GOSSEN METRAWATT

PROFITEST PV

Peak Power Meter and Curve Tracer for PV Modules and Generators up to 1000 V DC, 20 A DC, 20 kW

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2 Introduction

The PROFITEST PV *allows for the measurement of the characteristic IU curves of photovoltaic modules and strings. Thanks to a new process, the instruments are capable of calculating peak power, internal series resistance Rs and shunt resistance Rp on the basis of measured values directly at the PV system's installation site, and displaying them at the color graphic display.*

Peak power is power achieved by a module under standard test conditions (STC) [1]. Until recently, the measurement of peak power was only possible by means of a complex procedure in specially equipped laboratories. Thanks to a patented process developed by Professor Dr. Wagner at the university of applied sciences in Dortmund, Germany, this measurement can now be easily performed with the PROFITEST PV*. Quality control for PV systems is thus quick and economical without a long learning curve. In actual practice, this simple yet decisive test assures safety for the customer and for the installer. Beyond this, acquired characteristic curves make it possible to draw further conclusions regarding the electrical characteristics of the measured module or string. And thus the* PROFITEST PV *is also suitable for use in research and development.*

The PROFITEST PV is a portable measuring instrument with integrated battery (supply power) in a sturdy housing. The instrument is equipped with its own miniature industrial PC and a high-contrast, color graphic, daylight-compatible LCD, and can thus be used independent of additional devices. However, a PC can be connected via a standard USB port if required for data transmission and further analysis of the measured values.

The PROFITEST PV is operated conveniently via a touch-screen and a menu. The functions are designated in a self-explanatory fashion with simple pictograms, and the user is prompted continuously by the software. The leaning curve for becoming familiar with instrument operation is practically non-existent.

All commercially available irradiation sensors can be connected to the instrument, which generate a voltage of approximately 0 to 100 mV with linear dependence on irradiation (Phox sensors).

Depending on instrument variant, an additional Pt100 sensor can also be connected. This makes it possible to measure module temperature, and is mounted to the back of the module.

Measurement Description

The PROFITEST PV automatically measures the characteristic current-voltage curve of the generator at a capacitive load, as well as momentary temperature and irradiation at the point in time of measurement, and calculates the effective solar cell curve, P_{pk}, R_p and R_s, on the basis on the measured values [2][3]. Measurement data are saved to continuously battery-backed memory after measurement, and can thus be retrieved again later (for example at the office) [4]. The instrument has enough internal memory storage capacity for several thousand measurements.

The following values are displayed as results:
Absolute values:
- Peak power P_{Pk}
- Internal series resistance R_s
- Parallel internal resistance (shunt resistance) R_p

Instantaneous values:
- U_{pmax}, I_{pmax}, P_{max},
- U_{oc}, I_{sc}, FF, T_{mod}, E_{TRMS}

If desired, the ascertained characteristic IU curve appears directly at the integrated, high resolution color graphic display.

3 Use for Intended Purpose

The PROFITEST PV peak power meter and characteristic curve tracer is used exclusively for recording IC curves of individual photovoltaic modules and strings. Before the device under test is connected to the measuring instrument, it must be assured that the DUT cannot, at any time, exceed the measuring instrument's maximum permissible current and voltage values.

4 Safety Precautions

Before initial startup of the measuring instrument, read through the included operating instructions completely in any case, because it contains important information for the prevention of damage to the measuring instrument and personal injury! Keep this manual together with the PROFITEST PV.

Instructions regarding safety are identified with symbols signifying "Caution!" or "Caution: High-Voltage!," and must be carefully adhered to. Damages resulting from non-compliance with these instruction are excluded from the guarantee. No liability is assumed for consequential damages.

PV Analyzer software necessitates a PC with hard disk and MS Windows® NT, 2000, XP, Vista or 7, as well as a mouse for control purposes. An available USB port is required in order to connect the PROFITEST PV to the PC.

Available space on the hard disk required for PV Analyzer software amounts to roughly 10 MB prior to installation. Make sure that there is always adequate hard disk memory capacity for subsequent storage of data.

⚠️ **Caution!**
We would like to draw attention to the fact that, for purposes of data security, it's very important to create a backup for program data on separate data storage media at regular intervals, in order to be able to continue working without any significant loss of data in the event that data or the data storage medium is damaged. Even with the current state-of-the-art, damage of this sort cannot be ruled out. In the case of damage, do not restore individual program files: Always restore the entire data backup because inconsistencies amongst program functions might otherwise occur, which in turn may lead to loss of data! If you have any doubts in such cases, contact your supplier or the manufacturer.

4.1 Safety Features and Precautions
This instrument fulfills all requirements of applicable European and national EC directives. We confirm this with the CE mark. A corresponding declaration of conformity can be requested from GMC-I Messtechnik GmbH.

[1] Standard test conditions STC (IEC60904-3) specify irradiation: 1000 W per sq. meter, spectrum AM: 1.5, module temperature: 25°C.

[2] Wagner A.: Peak-Leistung- und Serien-Innenwiderstand-Messung unter natürlichen Umgebungsbedingungen. - EuroSun Kopenhagen 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.

5 Warnings

Non-observance of the following information may result in sever injury and/or mortal danger!

!! Very Important !!

⚠️ **Caution!**
Read the operating instructions before starting the instrument up.

⚡ **Caution: High-Voltage!**
Danger of electric shock

Caution: measuring category I. The instrument may not be used in measuring categories II, III and IV.

Measurement terminals may not be connected to ground.

This instrument may never be used in proximity to flammable gases.

Keep children and babies away from the measuring setup!

The measuring instrument may not be used in areas with excessive dust or high atmospheric humidity. No liquids may be permitted to penetrate into the instrument's interior.

In case of unusual sounds or odors, or if smoke develops, switch the instrument off immediately and disconnect it from supply power with the load disconnector.

Check the power measurement cable for damage prior to each measurement. If the measuring instrument's cables are damaged, they must be replaced immediately. Cables may not be repaired.

Only a limited DC power source (photovoltaic generator) with no more than 20 A may be connected to the power measurement input at the PROFITEST PV. Connecting other sources may lead to destruction of the instrument!

Cable connections to the PV generator may only be completed by qualified electricians. For safety reasons, measurement should only be performed by a trained electrician. Other required qualifications and laws (e.g. VDE 0100) must also be adhered to, because mortal danger prevails due to heavy current and high-voltage!

The devices included in the scope of delivery of the PROFITEST PV (PROFITEST PV basic instrument, irradiation reference sensor) may only be opened up and repaired by qualified personnel who have been authorized to do so by the manufacturer. All cables which might conduct dangerous voltage or current must be disconnected before each and every intervention. Caution: Even after disconnecting the device under test, life endangering voltage may still be present inside the PROFITEST PV!

Under certain circumstances, the solar generator may generate very high current and voltage, which may result in severe injury in the event of improper handling! The corresponding safety regulations (VDE) must be adhered to.

Observe all applicable safety regulations regarding work performed on roofs.

