

PVPM 1500X

Peak Power Measuring Device
and I-V-Curve Tracer
for PV Strings / Arrays

Users Manual



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2 Introduction

The devices of type PVPM enables the measurement of the I-V-curve of photovoltaic modules (limited current) as well as of strings or arrays. By a new developed procedure the device can measure and calculate the peak power P_{pk} , the R_s and R_p directly at the place of installation of the PV system. Calculation results and the diagram can be displayed on the internal TFT display.

The peak power is the power of a PV module under Standard Test Conditions (STC) [1]. In the past the very complex measurement of the peak power was possible only in particularly suited laboratories. By a new patented method [2], which was developed by Professor Wagner at the University of Applied Sciences Dortmund, this measurement can easily be performed with the PVPM. So the quality control of a PV system can be executed fast and economically. This simple and meaningful check in practice serves the certainty of the customer and also that of the installer. Beyond that the measured I-V-curves permit further explanations about the electrical characteristics of the checked module or string. So the PVPM is suitable as an instrument in research as well as for development purposes.

The PVPM is a mobile measuring device with integrated battery supply and battery charger in a durable and light weight plastic housing. The device has its own industrial miniature PC and a high-contrast TFT graphic display and thus its function is independent of other devices. Nevertheless (if desired) a PC can be attached for data transfer and further analysis of the measured values over a standard USB interface.

The PVPM is operated comfortably over the touch screen and an on-screen menu. The functions are defined self-describing and the user is always led by the program. So no long training activities for the operating personnel are necessary.

The device accepts the input from usual irradiance reference sensors that produce a voltage between 0mV and 150mV which linear depends on the irradiation. An additional temperature sensor (RTD, Pt100) can be connected and attached to the back surface of the modules under test for better results.

Description of the measurement:

The PVPM automatically measures the I-V-characteristic of the PV generator at a capacitive load. From the measured data it calculates the effective solar cell characteristic, P_{pk} , R_s and R_p [2], [3]. After the measurement the data are stored automatically in a non-volatile storage and so are available later (e. g. in the office) [4]. The device internally can store the data of several thousand measurements.

The following results are displayed:

Permanent values:

Peak Power P_{pk}

Internal Series Resistance R_s

Internal Parallel Resistance R_p (shunt resistance)

Current values, depending on irradiation and temperature:

V_{pmax} , I_{pmax} , P_{max}

V_{oc} , I_{sc} , FF , T_{mod} , E_{eff}

The determined I-V-characteristic can also be shown directly on the LC-display.

[1] IEC60904-3: STC= Irradiance 1000 W/m², Spectrum AM=1.5, Cell Temper. 25°C

[2] Wagner A.: Peak Power and Internal Series Resistance Measurement under Natural Ambient Conditions. –EuroSun Copenhagen 2000

[3] Bendel C., Wagner A.: Photovoltaic Measurement relevant to the Energy Yield. - WCPEC3 Osaka 2003

[4] Schulte K.M., Wagner A.: Die Effektive Solarzellenkennlinie. - Anwendung Teillast-Berechnung. Staffelstein. 2002

3 Normal use

The peak power and I-V-characteristic measuring instrument series PVPM is used exclusively for the admission of the I-V-characteristic curve of single photovoltaic modules (limited current), strings or arrays. Before connecting the PV generator under test to the measuring instrument it must be ensured that the test specimen cannot exceed the maximum current and voltage levels of the measuring instrument at any time.

4 Safety Requirements

Before the first use of the PVPM read this manual carefully and completely. It contains important hints to avoid damage to persons or the measuring device. These hints are emphasized by a frame around the text and should be paid attention to.

References in this document, which concern security matters, are indicated by a frame. Damages due to the neglect of the references in this document are excluded from the warranty. No warranty at all is guaranteed for consequential damages.

The program *PVPM.disp* requires a PC with hard disk and MS Windows® NT® or higher and a mouse pointing device. The connection of the PVPM requires a USB serial interface.

The required free space on the hard disk before installing PVPM.disp is about 20 MB. Please be sure later on that there is enough free space on the hard disk before storing measured data.

Attention: For the purpose of data security we would like to point out the importance of saving the database of the program regularly on another data medium, so in the event of damage you will be able to continue working without considerable data loss. Such a damage can not be excluded even under the present state-of-the-art. Please do not restore single data files, but always the complete data back-up of the program, otherwise you might cause malfunction, this in turn might lead to data loss! In case of doubt please contact the distributor or the producer.

5 Warnings

To disregard the following information can lead to severe injury and even entail a peril to life!



CAUTION! Before starting up the equipment please read this manual carefully!



NOTE: Danger of an electrical impact

Note: Measuring category I. Do not use this device in measuring categories II, III and IV.

Do not connect measuring inputs to ground.

This device may never be utilized close to inflammable gases.

Keep children and infants away from the measuring equipment!

The measuring device may not be used in locations with intense dust exposure or high humidity. No fluids may reach the interior of the measuring device.

At appearance of unusual sounds, the development of smell or smoke the device has got to be switched off immediately, the circuit breaker and the current source have got to be disconnected.

Before each measurement check the test leads for the power measurement for damages. Never operate damaged test leads! If the conducting wires of the measuring device are damaged they have to be replaced. Mending the wires is not admissible.

The current measurement input may only be attached to a limited source of direct current (photovoltaic generator) with at most 20A! The connection of other sources can lead to demolition of the device and to danger of life!

For security reasons only qualified personal must establish the cable connection between the PV generator and the PVPM security switch! The measurement should be carried out or accompanied by qualified personal. Additional qualifications and laws (e.g. VDE 0100) have to be observed, otherwise high currents and voltages involve danger of life!

The PVPM and all devices being part of it may be opened and repaired by authorized qualified personal only. Before opening a case every cable connection must be disconnected! Keep in mind that even with disconnected cables the may reside dangerous high voltage inside the case!

The solar generator can generate very high tensions and currents, which can affect your health when you do not handle with care!

!! VERY IMPORTANT !!



Never plug in or remove the cable connectors between solar generator and PVPM before the solar generator is deactivated! A security switch added to the measurement line allows the simultaneous disconnection and the safe connection of measuring wires to the PVPM.

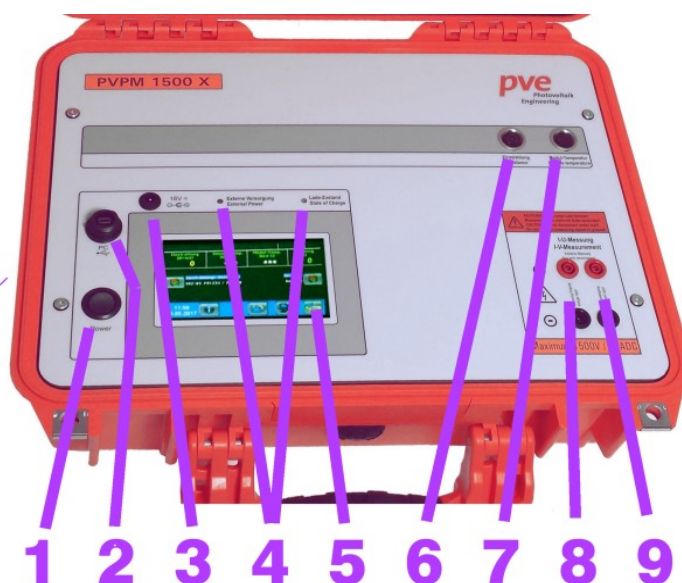
The plugs of the measuring cable for the power measurement (4-wire measuring cable) must be plugged into the corresponding sockets UP TO THE STOP. Otherwise, the meter and the cable may be damaged when measured by an electric arc in the connector (risk of fire!).

The PVPM will make a short circuit during measurement, and when you disconnect a cable under this condition, a light arc can arise and can cause serious damage to health and material! After the generator is deactivated you can remove the cable connection without harm.

6 Operation of the PVPM

6.1 Operating and connection elements

1. On/Off switch
2. USB connector (mini B)
3. Connector for external power supply (16V, 2ADC)
4. Status lights
5. TFT colour graphic touch display
6. Combined irradiation and temperature input
7. Temperature measuring input Pt100
8. Four-wire measuring connector (voltage)
9. Four-wire measuring connector (current)



6.2 General Hints

The PVPM, as nearly all electronic measuring device, can only operate in a defined temperature range (see appendix). That is why the PVPM should not be exposed to direct sunlight over a longer period of time. Keep the device in a shady place or protect it from direct sunlight using a sunshade.

The standard version of the PVPM cannot be integrated into other devices or e.g. brackets. It is very important that the air can move free around the case so that a proper cooling is guaranteed! Only if the PVPM is completely out of operation (even no charging) it may be stacked.

Attention: Never loosen a measurement cable connection during a measurement! The considerable dc tensions and currents can cause a light arc which may cause fire, serious injuries and even death! (see chapter 4/5)

The front panel of the PVPM is rather rough, but you should handle it with care anyway. To avoid damage of the front panel please take notice of the following hints:

- Do not touch the front panel with a sharp or pointed object. This could force scratches and might even destroy the foil especially in the regions with switches in the back.
- Clean the surface with a soft and damp tissue. Do not use materials that can scratch, especially on the cover of the display. A scratched display cover will dramatically affect the display quality.

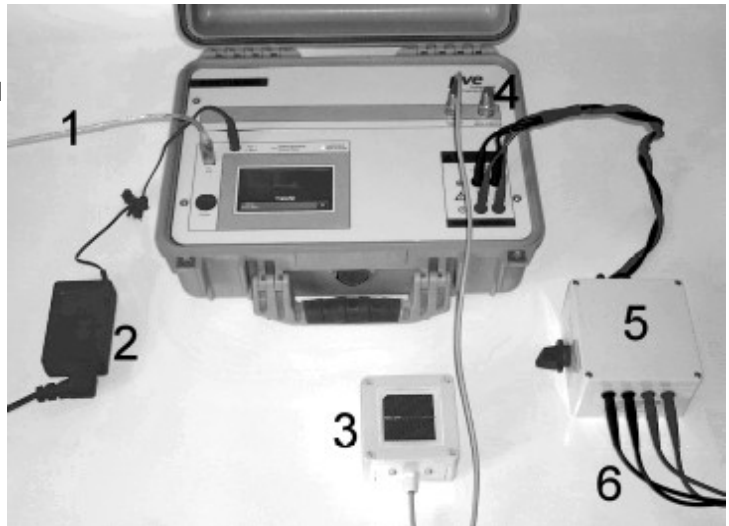
The case is water proofed (IP 67). Nevertheless do not expose the PVPM directly to influence of water, rain or similar.

For a good measuring quality the sun irradiance during the measurement should be above 500 W/m². IV-curve measurements are possible below this irradiance value, but the STC values would be less precise and meaningful. That is why the STC values will be suppressed in this case.

6.3 Connecting Peripheral Devices

For an I-V-curve measurement besides the PVPM the following components are required:

1. USB connection to operating PC (optional)
2. External power supply (optional)
3. Irradiance reference sensor
4. External RTD (Pt100) or short circuit adaptor
5. External security switch (see chapter 7) between power measurement cable and PVPM
6. 4-wire-measurement cable



The PVPM is equipped with the following input/output interfaces (you will find all interfaces at the front panel, they are all marked):

Interface	Function
Power supply	At the front panel of the PVPM, input 16Vdc/2A, coaxial power connector 5.5x2.1mm
Temperature	(External) temperature sensor: either short circuit connector or Pt100
Irradiance	Combined sensor: irradiance + Pt1000 temperature
4-wire-measurement	Voltage input (modules under test)
Current input	Current input (modules under test)
PC	Serial connection to PC (USB cable)

6.4 Power Supply

The PVPM contains a battery which let it become independent from mains grid power supply. The battery can be charged by the external power supply and an integrated charge controller. After connecting the external power supply to front panel of the PVPM the battery is charged automatically. The charging state is displayed by a LED at the front panel of the device.

6.5 Connecting a PC

The PVPM can operate independently from an external PC. For an extended evaluation of the measured data or just for controlling the PVPM from a PC you can connect the PC to the PVPM with the delivered USB cable. Attach this cable to a free USB port of your PC and to the "PC" connector of the PVPM.

Before you can control the PVPM from the PC you will have to:

1. install the software PVPMdisp (chapter 9)
2. install the device driver for the USB port (chapter 10)
3. Activate "Transfer" on the PVPM

Otherwise a transfer between PVPM and PC will not be possible.

Important: before you can operate the PVPM from a PC with PVPM.disp it is necessary to select the menu option "transfer" on the PVPM. Otherwise the PVPM will not listen to the serial port and the PC can not access the device.

6.6 Connecting the Solar Generator

Important: during an I-V-curve measurement the solar generator under test must be disconnected from all other devices like batteries, inverters or loads. During the measurement the PVPM will short circuit the solar generator for some seconds and it might be damaged by still connected batteries or load capacities of the inverter!

Connect the PVPM properly to the solar generator using the cables delivered with the PVPM. The **plus pole is marked RED**, the **minus pole is marked BLACK**!

Assure that all connectors of the power measuring cables are pushed in completely (until stop) into the sockets.

It is important, that all 4 plugs of the 4-wire-measurement are connected properly by the delivered 4-wire-cable or (if you don't want a 4-wire-measurement) the two red plugs should be connected and the two black plugs as well. Without this connection a measurement is not possible!

When connected in wrong polarity an internal diode will prevent the PVPM from damage.

Caution: keep a sufficient distance to power leading parts of the cables between solar generator and measuring device. These cables may lead high tension what may affect your health even without direct contact!

6.7 Connecting the Combination Sensor

For a measurement you must connect a Pt100/Pt1000 temperature sensor and an irradiance reference sensor (delivered as a combined device) to the relevant plug(s) of the PVPM. For just the measurement of serial resistance R_s or I-V-curve these sensors are obsolete. The plugs are constructed in a way which prevents you from connecting a sensor to a wrong plug.

