Reference Junction Temp.

Option 2 is used to calibrate the gain of the analog circuit based on the 2.5 V internal reference. The constant "a" is used to specify the number of samples that should be averaged to produce a reading. This averaging helps to reduce noise errors. Higher values of "a" reduce noise, but slow down analog input sample rates. A typical value for "a" is 40. The option 2 format does not return any values.

Example 1

```
command  "R,5" Read 2.5 V reference.
response "*"
response "2.499"
response ">"
```

Example 2

```
command  "R,C,40"   Calibrate and average 40 samples.
response "*"
response ">"
```

PV V & I Scales Factors "S"

This command returns the floating point conversion constant for the PV voltage and current inputs for the specified gain codes. There is a different conversion constant for each gain code. The integer values returned by the DS-Tracer for the PV voltage and current values are multiplied by these constants to convert these values to engineering units. The constants are returned in IEEE single precision (32 bit) binary format.

Format

```
"S,n1,n2"       n1 = Voltage gain code 0,1,2, or 3.
                n2 = Current gain code 0,1,2, or 3.

Gain Codes
0 = 1
1 = 10
2 = 100
```

3 = 1000

IEEE 32 bit floating point format:
1 sign bit, 8 bit signed exponent, 23(+1) bit mantissa.
Refer to IEEE documentation for more details.

Example

command "S,0,1"
response "*"
4 byte (32 bit) voltage constant
4 byte (32 bit) current constant
response ">"

Take I-V Curve "T"

This command causes the DS-Tracer to take an I-V curve using the specified current range. The I-V curve data is accessed with the "Transfer" command "X".

Format

```
"T,L"    Use low current range.
"T,H"    Use high current range.
```

Example 1

```
command  "T,L"
response "*"
response ">"
```

Take low current curve.

Example 2

```
command  "T,H"
response "*"
response ">"
```

Take a high current range curve.

Read DS-Tracer Version "V"

This command reads the DS-Tracer software version number, current and voltage ranges. Note: A "C" at the end of the version number indicates that the DS-Tracer has high and low current ranges and that it has temperature and irradiance inputs (i.e. its a DS-100).

Format

```
"V"
```

Example

```
command  "V"
response "*"
response "VERS 3.2C"
response "V LOW=150V"
response "V HI=600V"
response "I LOW=10A"
response "I HI=100A"
response ">"
```

Disable Power Down "W"

Normally the DS-Tracer turns itself off after 15 minutes without any activity. This command disables this feature until the DS-Tracer is reset by turning power off.

Format

"W"

Example

```
command  "W"
response "*"
response ">"
```

Transfer Curve Data "X"

This command is used to transfer curve data from the DS-Tracer. The command transfers the I-V curve data in binary format. If there are no errors, this command returns "*" followed by a 1056 byte binary data record.

Format

```
"X"      Transfer last data record.

Binary format.
   int   Voc;                /* Curve Voc  */
   int   Isc;                /* Curve Isc  */
   int   Num_Points;         /* Number of data points
                  */
   char  V_Gain;             /* V gain code used */
   char  I_Gain;             /* I gain code used */
   int   Volts[256];         /* Array of voltage data
                  */
   int   Amps[256];          /* Array of current data
                  */
   float   Vscale;           /* Voltage constant  */
   float   Iscale;           /* Current constant  */
   float   Temp1;            /* Temperature #1  */
   float   Temp2;            /* Temperature #2  */
   float   Irrad1;           /* Irradiance #1  */
   float   Irrad2;           /* Irradiance #2  */

int Format:    8 bit MSB|8 bit LSB

IEEE 32 bit floating point format:
1 sign bit, 8 bit signed exponent, 23(+1) bit mantissa.
Refer to IEEE documentation for more details.
```

Example

```
command  "X"
response "*"
```

```
response 1056 binary bytes
response “>”
```

8.0 TROUBLESHOOTING

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

- **I-V curve is flat.**
- PV short circuit current exceeds current range (check current range setting).

- **I-V curve does not start at 0 V (does not reach Isc).**
- Pre-charge fuse has blow (check and replace).