Never connect or disconnect the solar generator cables to or from the PROFITEST PV without first isolating the generator! An all-pole safety switch included in the measurement cable (see section 7) allows for isolation and hazard-free connection of the measurement cables to the PROFITEST PV.

The plugs at the ends of the measurement cables for power measurement (4-wire measurement cable) must be inserted into the corresponding sockets as far as they will go. The measuring instrument and the cable might otherwise be damaged during measurement due to arcing in the plug connection (fire hazard!).

During measurement and in the case of electrical damage to the measuring instrument, the generator is short-circuited inside the PROFITEST PV and arcing may occur between the plug and the socket when the plug is removed, which may cause severe damage to health, as well as property damage! Disconnection from the PROFITEST PV is only rendered safe after isolating the solar generator.

6 Operating the PROFITEST PV
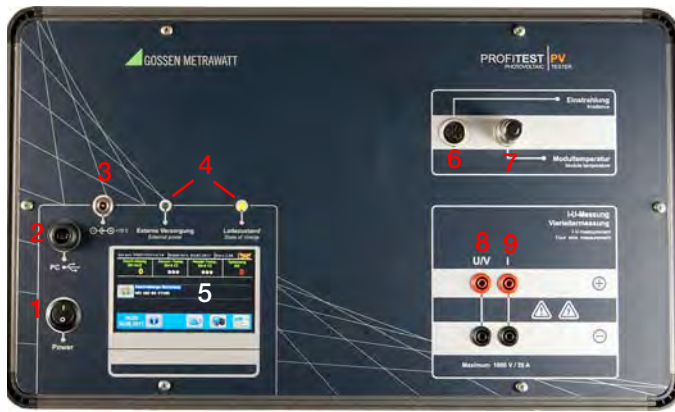
6.1 Controls and Connectors

1 On/off switch
2 USB port to PC
3 Socket for external power supply, 16 V DC / 2 A
4 Status LEDs
5 Color graphic display
6 Irradiation input or combined irradiation-temperature input
7 Temperature measurement input, Pt100 or Pt1000
8 4-wire voltage measurement input
9 4-wire current measurement input

6.2 General Notes

As is the case with nearly all electronic measuring instruments, the PROFITEST PV can only be used within a limited temperature range (see appendix). For this reason, it's important to avoid exposing the PROFITEST PV to direct sunlight for lengthy periods of time. Keep the PROFITEST PV in a shaded area if possible, or protect it from direct sunlight during long periods of work, for example with a screen.

In its standard variant, the PROFITEST PV is not intended for installation into other devices or holders. During operation, it's important that air surrounding the PROFITEST PV can circulate freely in order to assure sufficient heat dissipation. For strict storage purposes (without batteries – i.e. no charging of the batteries – when no heat is generated inside the instrument) the instrument can be stacked.

> ⚠ **Caution!**
> Under no circumstances may any plug connections be disconnected during measurement! Due to DC voltages/ currents which are very high in some cases, arcing may otherwise occur at the point of contact which may cause fire or severe personal injury (see section 4).

The membrane front panel at the PROFITEST PV is rugged. However, please take good care of it in order to assure that you will be able to enjoy your instrument for many years.
Observe the following suggestions in order to prevent damage to the front panel:

Do not contact the front panel with sharp or pointed objects. In addition to causing scratches, this may also result in destruction of the membrane at places at which, for example, keys are located behind it.

Clean the front panel with a soft, moist cloth. Do not use any plastic sponges or abrasive cleansers, because this would cause scratching of the Plexiglas sheet mounted in front of the LCD monitor, which in turn would impair display quality.

When closed, the instrument housing is waterproof (IP 67). Nevertheless, do not subject the instrument to the direct influence of water. Never leave the instrument in the rain.

In order to obtain good measuring accuracy, solar irradiation should amount to at least 500 W per square meter at the time of measurement if at all possible. Curves can be traced with lower irradiation values, but results for peak power are inaccurate in this case and are no longer displayed for this reason.

6.3 Connecting Peripheral Devices

The measuring setup consists of the peak power measuring instrument and the following additional components:

1 USB port for optional PC
2 External power pack, 16 V DC, 2 A
3 Irradiation reference sensor
4 External Pt100 for temperature at the back of the module or short-circuiting plug
5 External safety disconnector (see section 7) between the 4-wire power measuring cable and the PROFITEST PV
6 4-wire power measuring cable

The PROFITEST PV is equipped with the following inputs and outputs (except for the jacks for the external power pack, all interfaces are located on the front panel, and are labeled):

Interface	Function
Mains	External power pack: connection via jack plugs, 5.5 x 2.1 mm
Temperature	Connection for temperature sensor • Instruments with second temperature measuring input: external Pt100 for acquiring temperature at the back of the module • Other instruments: external Pt100 or Pt1000 (depending on variant) for measuring temperature at the back of the reference cell
Irradiation	Socket for irradiation reference sensor (Phox) • The Pt100/Pt1000 reference sensor and the measured irradiation value are combined into a single 8-pin plug.
4-wire measurement	Measurement input (voltage measurement)
Current input	Power input (for current measurement)
PC	Port for connection to the control PC via USB cable

6.4 Power Supply

The PROFITEST PV includes a rechargeable battery, thus allowing for use independent of mains power. The battery is charged by means of an external power pack.

Connect the power pack to the external power supply socket at the front panel. The battery is charged for as long as the power pack is connected and active. In order to interrupt charging, simply pull the plug from the power pack out of the socket at the PROFITEST PV.

The battery charge level is indicated by means of an LED at the front panel.

6.5 Connection to a PC

The PROFITEST PV is usually used independent of a PC. However, if extended data evaluation is required, or if the PROFITEST PV needs to be controlled externally, it can be connected to a PC: Connect one end of the included USB cable to an available USB port at your PC, and the other end to the output at the PROFITEST PV provided for this purpose ("PC" socket).

Before you can control the PROFITEST PV from your PC, you'll have to install the device driver for the USB port (section 10).

First of all, activate transfer at the PROFITEST PV.

Otherwise, <u>no</u> connection can be established between the PV Analyzer control program and the PROFITEST PV.

6.6 Connecting the Solar Generator

⚠ **Caution!**
During measurement, the solar generator under test may only be connected to the PROFITEST PV. It is **absolutely mandatory** to disconnect any power consumers, rechargeable batteries or inverters. Due to the fact that the PROFITEST PV short-circuits the solar generator during characteristic curve tracing, the PROFITEST PV could otherwise be severely damaged or destroyed by a battery connected in parallel or a charging capacitor at the input of an inverter.

Connect the measuring instrument, correctly polled, to the solar generator with the included, adequately dimensioned connector cable. The **plus pole is red** and the **minus pole is black**.

⚠ **Caution!**
Make sure that all of the power cable's plugs have been inserted as far as they will go into the sockets in the housing.