The combined sensor should be mounted near the modules to be measured. It must have exactly the same orientation (elevation and azimuth) regarding the sun as the modules have. Most time the easiest way is the direct assembly to the module frame. Please take care that the sensor will drop no shadow to the module! The sensor needs several minutes to adapt to the environmental conditions: the reference cell firstly should reach the temperature of the module, before you can start to measure I-V-curves with the PVPM (see chap.6.10).

For this reason the sensor should not be set up far away from the modules (e.g. modules on the roof, sensor in the yard). Since the solar cells do not react only to the direct irradiation, but also to light reflected in the environment, the sensor can possibly notice different light intensity in the same orientation of sensor and modules and so falsify the results of the measurement.

In the simplest case the sensor is fastened with a clamp to the modules under test. Pay attention that the sensor does not shadow the modules under test! The sensor should have some time in order to adapt to the site conditions. At PVPM devices that have no second temperature measuring input the sensor must approximately reach the temperature of the modules under test (the temperatures are readable on the display of the running PVPM). For security reasons we recommend to check the back surface temperature of the modules under test additionally manually e.g. with an infrared thermometer. Now a measurement with the PVPM can be carried out (s. also chapter 8).

6.8 Switching-on

Switch the power of PVPM on by activating the switch "Power" at the front panel. The TFT display will show the start-up screen:

The PVPM will now pass some self tests and will be ready after about 10-15 seconds of operation.



The device is ready when the main menu appears on the LCD-screen:

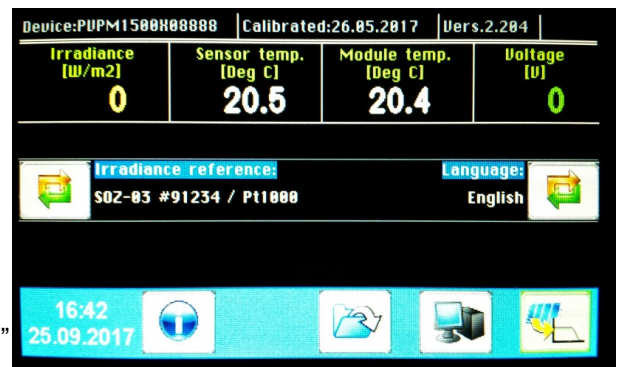
The following items are displayed:

Headline: device serial number, calibration date, firmware version

Data line: current irradiance, temperature of irradiance reference cell, temperature of module back surface (optional), voltage at power measurement input.

Sensor line: here the currently selected irradiance reference sensor is displayed and can be changed.

Bottom line: Current time/date, buttons "Info", "Archive", "PC" and "New measurement".



Lamps on front panel:

State of charge (3 color LED)	Lead-Acid battery	Red: battery discharged (charge at once!) Green: battery ready Yellow: battery charged completely *)	Operation not possible! Operation possible Operation possible
	Li-Ion battery	Blinking Red: battery nearly discharged (charge!) Red: battery is charged Grün: charge is nearly finished Aus: charge is finished	Operation time left <u>max. 30 minutes</u> Operation is possible Operation is possible Operation is possible
External supply	Lights up, when an external power supply is connected, the internal battery will be charged automatically.		

*) If the LED alternates between green and yellow steadily the battery is trickle charged.

The PVPM reports several system conditions, functions and errors by speaker signals. A list of signals you will find in the appendix.

6.9 Buttons

Possible actions will be displayed as buttons, which show a symbol according to the action, for example a PC for the transfer between PVPM and PC.



Info: displays an overview about the buttons



Change: here you can select a different value



New I-V-curve measurement, displays submenu



Retrieve measurement data from archive



Connection to PC („Transfer“)



Start I-V-measurement now



General: abort, cancel funktion



Display results



Display I-V-curve



Add entry



Previous page



Next page



Confirm, „OK“

6.10 Measurement

Please pay attention to the safety hints in chapters 4+6 and factors affecting measurement accuracy in chapter 8.

The measurement can be started from the PVPM or from a connected PC (see chapter 11). The measurement should not be started before the solar generator and the necessary sensors are connected properly. The I-V-curve measurement will take up to 2 seconds, then the calculated results will be displayed immediately on the PVPMs display (or on the PC).



Opens sub-page for measurement

6.10.1 Start measurement



This button activates a single measurement of the I-V-curve. The measurement runs automatically, errors will be reported and the results as Ppk, Rs and I-V-curve are displayed on the screen.

6.10.2 Archive



This button enables you to retrieve data of already made measurements. The data-sets are listed according to the creation date.



Goes to next/previous line in the list.



Selects next/prior page



Select a file with "OK", exit dialog with "Abort"



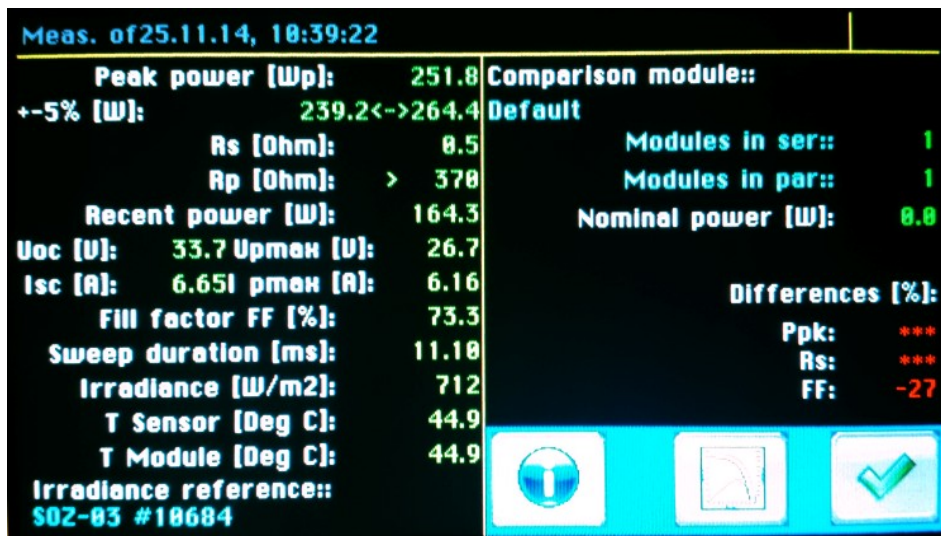
Use the button "Delete" to delete the selected data-set from PVPM memory. Caution: this operation is not reversible!

6.10.3 Transfer



This button activates the transfer between PVPM and a connected PC. You can cancel this transfer mode by pressing the "Abort" button at the PVPM screen.

6.10.4 Results



The page "Results" displays the measured (voltages, currents, temperatures etc.) and calculated values (Ppk, Rs, Rp, FF).



The button "Diagram" selects the page with the I-V-curve, the button "Results" displays the results as described above.

6.11 Messages

<i>Message:</i>	<i>Description:</i>
'Serial error'	An error in the serial connection between PVPM and PC occurred
'No measured data'	No measured data present
'Configuration file not found!'	Internal error, consult manufacturer. PVPM cannot work without its configuration file
'Irradiance varies (ref-cell)!', 'Irradiance too low!', 'Irradiance varies (module)!'	The irradiance is not constant enough for the peak power measurement (for example due to moving clouds)
'not available'	This result cannot be calculated
'No room for new data!' 'Delete files from PVPM'	There is no space left on the internal permanent storage, you have to delete stored data from the permanent storage of the PVPM (see chapter 11.3.2)
'Error when writing '	Problems during the writing of a measuring data to the internal permanent memory
Measurement runs', 'Please wait...'	Measurement is in process
'Error writing file '	An error occurred storing the measured data
'Data transfer:', 'Quit transfer with ESC'	Data connection to PC invoked
'Measurement not yet possible'	The security delay between two measurements is not yet elapsed
'Calculation of Rs not possible'	Data is not sufficient for calculation of Rs. Redo the measurement
'Values not evaluably'	Data is not sufficient for calculation. Redo the measurement
'Voltage too high!'	Immediately switch off the generator with the external security switch! The device could be damaged by the high voltage!
'Repair required immediately!'	The device is damaged internally and requires test and repair through authorised personnel.
'Wrong polarity!'	The measuring cables are mounted in the wrong way! Switch off the generator with the external security switch immediately! The device will short circuit the generator if the polarity is wrong and can take harm. If you disconnect the cables under voltage a light arc can cause serious damage to health and material

7 External Security Switch 1500V / 20A (1000V / 50A)

Use this switch to disconnect the PVPM from the PV power before connecting or disconnecting the measuring cables to/from the PVPM. This avoids damages of your own health or the PVPM.

Handling:

Turn the knob at the switch in a neutral position “0” (both “0” positions are equal).

Put the measuring cable delivered with the PVPM as far as possible to the sockets at the switch housing, red connectors to red sockets and black connectors to black sockets. You can reverse the two red connectors without harm, the two black ones as well. Now connect the cables mounted at the switch to the PVPM (red to red, black to black).

Before you can make a measurement you have to turn the knob at the switch to one of the “1” positions. **After the measurement turn the switch again in position „0 “!** Afterwards the wiring at the PVPM can be removed safely.

Security advice

CAUTION: Do never forget to switch to “0” before handling the connectors at the PVPM!

If you detect a defect at the switch, the housing or the connection cables, the switch must not be used any longer under any condition!

Only specially instructed professionals must do repairs!

Keep the switch and cables away from liquids, dust and dirt. Clean the surface with a damp cloth only.

8 Impacts on the accuracy of the measurement

Be sure, that there is no shadow (even not the smallest) affecting the modules under test. Even the shadow of grass may cause an error! This is also true for the reference sensor. Please consider that also a contamination of the modules becomes effective as shading.

The higher the irradiance to the modules, the more exact will be the result. The irradiance measured by the combined sensor should be higher than 500 W/m^2 for good results.

The combined sensor measures the irradiance and the cell temperature at the back side of the irradiance reference cell. If no external temperature sensor for the measurement of the back side temperature of the modules under test is available the PVPM expects the temperature of the reference cell to be nearly the same as that of the measured modules. This will be true with sufficient precision if the reference cell and the PV modules were exposed to the sunlight for same period of time (at least 15 minutes). In addition before a measurement modules and reference cell should be exposed directly aligned to the sun for more than 15 minutes. For sureness the back-surface temperature of the modules should be additionally checked before the I-V-curve measurement e.g. with an infrared thermometer.

The angle of the modules regarding the sun should be in an range of 10° regarding the right angle between sunlight and modules surface. Very important is a sufficient irradiance to the modules and precise alignment of the reference cell towards the modules. Often the easiest way is to clip the combined sensor directly to the side or top of the frame of the measured modules. However the sensor may also be installed in some distance to the modules if you can grant the correct alignment and the sensor does "see" the same light as the modules.

Principally the irradiance reference must have the same spectral behavior than the modules under test (according to IEC 60904). It is possible to use a module like that under test as an irradiance reference: the module will be short circuited by a precision shunt resistor which will operate the module near the I_{sc} . The voltage at the shunt resistor is proportional to the I_{sc} and so to the irradiance. That is how most irradiance reference sensors work.

Caution: even a few degrees deviation in the temperature of the reference cell towards the modules temperature can cause a significant error in peak power measurement. Before a you make a measurement be sure, that the reference sensor and the modules were exposed to the same ambient conditions for a sufficient period of time!

You can enhance the precision of the PVPM results by measuring the same object several times (e.g. 5 times) and after that do a statistical evaluation on these results.

Given below are once more the parameters, that are decisive for the accuracy of the measurements:

8.1 Accuracy of the peak power calculations from I-V characteristics of PV generators with the PVPM

Under following constraints the peak power results of the PVPM have an accuracy of +/- 5% relating to the actual peak power value of the device under test:

- The device under test consists of mono- or polycrystalline silicon cells
- The device under test is not (not even slightly) shadowed
- The irradiation reference sensor is not (not even slightly) shadowed
- The irradiation reference sensor must have largely the same spectral sensitivity as the tested device
- The measurement has to be carried out under natural sunlight
- According to IEC60904 the sun has to stand within +/- 10° at right angle to the active surface of the device under test
- According to IEC60904 an irradiation of at least 800W/m² is required. On the basis of comparative measurements we found 600W/m² to be sufficient for the PVPM
- The measurement of the irradiation has to take place immediately before/after that of the I-V characteristic, the time-lag between measurement of characteristic and irradiation should be less than 1ms.
- The measured value of the irradiation reference sensor has to be adjusted with the measured temperature of the reference cell
- The measurement of the cell temperature has to take place immediately before/after the measurement of the characteristic within 1second and an accurateness of 1K
- The active surface of the device under test must lie in-plane with the irradiation reference sensor (within +/- 1-2°)
- Before the measurement of the I-V characteristic the irradiation has to be constant enough (+/-10W/m²) for at least 10 seconds , in that way misinterpretations of the temperature of tested device and reference sensor can be avoided
- The irradiation must not vary more than 10W/m² during the measurement (PVPM will caution the user in this case)
- The temperature of the device under test and the reference sensor has got to be balanced (no alteration of temperature may be indicated)
- Current and voltage of the device under test are measured with distinct measuring lines (four-wire measurement)

9 Installation of the Transfer and Evaluation Software PVPM.disp

Please download the recent software PVPM.disp for MS Windows® from here:

<https://t1p.de/wkb5p>

This executable file contains the setup program for easy installation of the software on to your PC. The setup program will copy all necessary files to your hard disk and initializes the program. The installation can be performed by every person with basic experience of PC and MS Windows®.

For the installation of the software perhaps administrator rights are required

For the installation the following steps are necessary:

1. Download the setup application to an appropriate drive/folder of your PC.
2. Under Windows® "Start" select menu option "Execute". Select the downloaded file from the hard disk. Press ENTER now or click the OK-Button.
3. The setup application will be executed. Follow the messages on the screen.
4. Setup now copies all necessary files to your hard disk and will as well create a new program group for PVPM.disp.
5. After completing the installation please execute PVPM.disp. The program should now work as described in the following text.