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

- **Cannot establish connection of external computer to DS-Tracer .**
- DS-Tracer is not turned on or has turned itself off.
- DS-Tracer serial port is not connected to computer.
- IVPC is set to wrong COM port.
- Serial connection requires NULL MODEM cable.

- **DS-Tracer will not accept external command.**
- Parameters are not properly formatted.
- DS-Tracer is not capable of performing command.

- **Irradiance readings are incorrect.**
- Pyranometer coefficients are incorrect.
- Analog circuit requires factory calibration

APPENDIX A I-V Curve ASCII File Format

Note: Each line of the ".IVA" format starts with a unique ID letter followed by a space. The ID letter and space should be used to decode this file. Line arrangements are subject to change as additional information is added to this file format.

```
"F" curve name
"D" date
"T" time
"S" site
"B" sub-system
"M" module
"P" temperature #1
"Q" temperature #2
"R" irradiance #1
"U" irradiance #2
"X" miscellaneous
"H" short circuit current
"O" open circuit voltage
"C" current at peak power
"K" voltage at peak power
"W" peak power
"L" fill factor

        THERE CAN BE 0 TO 257 I-V DATA PAIRS

"I" current value  voltage value
"I" current value  voltage value
"I" current value  voltage value
        .
        .
        .
"I" current value  voltage value
"I" current value  voltage value
"E"
```

APPENDIX B 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 31 "OVER LOW VOLTAGE RANGE"

The take I-V curve command cannot continue because the PV system voltage exceeds the low voltage range (switch to high voltage range).

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 40 "DISCONNECT SWITCH IS OFF"

The DS-Tracer is trying to take an I-V curve, but the DS-Tracer DISCONNECT switch is off.

ERROR 50 "INVALID NUMERIC PARAMETER"

Parameter must represent valid numeric value.

ERROR 60 "INVALID ANALOG I/O CHANNEL #"

The DS-Tracer accepts channel numbers 0 through 13.

ERROR 63 "DSP ERROR"

DS-Tracer DSP board has an error. Usually an A/D has failed or the connect to the DSP board has failed.

ERROR "UNKNOWN ERROR"

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

APPENDIX C DS-Tracer Technical Specifications

PV Voltage Measurements

Gain Code = 0

Range	600 V dc.
Accuracy	Larger of +/- 0.5% of reading or +/- 0.3 V.
Resolution	146 mV.

Gain Code = 1

Range	60 V dc.
Accuracy	Larger of +/- 0.5% of reading or +/- 30 mV.
Resolution	14.6 mV.

Gain Code = 2 (DS-100 only)

Range	6 V dc.
Accuracy	Larger of +/- 0.5% of reading or +/- 3 mV.
Resolution	1.46 mV.

PV Current Measurements (DS-75)

Gain Code = 1

Range	75 Adc
Accuracy	Larger of +/- 0.5% of reading or +/- 37 mA.
Resolution	18.3 mA.

PV Current Measurements (DS-100)

Gain Code = 1

Range	100Adc
Accuracy	Larger of +/- 0.5% of reading or +/- 49 mA.
Resolution	24.4 mA.

Gain Code = 2

Range	10 Adc
Accuracy	Larger of +/- 0.5% of reading or +/- 4.9 mA.
Resolution	2.44 mA.

RANGE switch settings

V_{HIGH}	600 V dc (max.)
V_{LOW}	150 V dc (max.)

Temperature (DS-100 only)

Range	-30°C to 120°C.
Accuracy	+/- 1°C.

Resolution 0.1°C.

Irradiance (DS-100 only)

Ranges +/-10 V, +/- 1.0 V, +/- 100 mV, +/- 10 mV,
Accuracy +/- 0.1% of Range.
Resolution 1/65,536 of Range.

Power Supply

Power 120 V/240 V 50/60 Hz ac.
Battery 5 A-Hr sealed lead acid. (Gates Energy Products #0809-0020)
Hours of Use Up to 13 Hours on a full charge.
Charge Time Less than 8 hrs.

Load Capacitors

Low Voltage Range
Capacitance 5,000 uf.
Voltage Limit 350 V dc.

High Voltage Range
Capacitance 1,600 uf.
Voltage Limit 700 V dc.

Approximate. Weight

28 lbs.