Use the two sockets at the right-hand side of the housing for the solar generator ("current input"). In case of reversed polarity, short-circuiting of the PV generator inside the PROFITEST PV is prevented by means of a reverse polarity protection diode.

It's important to ensure that all of the 4-wire measurement inputs are connected in any case. If measurement will be conducted with only two measurement cables, connect the sockets at the PROFITEST PV to the neighboring sockets of the same color with the help of short-circuiting plug, laboratory cables or the like. Voltage measurement is not possible unless all of the 4-wire measurement inputs at the PROFITEST PV have been connected. Furthermore, significant voltage measurement error must otherwise be expected.

⚠ **Caution!**
Maintain an adequate distance from current conducting parts for the cable connection to the solar generator, because high voltages may be present and personal injury may result even if no direct contact takes place!

6.7 Measured Value Transducers for Temperature and Irradiation

In order to conduct a peak power measurement, a Pt100/Pt1000 temperature sensor (depending on equipment) and a Phox irradiation reference sensor must be connected to the appropriate sockets at the PROFITEST PV (included combination device). Neither of these measured value transducers is required for measuring internal series resistance or for strict characteristic curve tracing. The sockets are laid out such that temperature sensor and irradiation reference sensor connections cannot be reversed.

If at all possible, the combination irradiation-temperature sensor must be connected to the modules under test such that its orientation to the sun is the same as that of the modules (compass direction and installation angle). Be aware of the fact that any close-by bright surfaces such as buildings may distort light incidence.

For this reason, the sensor should not be set up at any considerable distance from the string (e.g. string on the roof and sensor in the driveway). Due to the fact that solar cells react not only to direct irradiation, but rather to die reflected ambient light as well, the sensor may detect other light and distort the measurement even if the sensor and the modules demonstrate the same orientation.

In the simplest cases, the sensor is secured to the module under test with a clamp. Make sure that no shadows are cast on the module to be measured as a result. After mounting, the sensor should be allowed to adjust to ambient conditions for several minutes. In the case of instruments without a second temperature measurement input, the irradiation reference cell must reach a temperature which approximates that of the module under test (temperatures can be read from the display when the PROFITEST PV is switched on). For safety reasons we recommend additionally checking the temperature at the back of the test object manually, for example with the help of an infrared thermometer. Only then should measurement be performed with the PROFITEST PV (see also section 8).

6.8   Switching the Instrument On

Switch the PROFITEST PV on with the "Power" switch on the front panel. The initial window appears at the color display:

The PROFITEST PV conducts several self-tests and requires approximately 10 to 15 seconds before it's ready for operation. The instrument is ready for operation when the main menu appears at the LCD panel:

The following information is displayed:

Header: instrument serial number, calibration date, firmware version

Data line: momentary irradiation, temperature of the irradiation reference sensor, temperature at the back of the module (optional), voltage applied to the power input

Sensor line: The currently active irradiation sensor is indicated here, and can be switched if applicable.

Footer: current date and time, "Info", "Archive", "PC" and "New Measurement" buttons

Indicator lamps on the front panel:

Charge level (3-color LED)	Red: battery depleted (charge immediately!) Green: battery ready for operation Yellow: battery fully charged *)	Operation is <u>not</u> possible! Operation is possible Operation is possible
External power supply	Lights up when the external power pack is connected and switched on. The integrated rechargeable battery is charged automatically in this case as well.	

* In the case of continuous alternation between green and yellow, the battery is being charged in the charge conservation mode. This charging procedure can be continued for 1 to 3 hours. Longer charging in this mode is not advisable because the battery might otherwise be damaged.

The PROFITEST PV generates acoustic signals in order to indicate various system functions and errors. A list of the individual acoustic signals is included in the appendix.

6.9   Buttons

Available functions are represented at the screen by means of buttons which are identified with symbols for the respective operations, for example a PC symbol identifies the data transfer function.

 Info: provides information regarding the buttons

 Switch: an entry can be selected here

 New curve trace, opens submenu

 Load measurement from the archive

 Connection to the PC (transfer)

 Start curve tracing now

 General: **cancel/exit function**

 Generate events list

 Display characteristic IU curve

 Add entry

 Previous page

 Next page

 Acknowledge selection, OK

6.10 Measurement

Observe the safety precautions in section 4 and section 5, as well as the measuring accuracy factors in section 8. Measurement is started either at the PROFITEST PV or from the interconnected analysis PC. Measurement should not be started until the solar generator and the required sensors have been connected. The measurement itself takes about 1 to 2 seconds, after which results are immediately calculated and displayed at the PROFITEST PV (or at the PC).

Accesses the measurement sub-page.

6.10.1 Entering Module, Customer and System Data

Before measurement is started, the user has the opportunity of entering module, customer and system data. The measured values can then be saved directly to the customer data.

Modules ser: Number of modules connected in series.

Acknowledge with "OK".
Abort returns to previous page.

Modules par: Number of strings/modules connected in parallel.

Acknowledge with "OK".
Abort returns to previous page.

Customer Enter / select customer from database
Create customer data either in PV Analyzer or directly at the Profitest PV (max. 30 characters).

Add entry

Acknowledge with "OK".
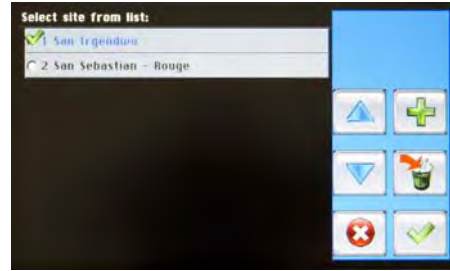Abort returns to previous page.
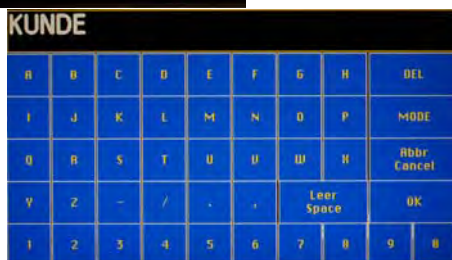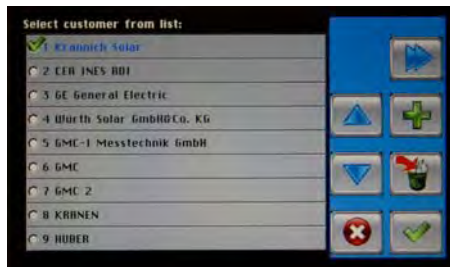
System Enter / select system parameters

System parameters are set up either in PV Analyzer or directly at the Profitest PV (max. 30 characters).

Add entry

Acknowledge with "OK".
Abort returns to previous page.

String / Module Enter / select installation parameters
Installation parameters are set up either in PV Analyzer or directly at the Profitest PV (max. 30 characters).

Add entry

Acknowledge with "OK".
Abort returns to previous page.

Module Type Enter / select module types / parameters
More than 20,000 entries in PV Analyzer's integrated database. Up to 50 module types can be exported to the test instrument → data transfer.