The operation of the program will be professed detailed in chapter 11 .

For the operation of the program these files are necessary:

{program} \ PVPMdisp	Program file and additionally files required for the operation of the application (eg language files)
{common} appdata \ PV Engineering \ PVPMdisp	Configuration and the database files
{user docs} \ PVPMdisp	Sample and measured data

The program will create data files with the extension .SUI, which contains measured data from one I-V-measurement. When these files are created automatically during the data transfer from the PVPM to the PC the file name will contain the date and time of the measurement.

A typical data file name could be "24-05-01 14_17_04.SUI", this file contains data from a measurement made May 24th, 2001 at 02:17:04 pm.

The measuring data are usually stored in files below "My Documents\PVPMdisp".

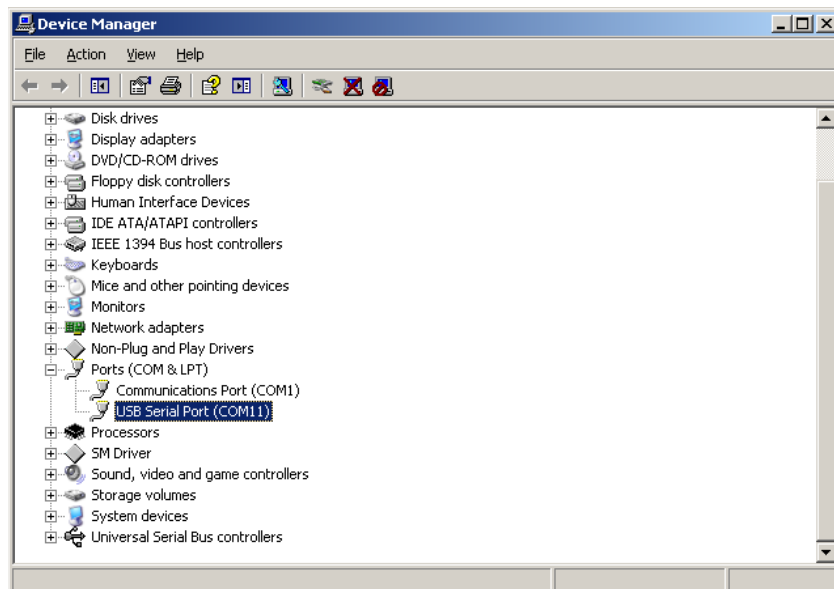
10 Installing the USB device driver

1. Please download the USB driver installation file from here:

<https://t1p.de/8wx3f>

The newest driver will as well be available on the website of FTDI (www.ftdichip.com).

2. Execute the installation file you have downloaded.
3. The application will guide you through the installation of the USB driver files.
4. After the successful installation the new COM port appears in the device manager.

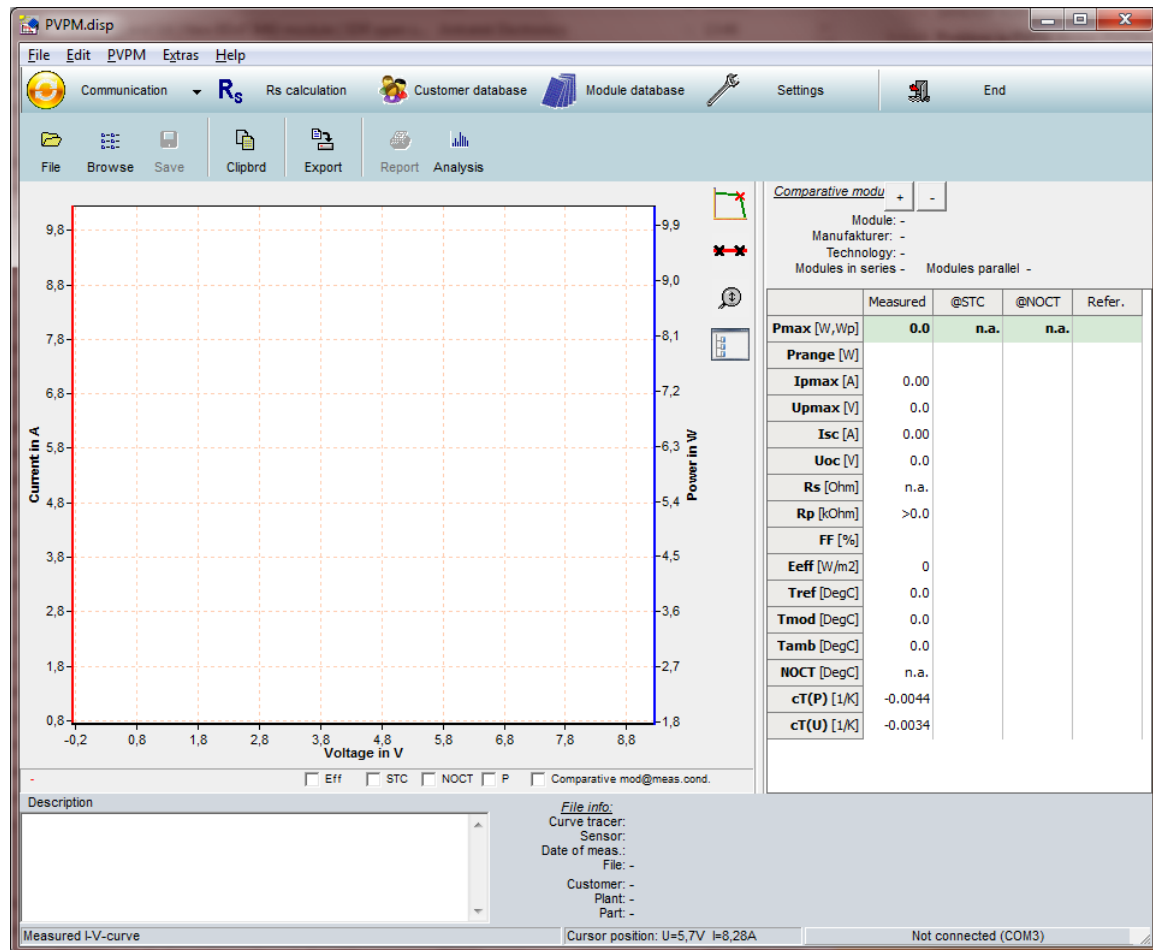


10.1 Uninstalling the CDM driver

The driver can be removed using the Windows device manager: select the device in the list of devices with the right mouse key and select "Uninstall". This will delete the entries for this device from registry.

11 Operation of the Software PVPM.disp

For the installation of the software please refer to chapter 9. After starting the software the following window appears:



The displayed document is empty, all values are zero. Now you can open an existing data file, make a measurement or retrieve already measured data from the PVPM. The new or received data will be stored to this document and you are able to continue evaluating these data or save it to a hard disk file. For the evaluation you can refer to the line diagram of measured data and the displayed results. The function "Export" lets you export the data to different file formats for further evaluation in other software.

Buttons are grayed out, when they are not active. They change to normal state, when this function is meaningful.

11.1 Main Menu File

11.1.1 Open

I-V-curves saved to disk before can be reloaded using the „Open“ button. The loaded data will overwrite the data in memory. If you want to re-use the current data later you will have to save it to a disk file before loading different data. The files have the default extension .SUI.

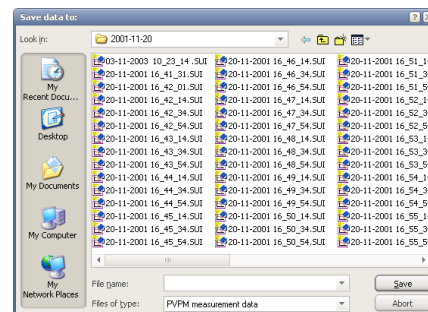
File	Date	Voc/V	Isc/A	Pm/W	TMod/°C	TSens/°C	Eff/W/m²	Mod.type	Cust.
26-11-2003 15_01_28_SUI	n.n.	314.62	4.8	781.7	28.9	28.9	317		
23-05-2007 12_31_32_SUI	n.n.	360.45	8.6	1719.6	46.5	46.5	908		
09-10-2002 11_02_06_SUI	n.n.	450.31	4.3	1276.5	23.5	23.5	581		
30-04-2004 13_18_20_SUI	30.04.2004 13:18:20	146.57	4.6	403.6	34.0	34.0	640		
18-05-2004 12_45_22_SUI	18.05.2004 12:45:22	384.23	6.8	1372.1	37.2	37.2	865		
17-08-2004 11_17_12_SUI	17.08.2004 11:17:12	449.42	2.2	289.2	49.9	49.9	667		
Durchgang 1 - String2_SUI	04.10.2004 12:25:28	193.31	1.7	235.3	32.7	32.7	620	Standard	
Pass 1 - String 2_SUI	04.10.2004 12:25:28	193.31	1.7	235.3	32.7	32.7	620	Standard	
01-08-2005 12_37_54_SUI	01.08.2005 12:37:54	316.07	3.4	696.0	38.6	38.6	379		
01-08-2005 12_37_54x_SUI	01.08.2005 12:37:54	316.07	3.4	696.7	38.6	38.6	520	Standard	PV-En
12-08-2005 12_28_24_SUI	12.08.2005 12:28:24	486.75	10.9	2674.2	-50.0	-50.0	853		
18-08-2005 14_56_00_SUI	18.08.2005 14:56:00	393.72	2.7	487.7	-50.0	-50.0	421		
Breiter Weg - String 3.1_SUI	08.09.2005 09:39:22	468.20	3.1	783.6	39.4	37.7	572	BP 4165 N	Muste
String 3.1_SUI	08.09.2005 09:39:22	468.20	3.1	788.0	37.7	37.7	572		
08-09-2005 15_25_34_SUI	08.09.2005 15:25:34	392.91	3.4	940.9	44.0	44.0	651		
Maifeld Solar	08-10-2005 13_40_58_SUI	376.80	0.8	161.2	40.1	40.1	775		
12-10-2005 12_18_32_SUI	12.10.2005 12:18:32	261.79	2.3	278.5	41.8	41.8	671		
14-10-2005 12_30_06_SUI	14.10.2005 12:30:06	551.51	3.0	875.7	37.7	37.7	628		
03-11-2005 15_45_26_SUI	03.11.2005 15:45:26	41.76	2.5	74.5	24.9	24.9	577		
02-03-2006 13_16_44_SUI	02.03.2006 13:16:44	30.59	4.1	94.0	11.8	11.8	558		
02-03-2006 13_16_44x_SUI	02.03.2006 13:16:44	30.59	4.1	94.0	11.8	11.8	558	Standard	

If you click on the directory symbol near the displayed directory in the above dialogue window, you can select the directory, whose measuring data are to be displayed in the list.

In this list you can now either select an entry by doubleclick (these data will automatically be loaded and represented in the working window) or you can select some or all entries in the list, which then may be deleted, exported or printed (→ test reports).

11.1.2 Save as...

Here you can save the current data to a disk file. Entries made in field "Remarks" will be saved as well. The default file extension is ".SUI".

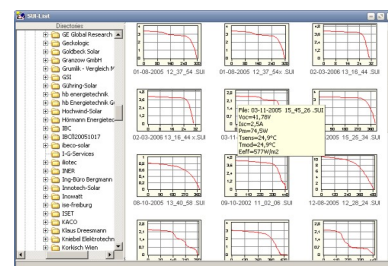


11.1.3 Browse

The "browse" window shows the thumbnail images of the measured curves in the selected directory. This gives you a quick overview over the existing measurements and you can detect a special curve.

If you go with the mouse cursor above one diagram a small hint window will display the significant values.

Double clicking the diagram will open the file for evaluation.

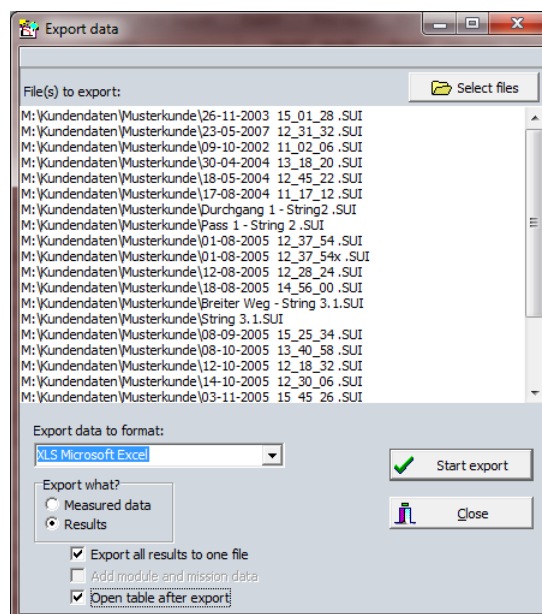


11.1.4 Export

The current data can be exported to disk files with several different file formats which can be read by other programs (e.g. spread sheet programs). You can use formats .XLS (Microsoft Excel), .DBF (dBase III+) and three different ASCII formats. For the selection of the right format please consult the manual of the destination program. The files can contain either pure measuring data (I-V-measuring points, temperature and irradiation) or the results of computations. In the latter case the results of several measurements can even be exported together into one table. The data in the target table are represented line by line.

Please select the desired export file format from the combo box. Now enter a valid file name for the export file or select an existing one with the button "Search", then press OK.

The export files are now created and stored in the same directory and under the same file name, but replaced file extension (for example .XLS instead of .SUI). You can process the exported files afterwards with a program of your choice. Changes at the exported files do not have influence on the original data.