Add entry (manually in the test instrument / characteristic module data required)

Acknowledge with "OK".
Abort returns to previous page.

6.10.2 Start Measurement

This option starts one-time only curve tracing: Measurement is conducted automatically, any errors are indicated and results such as peak power, internal series resistance R_S, as well as others including the characteristic IU curve can be accessed immediately at the graphic display.

6.10.3 Archive

This function makes it possible to access measurement series which have been saved automatically for a previous measurement. Existing measurement series are listed with names based on the dates on which they were performed.

A file can be selected with the help of the "Up" and "Down" buttons.

Any other additional pages can be displayed with the help of the "Left" and "Right" buttons.

A file can be selected with the "OK" button. The "Abort" button returns the display to the previous page.
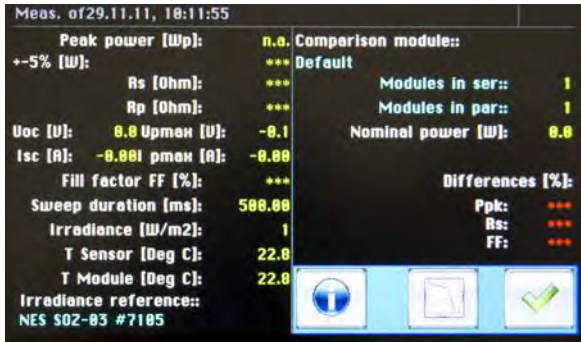
The "Delete" button can be used to remove the selected data from memory at the PROFITEST PV (Caution: this procedure cannot be undone).

6.10.4 Transfer

This function prepares the PROFITEST PV for control by means of an interconnected PC. The function can be exited by pressing a button at the PROFITEST PV.

6.10.5 Results

Meas. of29.11.11, 18:11:55

		Comparison module::
Peak power [Wp]:	n.a.	Default
+-5% [W]:	***	
Rs [Ohm]:	***	Modules in ser:: 1
Rp [Ohm]:	***	Modules in par:: 1
Uoc [V]: 0.0	Upmax [V]: -0.1	Nominal power [W]: 0.0
Isc [A]: -0.00	pmax [A]: -0.00	
Fill factor FF [%]:	***	Differences [%]:
Sweep duration [ms]:	500.00	Ppk: ***
Irradiance [W/m2]:	1	Rs: ***
T Sensor [Deg C]:	22.8	FF: ***
T Module [Deg C]:	22.8	
Irradiance reference::		
NES SO2-03 #7105		

Calculated values (peak power, Rs, Rp, FF), as well as measured values (voltage and current) are displayed in the results page.

The characteristic IU curve can be displayed with the "Diagram" button, and the display can be returned to the results page with the "List" button.

6.11 Messages

"Fluctuating irradiation (ref. cell)!",
"Too little irradiation!",
"Fluctuating irradiation (mod)!"

Irradiation at the reference cell or the module is not constant enough (e.g. due to clouds), and measurement results may be faulty.

"Not available"

This message indicates that the measured value could not be calculated.

"No space for new data!"

"Delete data from the PROFITEST PV"
Internal non-volatile memory at the PROFITEST PV is full. Before performing any further measurements, previously stored measurements should be deleted from the PROFITEST PV (see section 6.10.3).

"Write error"

Problems while writing a series of measurement data to internal non-volatile memory.

"Measurement not yet possible"

Safety waiting time between two measurement has not yet elapsed.

"Rs calculation not possible"

The measurement data do not allow for the calculation of R_s (see next point).

"Measured values cannot be analyzed"

The measured values include data which make an analysis of the characteristic curve impossible, for example the shape of the curve deviates significantly from the standard curve.

"Input voltage too high"

Switch the generator off immediately with the load disconnector! The measuring instrument may be damaged by excessively high voltage.

"Immediate repair required"

The instrument is damaged and must be inspected by authorized service personnel and repaired if necessary. In this case, the instrument must be immediately disconnected from the device under test (set the safety switch to "0" without delay!) and may not be used again until it has been inspected by the manufacturer.

"Incorrect polarity!"

The cables at the PROFITEST PV have been connected incorrectly. Isolate the generator immediately with the load disconnector and reconnect the cables correctly.

7   1000 V / 32 A Load Disconnector

This switch is used to isolate the PROFITEST PV peak power meter and characteristic curve tracer from PV generator voltage while working with cables, thus assuring safety for the user.

Operation:

Set the switch to the neutral position (0) before connecting cables (both "0" positions are identical).

Insert the measurement cables with MC plugs included with the PROFITEST PV into the sockets at the switch as far as they will go (red plugs to red sockets, black plugs to black sockets). The two red plugs are interchangeable, as are the two black plugs. Either of the red plugs can be inserted into either of the red sockets, and either of the black plugs can be inserted into either of the black sockets. Now connect the connector cables from the switch to the PROFITEST PV (red plugs to red sockets, black plugs to black sockets). Here as well, either of the red plugs can be inserted into either of the red sockets, and either of the black plugs can be inserted into either of the black sockets.

The switch must be set to one of the "1" positions in order to perform a measurement. **Set the switch back to the "0" position after the measurement has been completed!** The cables can then be safely disconnected from the PROFITEST PV.

Safety precautions:

⚠️ **Caution!**

Set the switch to the "0" position before working with the cables!
Under no circumstances may the safety switch be activated if you detect any defects at the switch, the housing, the connector cables or the sockets.

Repair work may only be carried out by trained personnel who have been specially authorized to do so by the manufacturer.

Keep the switch away from liquids, dust and contamination. Clean the surface with a slightly dampened cloth only.

8   Influences on Measuring Accuracy

Make sure that the module under test is not shaded (not even slightly). Even shadows from, for example, blades of grass may cause detectable error. The same applies to the reference sensor. Don't forget that contamination on the modules creates shade as well.

The more irradiation the module is exposed to, the more accurate the measurement results. If possible, irradiation (determined by the combination sensor) to which the module is exposed should be greater than 500 W per square meter.

The combination irradiation-temperature sensor measures temperature at the back of the reference cell. If the PROFITEST PV is only furnished with the temperature of the irradiation reference sensor because no external sensor for measuring temperature at the back of the module has been mounted, the PROFITEST PV assumes that the temperatures of the reference cell and the module under test are approximately the same. This is the case to a relatively accurate degree if the reference cell and the PV module have been subjected to the same amount of irradiation for a long enough period of time. The module and the cell should be aligned to the sun for more than 15 minutes prior to measurement to this end. In order to make sure, the temperature at the back of the module should be checked in this case, for example with an infrared thermometer, before curve tracing.

If possible, the module under test should be aligned perpendicular to the sun. However, this is frequently not possible. Sufficient irradiation at the surface of the module is important in this case (which automatically necessitates orientation toward the sun to at least a given extent), as is precise alignment of the reference cell: It must have exactly the same orientation as the module. In the simplest cases, the combination sensor can be clamped to the module under test. However, the combination sensor may also be located some distance from the module, but it must be assured that alignment to the sun is identical and that no local reflections will be able to influence irradiation measurement values (the reference cell must face the same pat of the sky as the device under test).

The irradiation reference cell and the device under test must also have the same spectral characteristics (in accordance with IEC 60904) – ideally, both have the same layout. It's entirely possible to use a module which is identical in design to the module under test as a reference: The module is subjected to a load via a precision shunt resistor, and measurable voltage occurring at the shunt as a result is used as a measure of momentary irradiation – most reference sensors function precisely in this way.

⚠️ **Caution!**

If alignment of the reference cell deviates even a few degrees from that of the PV module, considerable error may occur in the measurement results.

Maximized measurement accuracy can be achieved by performing several measurements (e.g. 5) for the same object, and statistically evaluating the results.

The parameters which are decisive for measurement accuracy are listed once again below:

Accuracy of Peak Power Calculations based on IU Curve Tracing at Photovoltaic Generators using the PROFITEST PV Measuring Instrument

Under the following conditions, peak power values obtained with the PROFITEST PV have an accuracy of ±5% relative to the actual peak power value of the device under test:

- The device under test is made of monocrystalline or polycrystalline silicon cells.
- The device under test is not shaded (not even slightly).
- The irradiation reference sensor is not shaded (not even slightly).
- The irradiation reference sensor must essentially demonstrate the same spectral sensitivity as the device under test.
- The measurement is performed in natural sunlight.
- In accordance with IEC 60904, the sun should be aligned perpendicular to the surface of the device under test within a tolerance of ±10°.
- According to IEC 60904, irradiation must be at least 800 W per square meter. On the basis of our own comparative measurements, we consider 600 W per square meter adequate.
- Irradiation measurement must take place immediately before or after characteristic IU curve tracing – elapsed time between curve tracing and irradiation measurement must be less than 10 ms.
- The measured value form the irradiation reference sensor must be corrected based on measured cell temperature.
- Cell temperature measurement must take place immediately before/after curve tracing (within 1 second) with an accuracy tolerance of 1 K.
- The active surface of the device under test must lie in the same plane as the surface of the irradiation reference sensor within a tolerance of ±5%.
- Irradiation must be adequately constant (±10 W per sq. meter) prior to IU curve tracing for a period of at least 10 seconds, in order to be able to prevent any misinterpretation of temperatures at the DUT and at the reference cell.
- Irradiation may not fluctuate by more than 10 W per square meter during IU curve tracing (the PROFITEST PV generates a warning in this case).
- The temperatures of the device under test and the irradiation reference sensor must be settled in (no temperature change may be displayed).
- Voltage and current is measured at the device under test with separate measurement cables (4-wire measurement).

9   Installing PV Analyzer Transfer Software

PV Analyzer is included with the instrument on a CD ROM. The data storage medium includes a setup program for simple installation to your PC. The setup program copies all of the necessary files to your hard disk and configures the program. The software can be installed by anyone who is experienced in working with PCs and is familiar with the MS Windows® user interface.

Administrator rights may be required in order to install the software.

The following steps must be completed to install the software:

1 Insert the CD ROM with the setup program into the corresponding disk drive.
2 If the setup program starts automatically after inserting the CD ROM, continue with step 5.
3 Select "Run" in the start menu.
4 Enter "x:SETUP" to the entry line which then appears under "Open" (x: designation of the disk drive with the setup file). Press the return key or click the OK button.
5 The setup program is now executed. Follow the instructions which appear at the screen.
6 All of the necessary files are installed to your hard disk by the setup program, and a new program group is added with an entry for PV Analyzer software.
7 After installation has been completed, start PV-Analysator.exe. The program should now function as described below.

Use of the program is described in detail in section 11.

At least the following files are required in order to run the program:

PV-Analysator.exe	The control program (directory path: \programs\PV-Analysator\ )
PV-Analysator.ini	The configuration file. This file may not be manually changed (directory path: \documents and settings\{username}\application data\GMC-I Messtechnik\PV-Analysator\ )
PV-Analysator.hlp	Help file (not yet available) (directory path: folders\programs\PV-Anlysator\ )

The program also installs files with the SUI ending, which contain measured data for IU curve tracing. When these measurement data are transferred automatically from the PROFITEST PV, the filename includes the date and time of the measurement in order to identify the data record, for example, the file with the name
24-05-01 14_17_04.SUI
contains data from a measurement conducted on 24 May 2001 at 14:17:04 o'clock.

The measurement files are usually saved to folders in the following directory path: "documents\PV-Analysator\".

10 Installing the USB Device Driver (CDM)

10.1 Installation via "Found New Hardware"

Using Windows XP as an example, the following describes how to install the USB driver for the virtual COM port for the PROFITEST PV:

– A device driver is included in the installation CD in a subdirectory designated "**x:\CDM** nnnnn". x: stands for the CD ROM disk drive with the installation CD and nnnnn stands for the version number of the USB driver. If necessary, you can download the latest version of the CDM driver form the FTDI website (www.ftdichip.com) and decompress the ZIP file to a directory at your PC.
– If you use Windows XP or Windows XP SP1, your Internet link should now be temporarily disconnected.

This can be accomplished either by removing the network cable from your PC, or by deactivating the network adapter card by right clicking on the corresponding connection under "Control panel / Network and dial-up connections", and then selecting "Deactivate" from the menu.

Connection can once again be established after installation has been completed.

This is unnecessary with Windows XP SP2, assuming that Windows is configured such that you are asked before a connection is established for the Windows update function.

– Connect the PROFITEST PV to an available USB port at your PC. The "found new hardware" dialog is started automatically.

If the PC is not connected to the Internet or if Windows XP SP2 is correspondingly configured, you are asked before the Windows update function is started as shown in figure 10.1.

Select "No, not this time" and click the "Next" button in order to continue with installation.
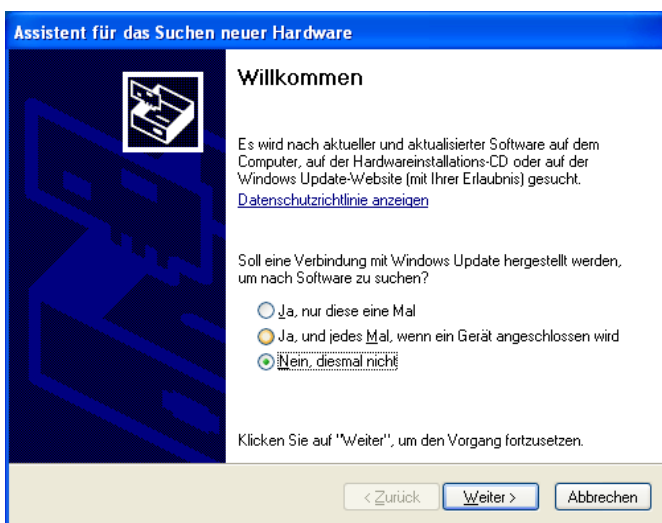
Figure 10.1