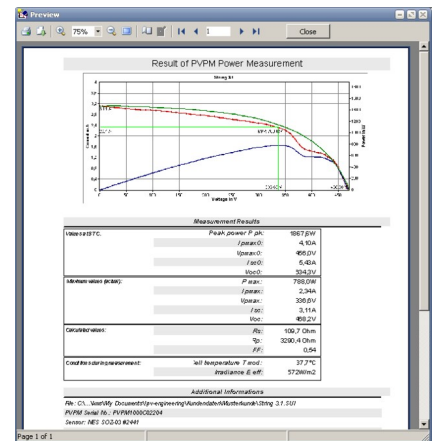
11.1.5 Report

This button creates a measurement protocol containing the I-V-diagram and measured as well as calculated values of the currently loaded data. This report may be printed out or written to a PDF document.

Please pay attention to the fact, that in some cases the page orientation of the printer has to be changed before printing out. The print uses the whole available printing area.

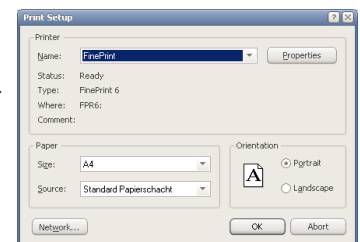
The buttons on top of the preview window are from left to right:

- Print
- Export to PDF
- Zoom factor
- Full page
- Page settings
- Page backward / forward
- Close preview



11.1.6 Printer Settings

Calls the windows standard dialogue "Printer Settings". Select the desired printer settings here.



11.1.7 Quit Program

Here you finish the program PVPM.disp. The current data are not saved automatically but you will get an warning, that your data should be saved before closing the program

Don't forget:

Finish "Transfer" on the PVPM when you close PVPM.disp

Quit PVPM.disp always using one of the functions "Quit program", the button "End" or the key combination <ALT>-<F4>. It is also important, that you shut down your operating system properly, because else a data loss might occur due to a write back cache etc.

11.2 Edit

This function is only active when the cursor is placed in a text edit field.

11.2.1 Cut

Cuts the marked text and moves it to the clipboard.

11.2.2 Copy

Copies the marked text and moves it to the clipboard.

11.2.3 Insert

Inserts the contents of the clipboard at the cursor position.

11.3 Extra

Switch the PVPM at first to „transfer“ (the solar generator under test as well as the sensors should, if necessary, already be attached), before you use the following function „measurement“.

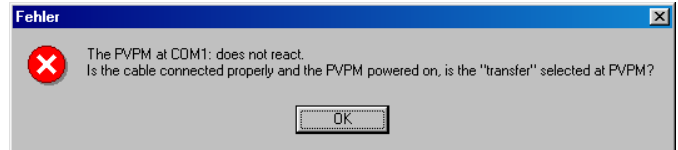
11.3.1 Start Measurement on PVPM / Button „Measure“

After starting the function the status line will display the message „Measurement processing– Please wait“.

The measurement will take up to 2 seconds. Directly after the measurement the measured values will be transferred to the PC (process will be displayed in the status line) and the main window will display the values and results. Now you can display the data in a diagram (chap. 11.4) or a list (chap. 11.5), export (chap. 11.1.4) or save to file (chap. 11.1.2).

Important: When the measurement is initialized from the PC the data will **not** be stored in the PVPM!

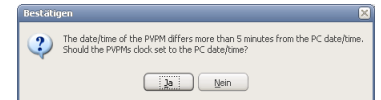
If this message appears (see right), the cable to the PVPM is not mounted properly or the function „Transfer“ on the PVPM is not activated.



11.3.2 Manage Files on the PVPM

At first the time settings of PC and PVPM will be compared – if the time differs more than 5 minutes the application will ask whether to correct the PVPM time with the PC's time setting. Now the measurement data stored on PVPM will be displayed in a list (the PVPM has to be connected and online for this function).

Now you can select data sets from the list (even more than one) and either transfer it to the PC for further processing (Button „Get data“) or just delete it from the PVPM (Button „Delete data“). You can set the destination directory with a directory dialogue that appears if you click on the directory symbol right of the displayed directory.



Caution: Carrying out the „delete“ function can not be withdrawn!!

When you select data transfer the data sets will be transferred one after the other and the files are stored to disk automatically using a file name that contains the date and time of the measurement.

If the check box „Delete data after transfer“ is checked a dialog will appear after the transfer and ask, whether the transferred data should be deleted now from the PVPMs memory. Only if you are really sure that the data on the PVPM will not be used any more you can answer „Yes“ here – the marked data-sets will be deleted from the PVPMs memory.

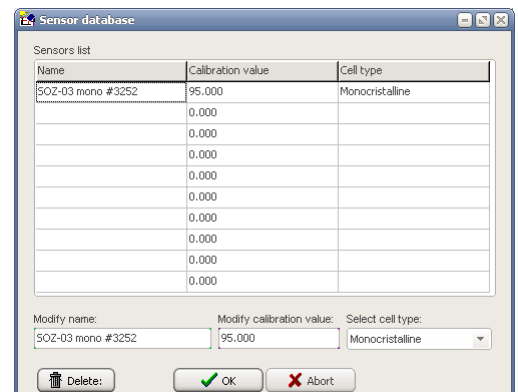
11.3.3 Synchronize PVPM to PC date/time

With this function the internal real time clock of the PVPM is set to the PC's date/time.



11.3.4 Modify PVPM sensor database

You can connect different irradiance sensors to the PVPM. Every sensor has its own calibration value, the PVPM needs to know this value for correct operation. To make the selection of a sensor simple during measurement you can define a table with up to ten different sensors, its names and calibration values, which will be stored in the PVPMs permanent memory. So later on you just have to select the appropriate sensor at the PVPM. The name you give the sensor is more or less free selectable, but it should be short and informative. It will be displayed later on the PVPMs display and informs you about the actually selected sensor. You can select the sensor at the PVPM via the menu „Service“ and „Select sensor“.



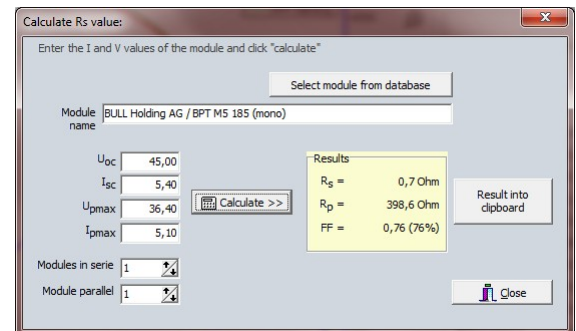
If you want to modify the sensors database the PVPM must be connected and ready for data transfer. When you start this function the database is loaded from PVPM and will be stored back to PVPM when you close this form.

To enter a new value just select a free line in the list and enter the values in the edit fields below the table.

After finishing all entries, press OK. Now you will be asked whether the data should be transferred to PVPM. You should select "Yes" here or your changes will be discarded.

11.3.5 Calculate internal series resistor

Basing on the nominal values of short circuit current, open circuit voltage, and the I and V value of the MPP the PVPM can calculate the effective solar cell curve and with this the expected internal series resistance R_s . This theoretical value can be compared to the actually measured value and give a hint, whether there are problems for example in the cabling.



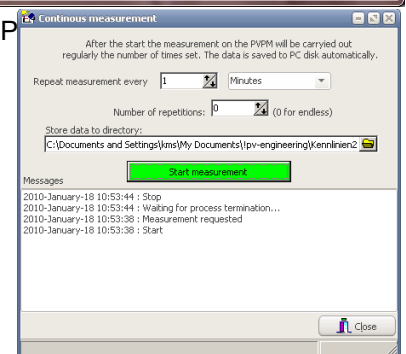
11.3.6 Continuous measurement

This function allows the automatically timed measurement controlled from the P

Set the desired time interval and the time unit (seconds, minutes, hours) for the execution of the measurement and the number of repetitions (0, if measurements shall be repeated infinite).

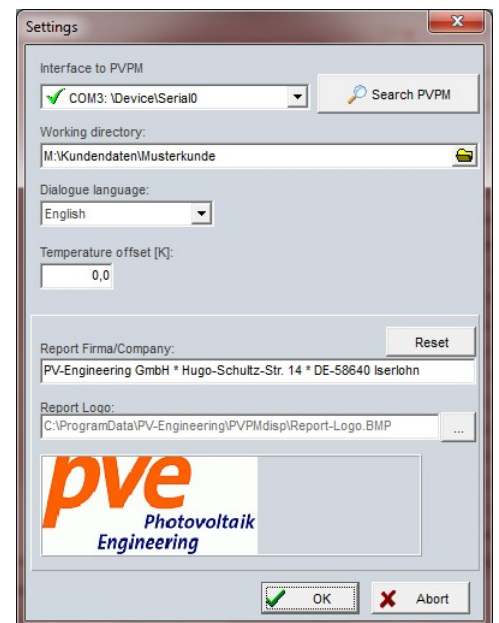
After pushing the button "Start measurement" the measurement runs automatically and can be canceled by the "Stop" button. The measured data will automatically stored to files in the predefined directory. The file names contain the date and time of the measurement.

The automatic measurement will stop, when the given number of repetitions are finished or when the PVPM does not answer or the user cancels the measurements.



11.3.7 Settings

All changes made here will be saved automatically and are valid until the next change:



11.3.7.1 Serial Port

You can select the serial USB port (COMn:) used for PVPM communications from the combo box.

If the application can read the list of existing serial interfaces from the Windows registry, the identifiers of the interfaces defined there are represented in the combo box - together with the reference whether this interface is available or not. In the latter case this interface is already occupied by another application. If the registry cannot be read (insufficient user rights), the application will only display simple interface identifiers like „COMx“. A selection of the interface is possible anyway. If you do not know, to which interface the PVPM is attached, you can use the button



„look for“: that allows the application to automatically try all available interfaces in order to establish the communication with the PVPM. The PVPM must be attached to the PC and set to „transfer“. If the application receives a valid answer from a PVPM, the search stops and the detected interface is used now for communication with the PVPM.

11.3.7.2 Working directory

The working directory is used in file open and file save dialogs and for the automatically saving of files. Select here the directory which contains your measured data or to which the measured data should be saved to. This listing is used also during the automatic data storage (data transfer of PVPM or continuous measurement) The entry field has a button at its right side. Press this button to display a directory selection dialog.

11.3.7.3 Dialogue language

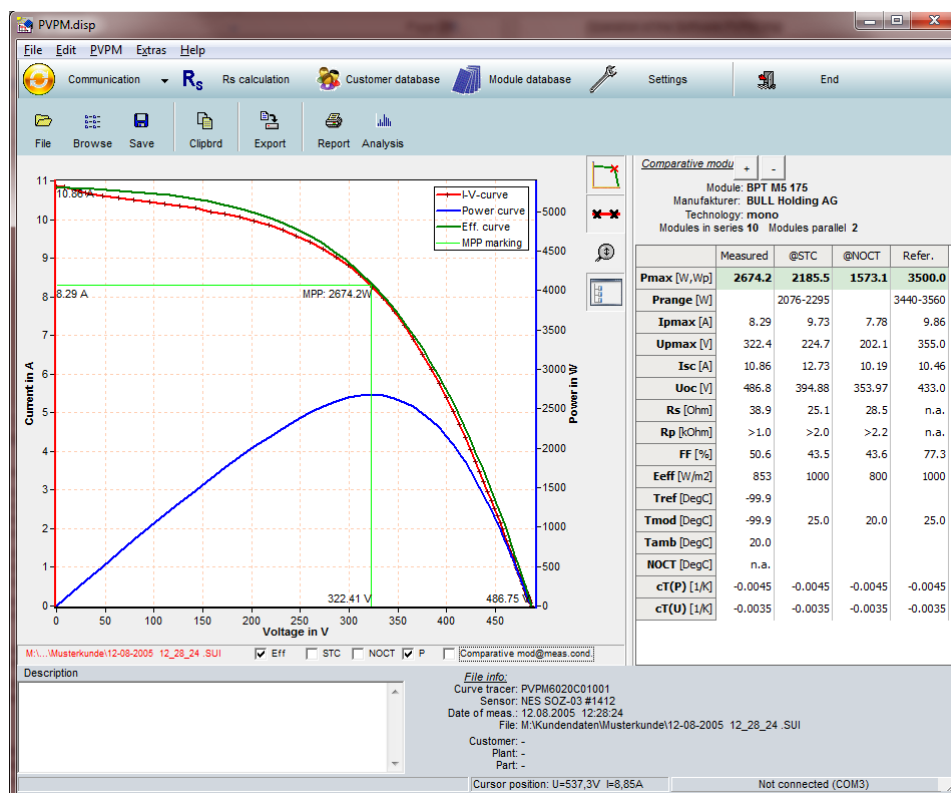
PVPM.disp supports the dialog languages English and German. The language can be changed during program execution. Just select your desired language from the combo box „dialog language“. After you close the dialog box the labels of PVPM.disp will be displayed in the selected language. PVPM.disp will remember the language setting.

Please note, that the standard and system dialogs will always be displayed in the language of the current windows version!

11.3.7.4 Temperature correction

Sometimes it may be useful to add a correction factor to the measured temperature values. In this case you can enter the factor here. The factor will be added to the measured temperatures: enter a negative value, if you want to decrease the temperature. If the factor is not zero the displayed temperatures will be displayed like „xx.x°C korr.“ to remember you, that this value is not the measured one. The altered value will not be stored.

11.4 Diagram



After loading the data of a measurement the diagram will be displayed.

In the diagram you can draw up a rectangle with the mouse cursor (from top left to bottom right with pressed left mouse button). This marked region then will be displayed zoomed. To come back to normal view just click onto

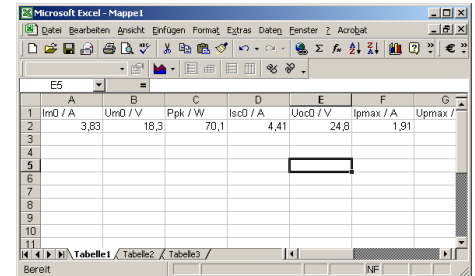
the drawing region. If you press the Shift-Key and the right mouse button in the viewing area and keep the buttons pressed, you can move the diagram area in every direction (pan).