– Select "Install from a list or specific location (advanced)", as shown below in figure 10.2, and then click the "Next" button.
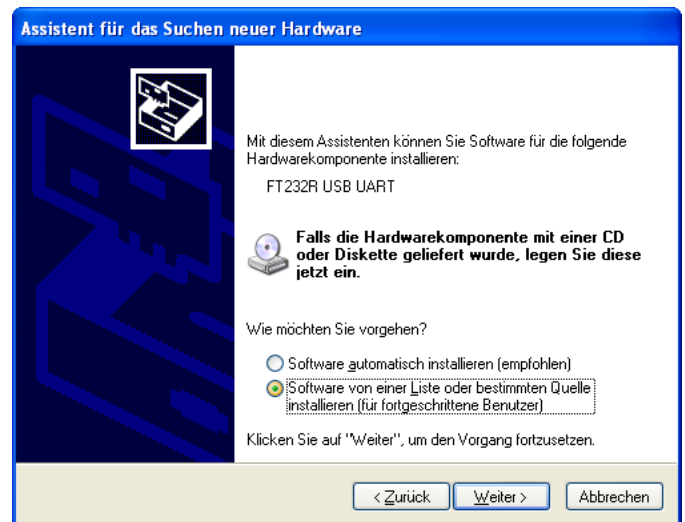
Figure 10.2
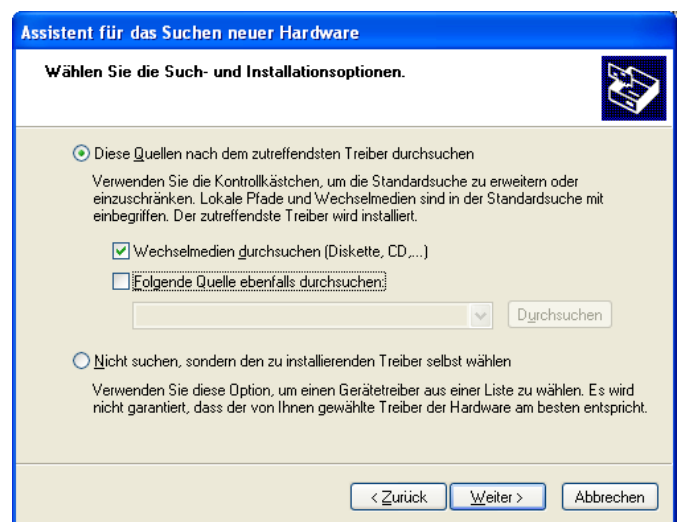
Figure 10.3

– Select "Search for the best driver in these locations" and enter the directory path for the driver files to the box (e.g. "D:\CDM 2.02.04"), or search for the directory by clicking the "Browse" button. After the directory has been entered, click the "Next" button to continue.
– If Windows is configured such that a warning is displayed when drivers are installed which are not WHQL certified, a corresponding warning appears. Click "Continue anyway" in order to install the driver.
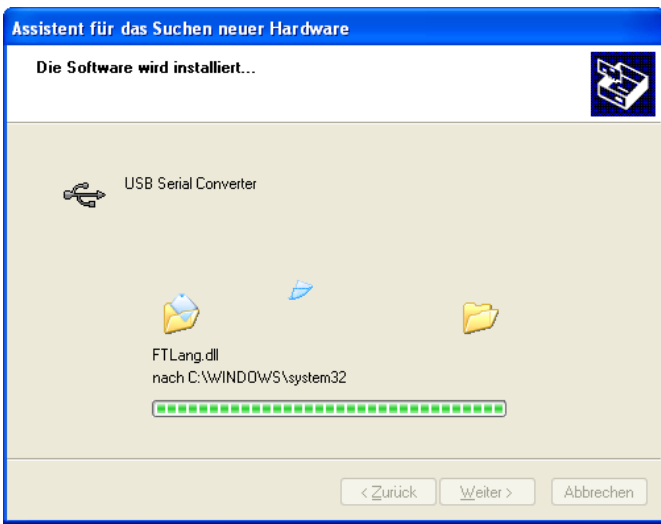
Figure 10.4

– The screenshot in figure 10.4 shows Windows XP copying the required driver files.

Figure 10.5

– Windows then displays a message indicating that installation has been successful (fig. 10.5). Click the "Finish" button to conclude installation for the instruments first port.
– If applicable, the hardware wizard now reappears to install a second port.

The procedure for installing the second port is the same as for the first (see above).

– After installation has been completed, the new COM port appears in the device manager (figure 10.6).
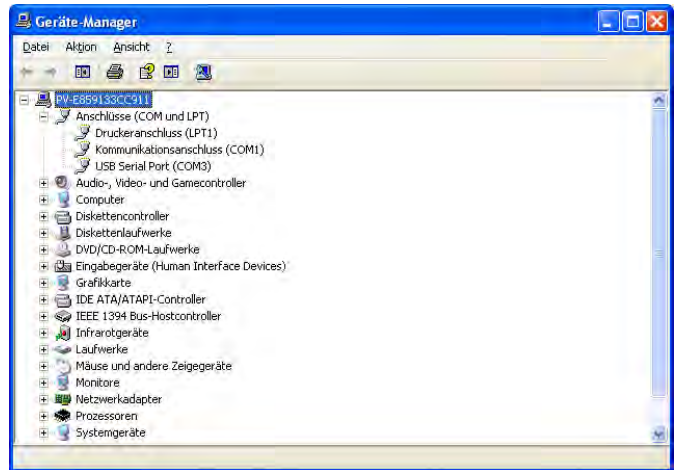
Figure 10.6

10.2 Uninstalling the CDM Driver

Drivers can be removed with the help of the device manager by simply right clicking the respective device and selecting uninstall. The device's associated registry entries are deleted as a result.

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11 Using PV Analyzer Transfer Software

Software installation was described in section 9. After starting PV Analyzer, the following display appears:
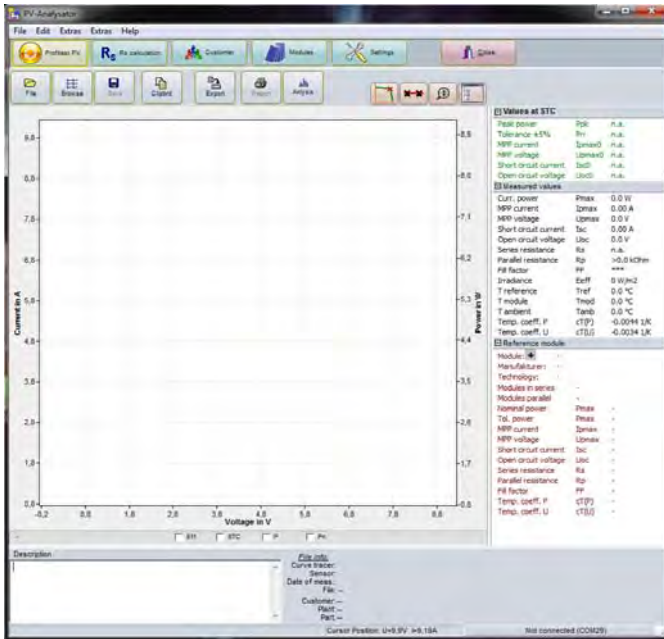
The document shown above is empty – all displayed values are zero. You are now able to access measurement data which have been stored to the hard disk, perform a measurement, or transfer measurement data from the PROFITEST PV (ascertained measured values are entered to this document and you can analyze them further or save them to a file). A diagram (line graph of the measured values) and results (right column), as well as an export function (creation of a file with measured values or results in a format other than the one specified) are available for analysis purposes.