A modification of the data is at present only possible in the fields irradiation and temperature: a double click on the displayed value opens a dialogue box, in which you can enter the new value. The changed values remain, if the file is now stored to disk again.

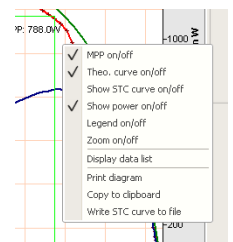
Into the field „remark“ you can write your notes. These are stored along with measured data. The first line of the remarks is used as title of the diagram.

With the button “Clipb” you can copy important data in a tabular form to the clipboard and then for example into MS Excel.

So you can easily setup a table of different measurements and compare them using a software other then PVPM.disp without exporting the files.



Clicking the viewing area with the right mouse button lets a popup menu appear. The same functions are available if you use the buttons on left of the diagram region. The following options are available:



11.4.1.1 MPP display on/off (button “Show MPP”)

You can select whether the MPP shall be displayed in the diagram or not. Note: The displayed MPP is not exactly one of the measured data points but will be interpolated and thus more precise

11.4.1.2 Theo. curve on/off (button “Eff. curve”)

You can select whether the effective solar curve will be calculated from the data and whether this curve will be displayed additionally to the measured curve. Depending on the measured data this calculations may be impossible.

11.4.1.3 Show STC curve on/off (button “STC curve”)

If a effective solar curve can be calculated it can be converted to STC conditions as well and also be displayed. Here you can switch the display of this curve on or off. The axis scale will be corrected automatically (if necessary).

11.4.1.4 Show power on/off (button “Power curve”)

You can select whether the power graph is displayed or not.

11.4.1.5 Zoom on/off (button “Zoom max”)

The Y-scaling is changed in such a way that the diagram uses the complete Y axis.

11.4.1.6 Legend on/off (button “Legend”)

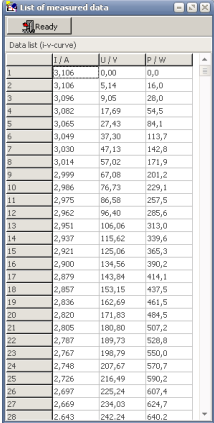
A legend of the displayed graphs can be displayed optionally. Here you can switch the display of the legend on or off.

11.4.1.7 Copy to clipboard (button “Clipboard”)

Copies the actual diagram to the clipboard, you can enter this copy for example into a word document.

11.5 Results / Lists

By clicking the option "Display data list" in the local menu a window with the measured characteristic data (in a list) appears.



The screenshot shows a window titled "List of measured data" with a status bar indicating "ready". The window contains a table with the following data:

	I / A	U / V	P / W
1	3,106	0,00	0,0
2	3,106	5,14	16,0
3	3,096	9,05	28,0
4	3,082	17,69	54,5
5	3,065	27,43	84,1
6	3,049	37,30	113,7
7	3,030	47,13	142,8
8	3,014	57,02	171,9
9	2,999	67,08	201,2
10	2,986	76,73	229,1
11	2,975	86,58	257,5
12	2,962	96,40	285,6
13	2,951	106,06	313,0
14	2,937	115,62	339,6
15	2,921	125,06	365,3
16	2,900	134,56	390,2
17	2,879	143,84	414,1
18	2,857	153,15	437,5
19	2,836	162,69	461,5
20	2,820	171,83	484,5
21	2,805	180,80	507,2
22	2,787	189,73	528,8
23	2,767	198,79	550,0
24	2,746	207,67	570,7
25	2,726	216,49	590,2
26	2,697	225,24	607,4
27	2,669	234,03	624,7
28	2,643	242,24	640,2

11.6 Help (not yet implemented)

11.6.1 Contents

Displays the contents of the online help.

11.6.2 Search

Here you can search within the online help.

11.6.3 Use help

Basic hints for the windows help system.

11.6.4 Info

Displays an information window with the version number of the program.

12 Technical data

Device:	
Device designation	Peak Power and Characteristic Meter
Type	PVPM 1500X
Display	4,3" Color TFT Display 480x272Pixels
Power supply	16VDC
Current consumption	1.8 ADC
IP protection	IP40 (IP67 with closed lid)
Dimensions	40.6 cm x 17.5 cm x 33.0 cm (W x H x D)
Working temperature	0° C to +50°C at 10% to 90% rel. humidity, not condensing
Storage temperature	-10°C to +60°C at 5% to 95% rel. humidity, not condensing
Weight	About 8.5 kg
Safety	EN 61010-1:2010 / EN 61010-2-030:2010
EMV	EN 55011:2016 / EN 55032:2015 / EN 61326-1:2013 / EN 61326-2-2:2013 / EN 61000-3-2:2014 / EN 61000-3-3:2013 CFR47 FCC part 15, Class B
Power Supply:	
Voltage input	90 – 264 VAC
Grid frequency	47- 63 Hz
Rated power	about 50VAC at U _e 230VAC
Rated current	220mA at V _e 230VAC
Output voltage	16VDC
Current load	Max. 2,5A
Output power	40W
Lithium-Ion battery pack:	
Nominal voltage	11.25VDC / 8.85Ah / 99.6 Wh (UN 38.3)
Capacity	8.85 Ah / 99.6 Wh
Operating time	About 8 hours
Working temperature	0°C to +45°C (charge), -20°C to +60°C (discharge)
Conformity	UN 38.3 / IEC62133
Measurement inputs:	
Measurement category	Measurement category I
Input voltage measurement range	25 / 100 / 500 / 1500 VDC
Input current measurement range	2 / 5 / 10 / 20 ADC
Measurement accuracy	≤ 1%, peak power ± 5%
Disconnecter switch:	
Max. input voltage	1500VDC
Max. input current	20ADC
IP protection	IP65
Irradiance reference sensor:	
Measuring range	0 to 1300W/m ²
Output voltage	about 0 - 100mV at 0 - 1000W/m ²
IP protection	IP54
Surface temperature sensor:	
Type	PT 100 DIN 1/3 B
Measurement temperature range	-40°C to +120°C

13 Hardware Information

(Subject to change without notice)

Build in a stable and water proof (IP67) plastic case with carrying handle, automatic pressure valve and tough front panel.

13.1 Measuring Unit

Sampling rate max. 100kHz

Resolution 0.01V - 0.25V, 0.0005A – 0.005A (depending on sel. range)

Accuracy of the a/d converter 0.08% of FSR \pm 1 LSB

Peak power measurement: \pm 5%

Reproducement: \pm 2%

Sweep time string measurement: 20ms up to 2 seconds, avoiding the influence of capacitive properties of the modules under test.

Irradiance reference sensor with integrated Pt100 or Pt1000 temperature sensor measures irradiance and cell temperature. Other commercially available sensors can be connected using a reliable cable connection.

Measuring ranges of the PVPM:

	Voltage [V]	Current [A]	Temperature	Irradiance
PVPM1500X	25/100/500/1500	2/5/10/20	-100°C - +120°C	0 - 1300 W/m ²

Ranges for current and voltage can be combined in any order

An optimal range is selected by the device automatically.

13.2 Pin allocation of the sensor connectors:

Temperature (external): 4 pin female receptacle Amphenol T 3327-500 (plug: T 3324-501)

Pin 1 = Current source + (~1 mA)

Pin 2 = Pt100 +

Pin 3 = Pt100 -

Pin 4 = Current source - (~1 mA)

Irradiance: 8 pin female receptacle Amphenol T 3527-500 (plug: T 3524-501)

Pin 1 = Irradiance+

Pin 2 = Pt1000 (reference) +

Pin 3 = Irradiance-

Pin 4 = Current source + (~1 mA)

Pin 5 = Current source - (~1 mA)

Pin 6 = do not connect

Pin 7 = do not connect

Pin 8 = Pt1000 (reference) -

13.3 Calculation Unit

Low power industrial PC, real time clock

No mechanically moved parts like hard disk, fan etc.

Flash disk 512MB (can store several thousand results)

A/D-Sampling Rate max. 100kHz, resolution 12Bit

Accuracy for the I-V-curve better 1%, Peak Power \pm 5%

The data of several thousand measurements will be stored automatically in the device (flash memory)

13.4 Display

Bright TFT touch display with LED back-light,
resolution 480 x 272 pixels,
RGB 32Bit color, high contrast
sunlight suitable

13.5 Operation

Menu driven with touchscreen on the front panel
Operation and evaluation alternatively by Windows software, connected via USB
USB 2.0 standard cable

13.6 Power Supply

Li-Ion battery 11.25V, 8.85Ah, 99.6Wh (continuous operation about 8h),
(tested acc. UN T1-T8 transportation tests, compliant UN 38.3 / PSE / RCM)
External power supply wide range input (90-263Vac, 47-63Hz, 40W, Out 16Vdc)
Integrated battery charger with overload protection for battery
Display of battery state with LEDs at the front panel

13.7 Dimensions

Width: 40,6cm, height: 17,5cm, depth: 33cm, weight 8kg

13.8 Operation Conditions

	Temperature:	Humidity
Operation:	0°C to 50°C	10% to 90% (not condensing)
Storage:	-10°C to 85°C	5% to 95%

13.9 Optionally available accessory

- Software for MS-Windows for the automatic generation of test reports
- test leads e.g. with length 15m or 25m (different lengths on request)

14 List of symbols

AM	Air-Mass, relative way length for the sunlight through the atmosphere of the earth
E	Irradiance
E_0	1000 W/m ² (Irradiance at STC)
E_{eff}	Irradiation, measured with a crystalline PV cell
FF	Fill factor: relationship $I_{sc} \cdot U_{oc} / (I_{pmax} \cdot U_{pmax})$, for crystalline modules about 0.75 = 75%, smaller values can indicate insufficient power
I	Current
I_m	Short form for I_{pmax}
I_{ph}	Photo current
I_{pmax}	Current at Pmax
I_{pmax0}	Current at Pmax0 (at STC)
I_{sc}	Short circuit current
I_{sc0}	Short circuit current (at STC)
MPP	Maximum Power Point, other description for P_{max}
NOCT	Nominal Operating Cell Temperature, cell operating temperature at T_{ambN} and E_N .
P	Power
P_{max}	Recent maximum power of a solar cell
P_{pk}	Peak Power, maximum power of the solar cell at STC
PV	Photovoltaic
R	Resistance
R_{pv}	Photovoltaic resistance (calculation factor only, no real resistor)
R_s	Series internal resistance, apart from resistances in the module e.g. cable/plug resistance, intrinsic resistance of crystalline modules about 0,5 ohms, of thin film cells 2-3 ohms. In strings R_s is determined strongly by the resistances of the cables.
R_p	Parallel internal resistance
STC	Standard Test Conditions $E_0=1000\text{W/m}^2$, AM1.5, $T=25^\circ\text{C}$
T_{mod}	Current module temperature (at the back side of the module)
U	Voltage
U_m	Short form for U_{pmax}
U_{oc}	Open circuit voltage
U_{oc0}	Open circuit voltage (at STC)
U_{pmax}	Maximum power voltage

15 Reasons for decreased Power and Yield of PV Generators

Error	To be detected by:	Possible reason / workaround
System configuration chosen inadequately	Measurement of mismatch losses	Design fault / <i>redesign</i>
Erroneous match of strings and inverter	Fed power too low for location and in relation to nominal generator power	Design fault / <i>redesign, replacement of inverters</i>
Cast shadow	I-V-curve shows "bulge", peak power too low, optical check	Barrier near module (e.g. tree, chimney, birds excrements) / <i>remove barrier</i>
Diffuse shading (may be hardly visible for bare eye!)	I-V-curve is "impressed", peak power too low	Barrier in some distance to module (high portion of diffuse light) / <i>remove barrier</i>
Corrosion at plugs and cables	Serial internal resistance R_s too high	Material, planning or mounting fault / Clean, <i>replacement</i>
De-lamination of cell embedding	see shading diffuse	Material / production fault / <i>Replacement</i>
Bubbling in resin	see shading diffuse	Material defect / <i>replacement by supplier</i>
Transparent covering material (glass, plastics, resin) becomes blind	Optical check, peak power too low (s. a. shading diffuse)	Material defect / <i>replacement by supplier</i>
Discoloring of the transparent cover material (plastics, resin)	Optical check, peak power too low (s. a. shading diffuse)	Material defect / <i>replacement by supplier</i>
Intrusion of water into the laminate, leads to other problems (corrosion, discoloring)	Optical check	Material or production fault / <i>replacement by supplier</i>
Faults in the crystalline structure of single cells (hot-spot effect)	see shading diffuse	Production fault / <i>reduction of price, replacement by supplier</i>
Pollution of the module by dust	Optical check, see shading diffuse	High dust impact. Check modules periodically / <i>cleaning</i>
Moss / algae on module, birds excrements	see cast shadow	Normal for several regions / <i>cleaning</i>
Broken cover glass, leads to other problems (corrosion, discoloring)	Optical check	Hailstorm, mounting or transportation fault / <i>replacement by supplier</i>
Crack of single cells in module	Peak power too low, possibly deformation of I-V-curve	material defective / <i>replacement by supplier</i>
Improper electrical connections in module	Peak power too low, internal series resistance R_s higher than calculated	Fault in soldering, material defective, corrosion / <i>replacement by supplier</i>
Bypass diode defective (short circuit)	Peak power of strings reduced by module power	Overload, material defective / <i>repair</i>
Bypass diode mounted the wrong way	Peak power of strings reduced by module power	Mounting fault / <i>repair</i>
No bypass diode mounted or diode defective (high resistance)	Shading of one module reduces power of the string dramatically	Planning / mounting fault / <i>repair</i>
Dimension of cabling too small	Internal series resistance R_s too high	Design fault / <i>replacement of cables</i>
Cable defective (e.g. break, corrosion)	Internal series resistance R_s too high	Mounting fault / <i>repair</i>
Insufficient mounting of connectors	Internal series resistance R_s too high	Mounting fault / <i>repair</i>
Corrosion in screwed or plugged connectors	Internal series resistance R_s too high	Mounting fault / <i>cleaning, repair</i>
Insufficient preselection of modules regarding peak power	Peak power of plant too low	Planning or mounting fault (match losses) / <i>New preselection of the modules after peak power measurement</i>
Insufficient preselection of single cells regarding power during module production	Peak power of module too low	Production fault / <i>reduction of price, replacement by supplier</i>
Short circuit between cells in the module	Peak power of plant too low, open circuit voltage U_{oc} too low, shape of curve	Production fault / <i>replacement by supplier</i>
Fabrication tolerances in cell production	Peak power too low, shape of curve	Production fault / <i>reduction of price, replacement by supplier</i>

Please notice: some faults may appear only under special operating states, e.g. high module temperatures.

This compilation does not claim to be complete or free of failures.

16 I-U diagram: Explanation

The diagrams represented in the following are from the books (with friendly permission of the authors):

Quaschnig, Volker: *Simulation der Abschattungsverluste bei solarelektrischen Systemen*. Verlag Dr. Köster, Berlin, 1996

Wagner Andreas: *Photovoltaik Engineering – Handbuch für Planung, Entwicklung und Anwendung*. Springer Verlag, Berlin Heidelberg New York, 2005

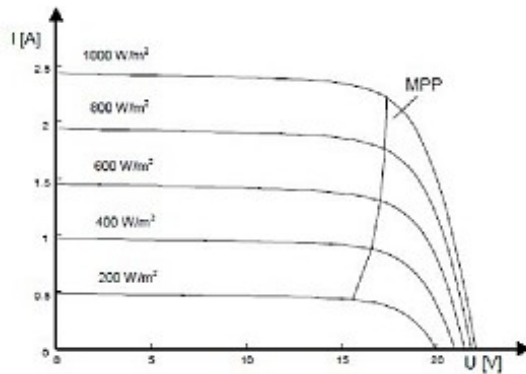


fig: Current voltage characteristics with an irradiation of 1000W/m² and different irradiances

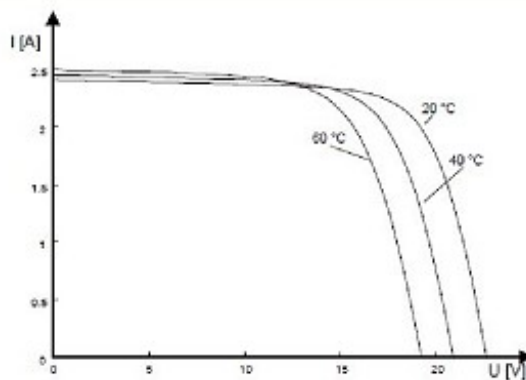


fig: Current voltage characteristics with an irradiation of 1000W/m² and different cell temperatures

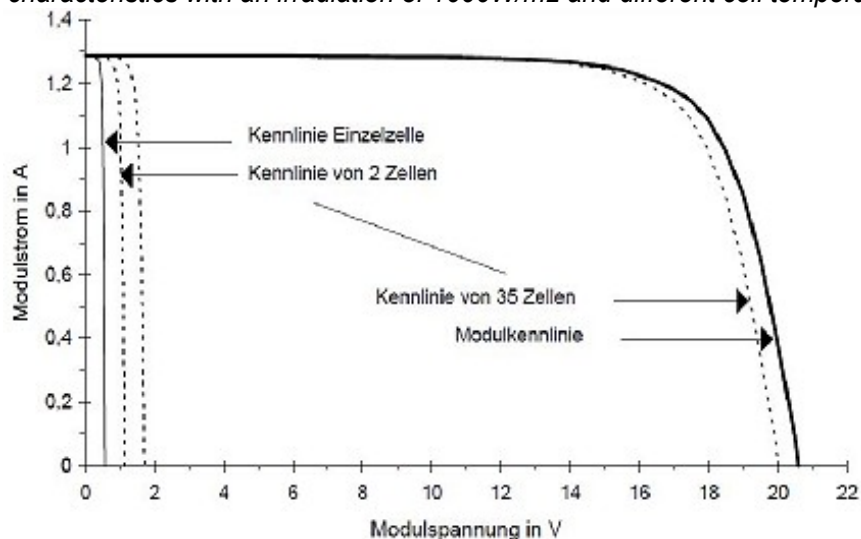


fig: Construction of the module characteristic from the cell characteristics (irradiance $E = 400\text{W/m}^2$, $T = 300\text{K}$)

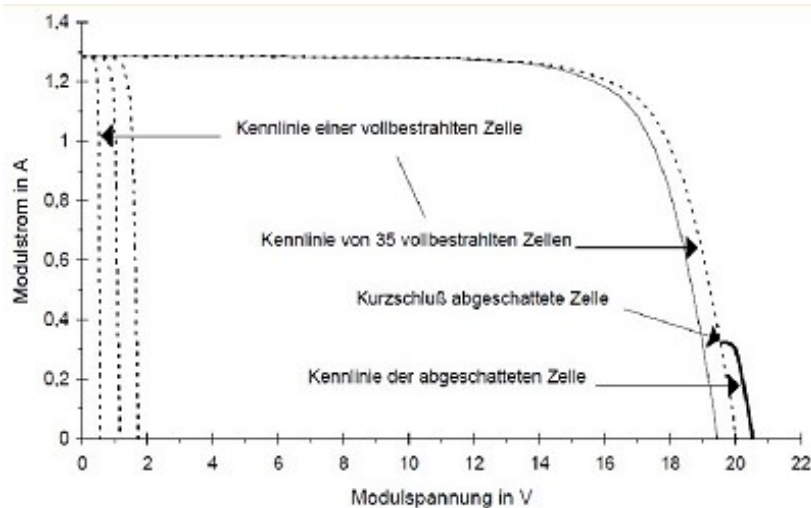


fig: Partial construction of the module characteristic with a part-shaded cell

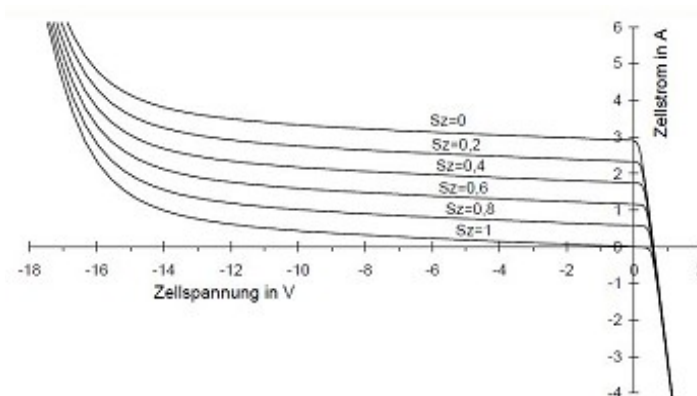


fig: Solar cell characteristic of a polycrystalline cell over the whole voltage range with different shading degrees ($E_0 = 1000\text{W/m}^2$, $T = 300\text{K}$)

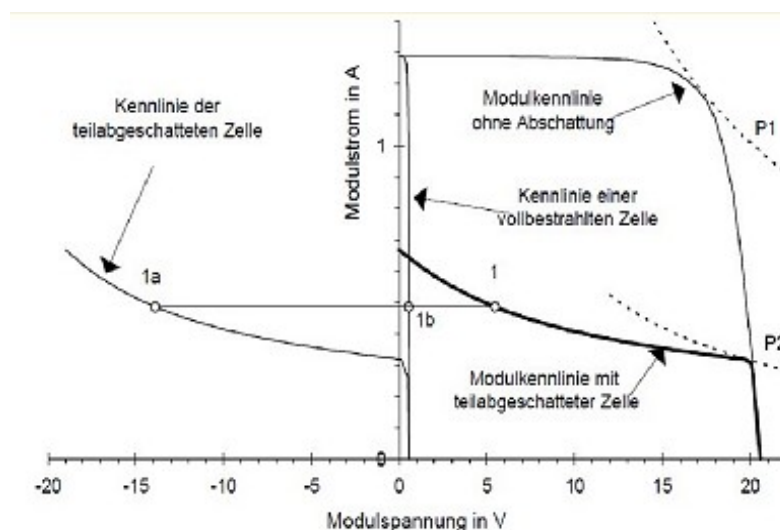


fig: Construction of the module characteristic of the module SM50 with a 75% shaded cell ($E = 407\text{W/m}^2$, $T = 300\text{K}$)

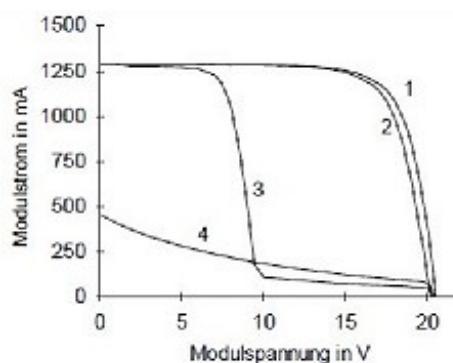


fig: Solar module characteristic: (1) fully illuminated; (2) a cell completely covered, with bypass diode over the cell; (3) with bypass diodes over half cell string; (4) without bypass diode

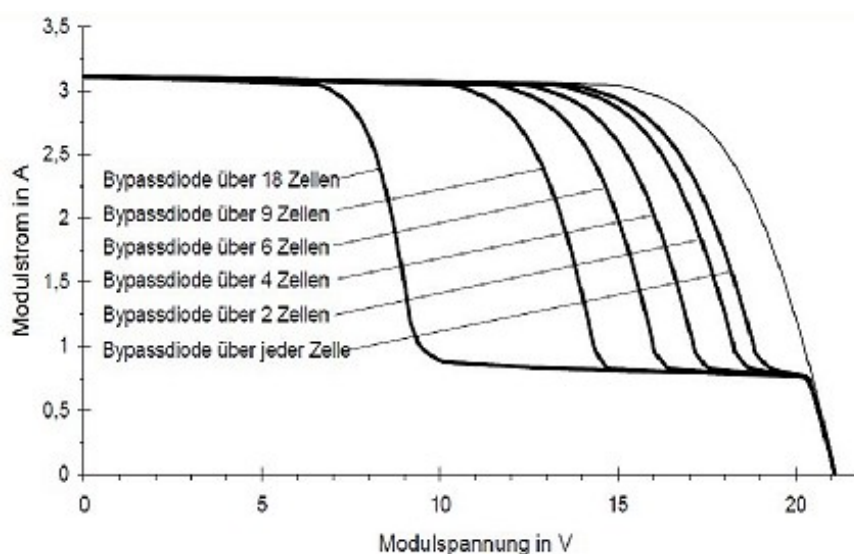


fig: Simulation of different module characteristics with bypass diodes over a different number of cells ($E = 1000\text{W/m}^2$, $T = 300\text{K}$)

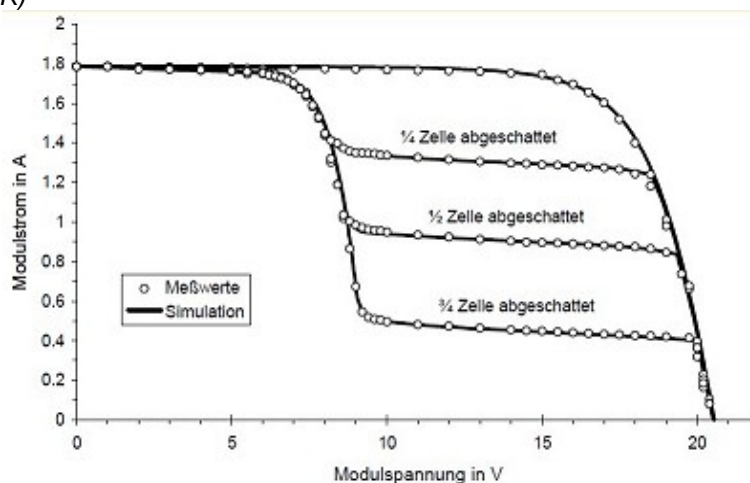


fig: Comparison of simulation and measured values by the example of the module SM50, 36 cells with two bypass diodes over in each case 18 cells. A cell was differently shaded, the others was fully illuminated ($E = 574\text{W/m}^2$, $T = 300\text{K}$)

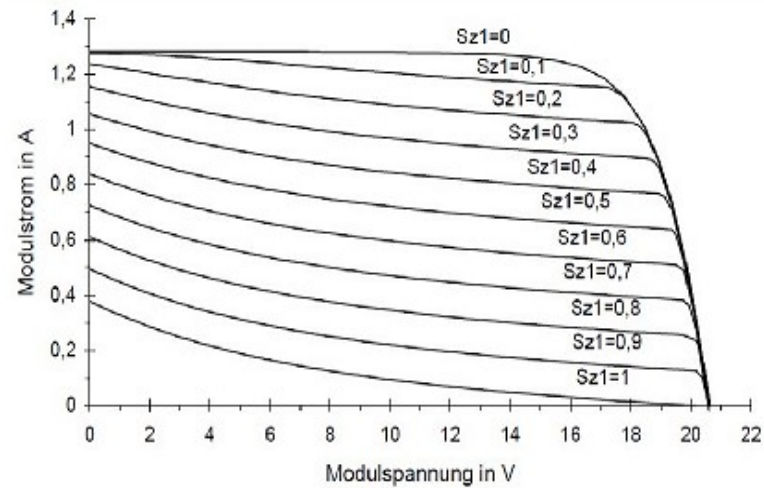


fig: Module characteristics of the module SM50 without bypass diodes, first cell differently shadows (shading degree of $Sz1 = 0..1$), $E = 407W/m^2$, $T = 300K$