Buttons which appear gray are disabled. They cannot be used until data are actually available.

11.1 The File Menu

11.1.1 Open

Previously acquired and saved characteristic curves can be retrieved by clicking the "Open" button. The last data processed by the program are overwritten in RAM in this case. If you want to keep these data, they have to be saved before opening another document. The files have the SUI ending as a standard feature.

After clicking the folder icon next to the displayed directory at the top of the dialog window, you can specify the directory from which measurement data will be displayed in the list in the following dialog box.

After double clicking an entry in this list, the respective data are automatically loaded and displayed in the editing window. You can also select several or all of the entries in the list, and delete or export the selected data records by clicking the corresponding button, or print out test reports for them.

11.1.2 Save as ...
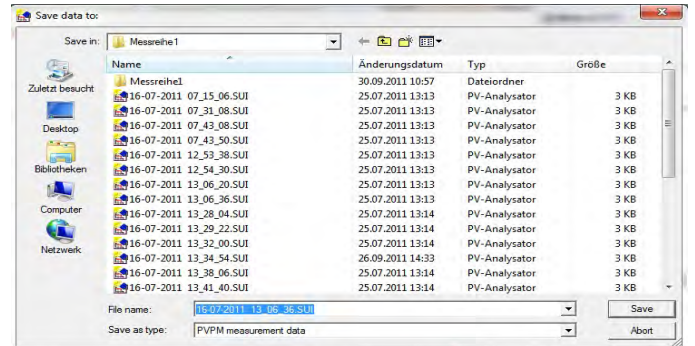
The current characteristic curve can be saved to a data storage medium by clicking the "Save" button. Plain text entries in the "Description" field are saved along with the curve. The program supports long file names. The standard filename ending is SUI.

11.1.3 Browse
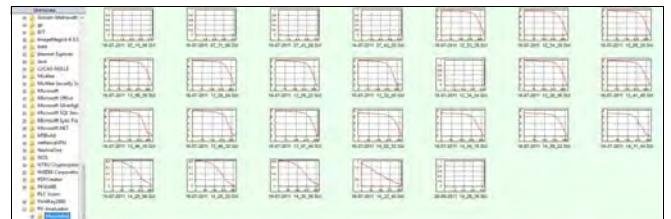
The browse window displays miniature versions of the characteristic curves for the measurement files in the selected directory. This provides you with a quick overview of the measurements included in the directory and makes it easy to find any conspicuous characteristic curves.

After moving the mouse pointer to a given graphic, the most important measurement results appear in a small window.

The respective file is opened by double clicking the graphic.

11.1.4 Export
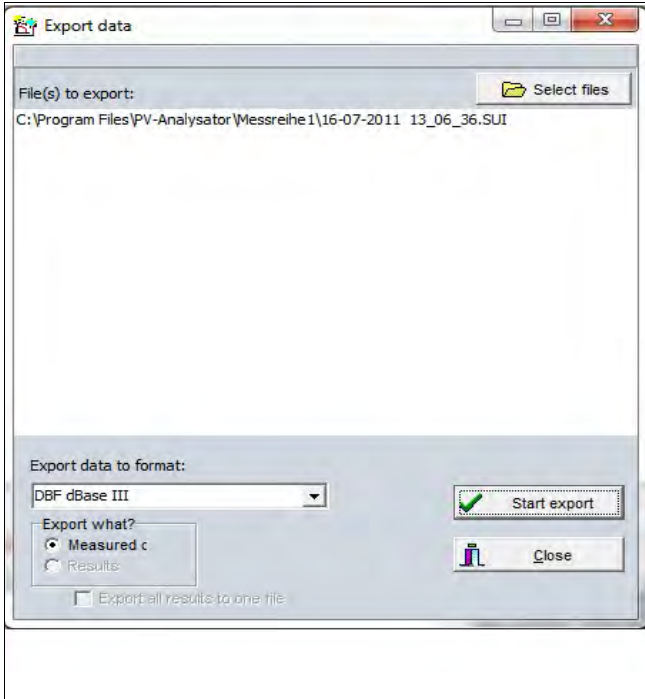
Measurement data files from the PROFITEST PV can be converted to formats which are readable for other programs with the export function. You can use XLS (MS Excel) and DBF (dBase III+) formats, as well as three different ASCII representations. Refer to the manual for the program with which the measured values will be processed regarding the correct format.

You can export either pure measurement data (IU measuring points, temperature and irradiation) or calculation results. In the latter case, the results of several measurements can be exported together into a table. The data are represented line by line in the target table.

Select the desired export format with the help of the combo box. The files to be exported are selected in the file selection dialog box which appears after clicking the "Select Files" button. Click the "OK" button after selecting your files.

Export files are now created and saved to the same directory using the same filename with the appropriate filename ending (i.e. XLS instead of SUI). You can then process the export files in the program of your choice. Changes to the export files have no effect on the original data.

11.1.5 Report
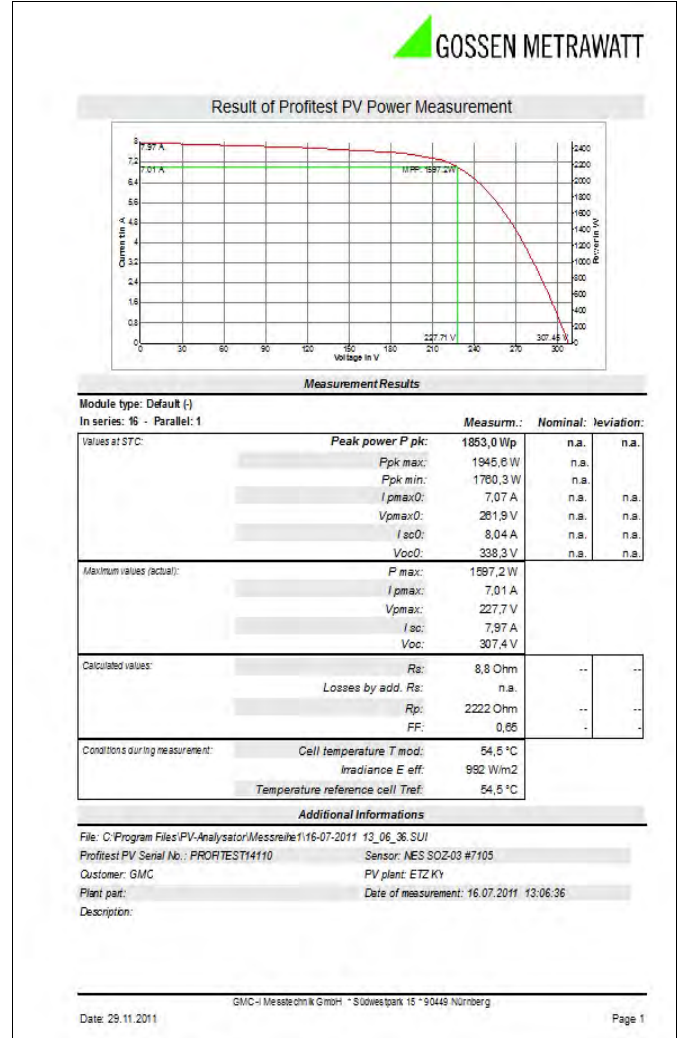
This button opens a measurement report for the currently loaded data record. The report can be printed out or written to a PDF file.