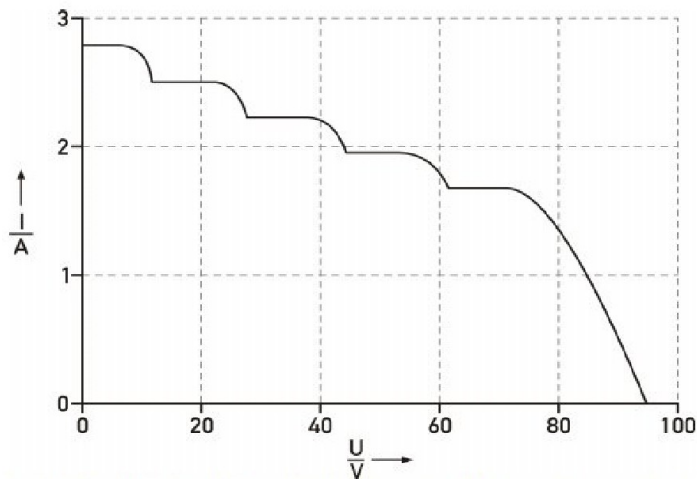
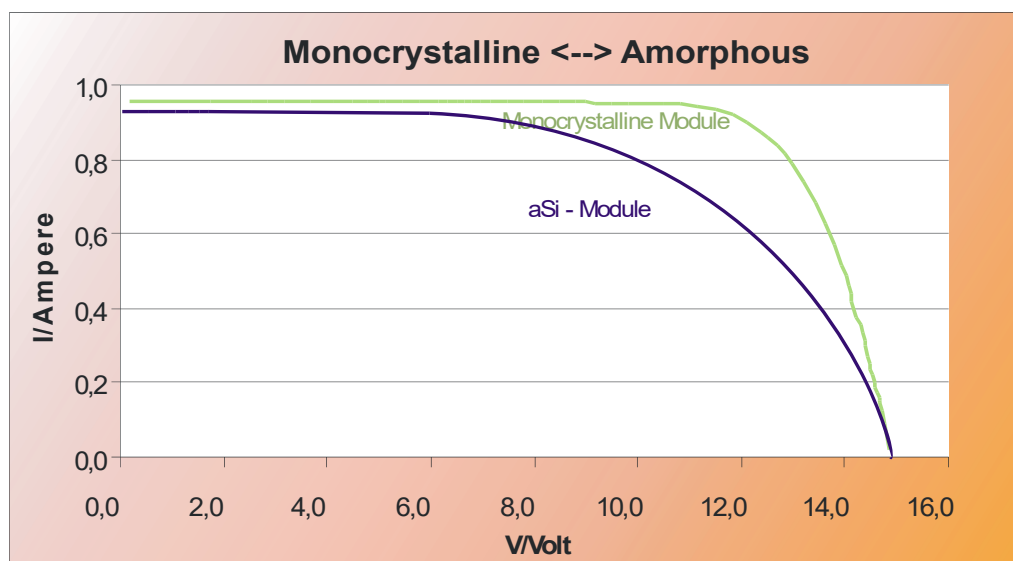
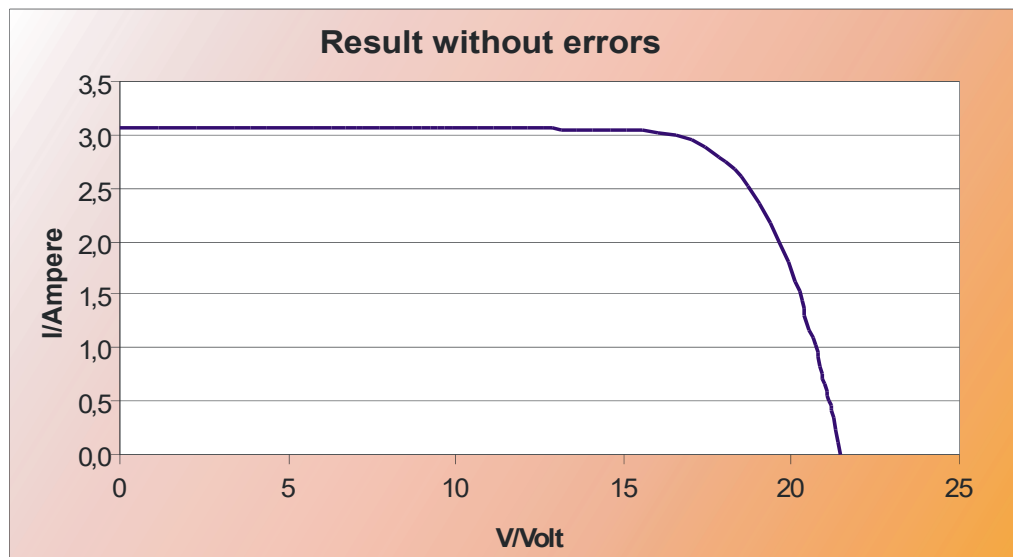
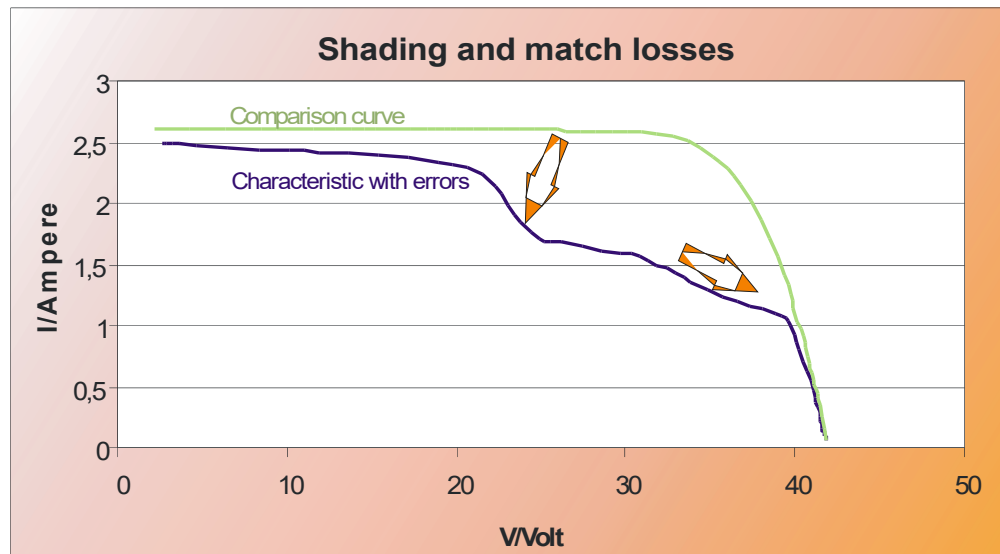
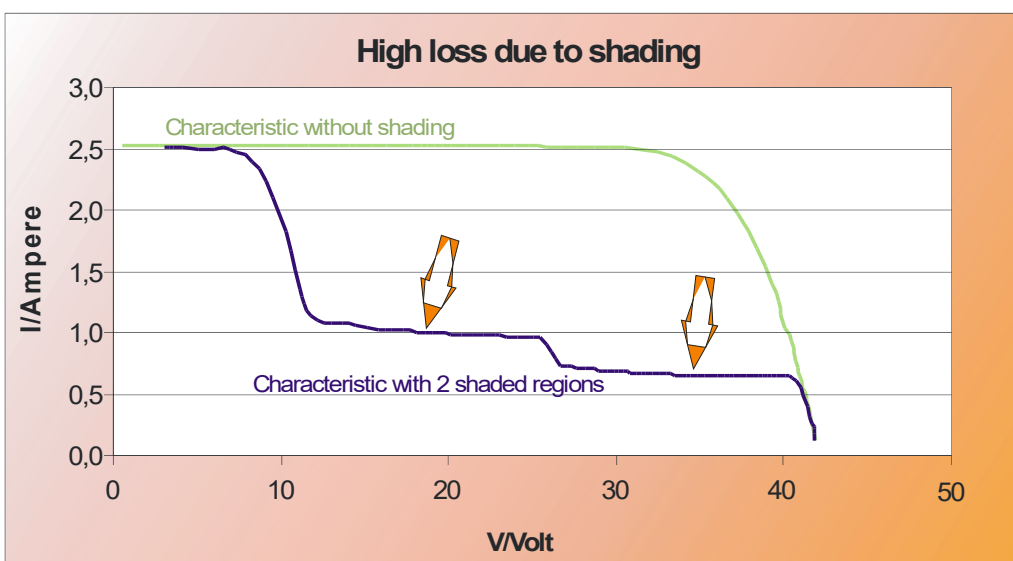
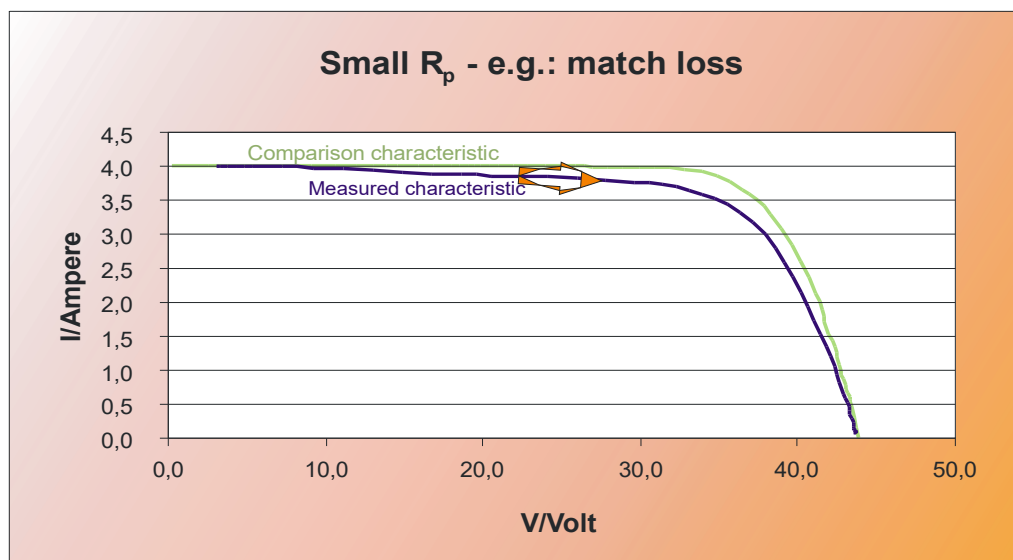
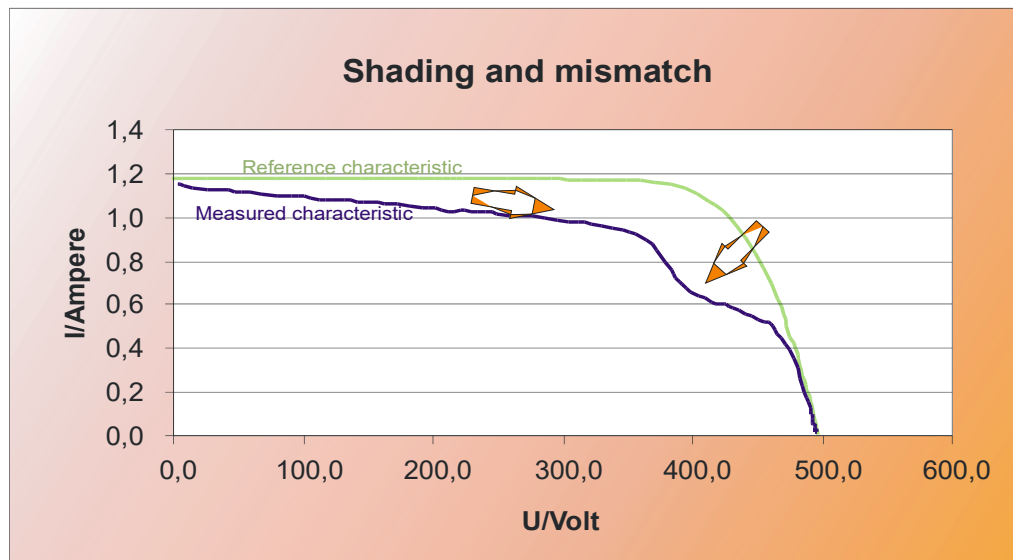
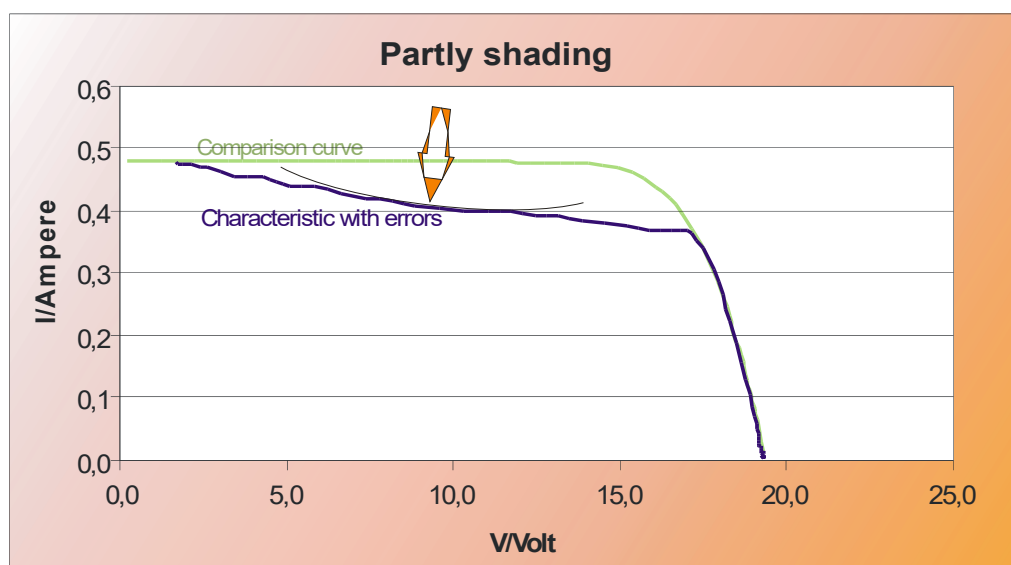


fig: Resulting characteristic during series connection with bypass diode

17 Sample Curves







18 Glossary

18.1 Azimuth (β) and elevation (α)

For the optimal use of solar radiation the modules and collectors are arranged in a way that allows a preferably large solar yield. In this context the incidence angle of the sun, but also the azimuth and the elevation of the modules and collectors play a certain part. The azimuth angle specifies the angle between the orientation of the modules or the collectors and the exact adjustment to the south. The elevation means the angle of the modules from the horizontal. Studies have approved that PV plants with an azimuth of 0° and an elevation of about 30° are aligned in the best possible way. Nevertheless small deviations are not implicitly problematic: with the orientation to south-east or south-west still around 95% of the possible yield can be realized. Larger plants are, to enhance the profit, tracked towards the sun by electric motors. (see also → tracking).

For measurements with the PVPM the accurate alignment of the irradiation sensor with the modules is very important. The sensor has to 'see the same part of the sky' as the modules. At the same time it is to be taken in account that by reflections from the environment (by house walls or other light surfaces) the incidence of light on the modules and the sensor can be intensely influenced.

18.2 Slope

When planning a solar plant the question for the slope of the roof (e.g. on the internet) leads to wrong conclusions, as it is not the slope of the roof - but the slope of the collectors that is important. Through an appropriate elevation and mounting the collectors can be brought into a good position even if the slope or the adjustment of the roof are disadvantageous.

For the optimum use of solar radiation the sun rays should fall on the collectors in a right angle. The optimum elevation and angle of setting-up correspond to the geographical latitude of a location. (Freiburg is located on the 48. degree of latitude; Lübeck on the 54. degree of latitude) Since the sun stands higher in the summer than in the winter it depends on in which time of the year the solar equipment is predominantly being used. Photovoltaic plants for example carry the highest yield on long summer days, while thermal solar plants are taken to support heating installations in the winter. As a rule of thumb for the elevation of the collector you can use latitude minus 10° in the summer and latitude plus 10° in the winter is considered to be effective.

Not to be confused with the slope is the orientation (azimuth angle) to the south. In practice smaller deviations from the optimum slope or orientation decrease the productivity insignificantly. A temporary shading of the collectors impairs the effectiveness far more.

18.3 DC

Short form for direct current, as it is being produced by solar cells and modules and stored by a battery. If many solar cells are connected in series to a module, the single voltages add.

18.4 Degradation characteristic

The degree of efficiency of amorphous solar cells declines at the beginning of the phase of irradiation rapidly and first stabilizes after a time between 3 weeks and 5 month. Besides this irreversible degradation, another reversible degradation is taking place. That means that amorphous solar cells have a better degree of efficiency in spring-/summer-time compared to autumn/winter.

18.5 Direct radiation / diffuse radiation

Direct radiation (forces casting shadows) meets a surface without scattering through components of the earth's atmosphere. Through scattering (fog, haze, clouds) diffuse/ indirect radiation develops.

18.6 Generator

Lat.: producer. Generators dissipate other forms of energy into current. In the photovoltaic the entirety of the interconnected photovoltaic modules is characterized as generator or as solar power plant.

18.7 Global/total radiation

Denotes the irradiation of the sun towards a horizontal surface on the earth. It is composed of the direct irradiation and the reflected irradiation (e.g.: by snowfields).

18.8 Short-circuit current of solar cells

Current that circulates, if the positive and the negative pole of the PV generator is connected, that means when there is no resistance or load between the two poles. It is not dangerous for the generator, but a disconnection might cause a light arc which is dangerous for health and environment!

18.9 Mismatching

The connection of weak and better modules in one string, whereby the weaker module in a row affects the current of the string and in that way impairs the total power.

18.10 MPP

Denotes the point of maximum power in the I-V-curve. A solar cell has a point of maximum power in its I-V-characteristic depending on the current irradiation, temperature and light spectrum. The product of usable voltage and corresponding current of a solar cell does not always have the same value.

18.11 Tracking

The module-surfaces of 'trackers' follow the state of the sun during the course of the day. The tracking can be carried out by one or two axis, whereby the production of two-axe tracking is more effective. Compared to a permanent south orientated plant the annual yield increases with up to approximately 30%. Tower mounted, tracked and elevated solar plants allows the choice of an optimum position. That way, irrespective of structural circumstances, a panning range of 180° free from shadowing is made possible.

18.12 Peak Power

To guarantee the comparability of power output of PV-modules it was generally accepted that the nominal power of a module is measured at a cell temperature of 25°C, an irradiation of 1000W/m² and a spectrum of light according to AM=1,5 and named "Peak Power" (some producers also characterize it as "nominal value"). The boundary conditions are called Standard Test Conditions (STC).

Unfortunately the natural appearance of the STC is rare, that is why the relevant measurements so far were only realized in laboratories, where the conditions had to be produced under high effort.

With the new methods of the Peak Power measuring devices and curve tracers series PVPM, it is now possible to realize these measurements under current ambient conditions - the measuring device automatically converts the results to STC. Thus after just one I-V-curve measurement the Peak Power P_{pk} , the internal series resistance R_s and the parallel resistance R_p are available as a result. This result is, in comparison with the specified value, an indication for different errors in the PV generator, that is how they simplify quality control and error detection.

18.13 Performance Ratio

In the photovoltaic the "Performance Ratio" means the ratio of available profit and specified value of a plant. The Performance Ratio is the quotient of the yield of alternating current and nominal yield of generator DC. It indicates what proportion of the current produced by the generator is in real terms available. PV plants of high capacity reach a Performance Ratio of more than 70%. The Performance Ratio is often denominated as quality factor (Q). Solar modules on the basis of crystalline cells reach a quality factor of 0,85 to 0,95, network coupled plants average out at 70% to 75%.

18.14 Internal series resistance

This resistance results physically from the material being used for the production of the module as well as from its cable connections. For crystalline modules it amounts about 0.5Ohm, for thin-film modules more than 2 Ohm.

The measurement of the internal series resistance is latterly possible with the measuring devices series PVPM. For that purpose just one I-V-curve of the module has to be measured. With this data the device automatically calculates the R_s as well as the P_{pk} and the parallel resistance R_p .

The theoretically expected value of the internal series resistance R_s can be calculated. The calculation can be carried out with the software PVPMdisp, if the STC characteristic values for V_{oc} , I_{sc} , V_{pmax} and I_{pmax} of the module are known.

The calculated R_s can be compared to the measured value which the PVPM measuring device displays after the I-V-curve measurement. If the measured value is too high the wiring should be checked for burst, corrosion, connection errors or wrong dimensions.

18.15 Solar Constant

Denotes the solar radiation that hits vertically on a surface outside the atmosphere. $s=1,37 \text{ kW/m}^2$. Outer space the solar radiation is almost constant; on earth it fluctuates in the course of daytime or time of the year and varies depending on latitude and weather. The maximum value on earth lies between about 0,8 and 1,2 kW/m^2 . In annual means the irradiation in Germany amounts according to region between 850 and 1100 kWh/m^2 .

18.16 Solar irradiation / insolation

The solar irradiation consists of the radiation which is directly from the sun and divers indirect proportions. Those are radiation reflected by the environment, e.g. snowfields reflect very intensive the radiation of the blue sky, and other diffuse radiation. For the exact calculation of the energy that hits a surface the angle between the sunlight and the surface is decisive. It changes according to time of year and time of the day. Informations about the exact calculation are offered at different internet addresses. The radiation is delimited by several factors; even if the sky is beaming blue only around 90% of the total solar energy arrives on earth.

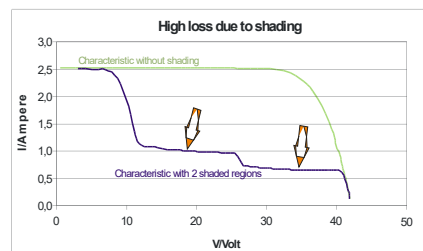
18.17 Standard Test Conditions

To make the power of PV modules comparable they always are measured at the same conditions: according to IEC60904-3 the Standard Test Conditions (STC) consists of an irradiation of 1000W/m^2 , a light spectrum according to AM=1,5 as well as a module temperature of 25°C . Since these requirements are hardly to find under natural sunlight, methods were developed to calculate the STC values of PV modules from I-V-curves measured under ambient conditions.

18.18 Current-Voltage-Characteristic

The Current-Voltage-Characteristic of a PV-Generator shows different qualities and problems of the generator and is the basis of a few substantial specific values.

For example partially or hard shading will modify the characteristic as well as high internal series resistance and defective or missing bypass diodes.



Besides short circuit current I_{sc} and open circuit

voltage V_{oc} , voltage and current at the maximum power point (MPP) I_{pmax} and V_{pmax} as a result you get the fill factor FF:

$$FF = I_{sc} * V_{oc} / (I_{pmax} * V_{pmax})$$

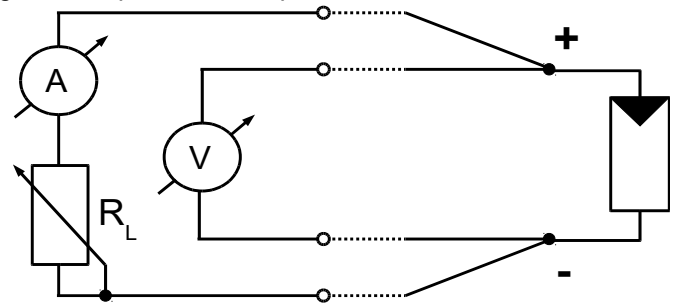
The I-V-curve is the basis for the calculation of the effective solar curve, which then allows the determination of the peak power P_{pk} and the internal series resistance R_s .

18.19 Efficiency

General: Relationship of the usable to the assigned energy. For illustration: Conventional bulbs transform about 3 - 4% of the assigned energy into light, photovoltaic generators respectively solar cells at present reach an efficiency of 11 - 17%, thermal solar plants between 25 and 40% regarding the solar radiation.

18.20 Four-wire measurement (Kelvin measurement)

If an current flows through an electric conductor a voltage will drop due to the specific resistance of the conductor. This interrelationship is known as Ohm's law ($R=V/I$). The voltage at the end of the wire is lower as at the beginning of the wire (the point of measurement). To get the exact voltage at the point of measurement anyway the four-wire method is used: here the current flows through two of the four wires where the input resistance of the measurement device is low (here voltage will drop on the wire), the voltage is measured over the other two wires that are connected to a high resistance input (here nearly no current flows and thus no significant voltage drops).



19 Appendix A

19.1 Indicator lights in the front panel

LED	Function	Remark
State of charge (2 color LED)	Blinking Red: battery nearly discharged (charge!) Red: battery is charged Green: charge is nearly finished Off: charge is finished	Operation time left <u>max. 30 minutes</u> Operation is possible Operation is possible Operation is possible
External Power	On, when an external power supply is connected, the internal battery will be charged autom.	

19.2 Speaker signals:

PVPM reports errors and operating conditions by speaker signals: in the following deep sounds are represented by „da“, higher sounds as „dee“.

<i>audio</i>	<i>declaration</i>	<i>reaction</i>
click	„Keyboard-click “when pressing the transparency keyboard one simulates	--
dee	During the operation: signals the start or the end of a function	--
da	generally in the case of errors	Consider, which error the device shows on display
dee	If this signal is given with the first appearance of the main menu, the device is ready for operation	Device is ready
da or da-da	Shortly after switching on: CPU Is working	--
da or da-da followed by da-da	Shortly after switching on : probably the lithium buffer batttery of the CPU is empty.	Customer service necessary
dee-dee-da-da	The LC-display cannot be addressed.	Switch the equipment out, after short waiting period on again. If the error arises once more: Customer service necessary
dee dee	After a transfer of a file to the PVPM (only service mode)	File transfer O.K
da-dee-da	After a transfer of a file to the PVPM (only service mode)	File transfer not o.k . destination file is deleted
dee-dee-dee-dee	During measurement: irradiation varies or is too small	Measurement is inaccurate and must be rejected
dee-dee-dee-da-da-da-dee-dee-dee	A/D converter could not be initialized	Customer service necessary

20 Declaration of Conformity**EU-Konformitätserklärung** im Sinne der EU-Richtlinien /
EC Declaration of Conformity as defined by the EC Directives

Der Hersteller / **PV Engineering GmbH**
The manufacturer **Hugo-Schultz-Str. 14**
58640 Iserlohn
Deutschland/Germany

erklärt hiermit in alleiniger Verantwortung, dass folgende Produkte /
herewith certifies in sole responsibility that the products

Produkt: / I-U-Kennlinienmessgerät
Product: I-V-Curve tracer
Typ: / PVPM1500X
Typ:
Baujahr: / 2018
Year of manufact.:

auf das sich diese Erklärung bezieht, ausschließlich für die Messung der I-U-Kennlinie von Photovoltaikmodulen
oder -strings verwendet wird und den Anforderungen der EG-Richtlinien /
*to which this declaration refers to are exclusively used for the measurement of the I-V-curve of photovoltaic
modules or strings and are in conformity with the directive(s)*

- **Niederspannungsrichtlinie 2014/35/EU**
- **EMV-Richtlinie 2014/30/EU**

entspricht.

Folgende harmonisierte Normen wurden angewandt: /
The following standards are in use:

EN 61010-1:2010, EN 61000-3-2:2014,
EN 61000-3-3:2013, EN 61326-1:2013, EN 61326-2-2:2013

Eine technische Dokumentation ist vollständig vorhanden. Die zum Messgerät gehörende Betriebsanleitung
liegt in der Originalfassung vor. /
*A technical documentation is completely available. The operation manual of the device is available in its original
version.*

Iserlohn, 01.06.2018
(Ort/Place, Datum/Date)

Dipl.-Ing. Klaus M. Schulte
Geschäftsführer/Managing Director