Please note that under certain circumstances you printer's page layout may have to be changed before printing. The print-out utilizes all available space on the paper.
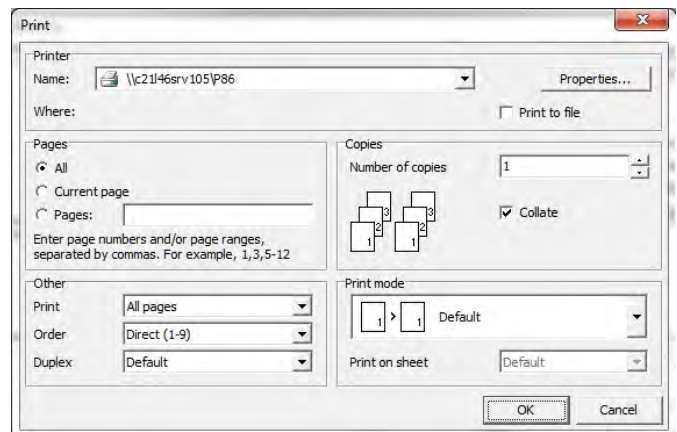

The buttons in the print preview are as follows, from left to right:

- Start printing
- Export to PDF
- Zoom factor
- Full page
- Page layout
- Next/previous page
- Close preview

11.1.6 Analysis

The analysis is used to evaluate the characteristic curve measurement. All of the relevant data are arrange in a table. In the event of errors, reference is made to possible causes in the overview.
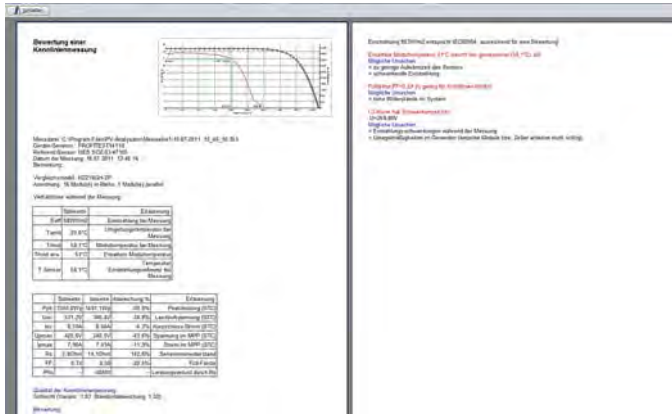
11.1.7 Printer Setup

This function opens the Windows "printer setup" dialog box, with which the desired printer can be set up.

11.1.8 Exit

PV Analyzer software is closed with this option. Current data are not saved automatically, but you are notified that data still need to be saved, thus providing you with the opportunity of storing them before exiting the program.

Don't forget:
Switch transfer back off again at the PROFITEST PV when you exit PV Analyzer.

Always log off the PROFITEST PV with the "End" function, by clicking the "End" button or with the <ALT>-<F4> key combination and return to the system. Be sure to shut down your system correctly afterwards because, for example, data loss might otherwise be caused by a write-back cache.

11.2 Edit

This function is only activated when the mouse pointer is located within a text entry field.

11.2.1 Cut

Cuts out the selected text and writes it to the clipboard.

11.2.2 Copy

Copies the selected text and writes it to the clipboard.

11.2.3 Paste

Inserts the content of the clipboard to the selected text.

11.3 Extras

First switch the PROFITEST PV on and set it to "Transfer" (the solar generator to be measured and the sensor should already be connected if applicable), before using the following "Measurement" transfer function.
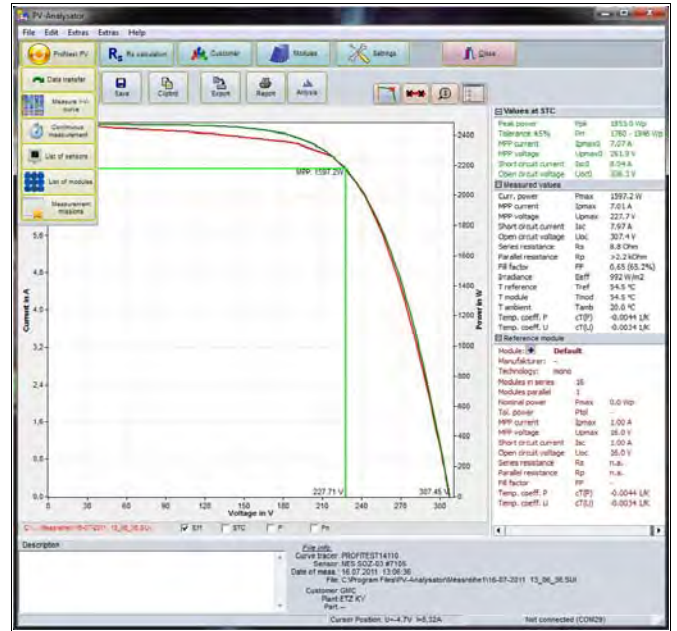

### 11.3.1 Start Measurement at the PROFITEST PV ("Trace Curve" button).

"Performing measurement – please wait" appears in the status line.

Measurement takes about 2 seconds. The measured values are transferred immediately after measurement has been completed (procedure is displayed in the status line), and the main window is now filled with the respective values. You can display the data as a diagram (section 11.4) or in a tabular overview (section 11.5), export them (section 11.1.4) or save them to a file (section 11.1.2). Curve data are **not** saved to the PROFITEST PV in this case, but rather only to the PC! This is advantageous when conducting long measuring sequences with large volumes of measurement data. Memory capacity at the PROFITEST PV might otherwise be exhausted.

If the message shown below appears, the cable to the PROFITEST PV is not correctly connected or the "Transfer" function has not been activated at the measuring instrument.
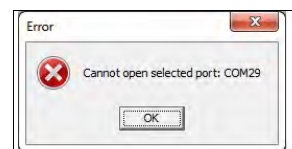
### 11.3.2 Managing Files at the PROFITEST PV ("Data Transfer" button)
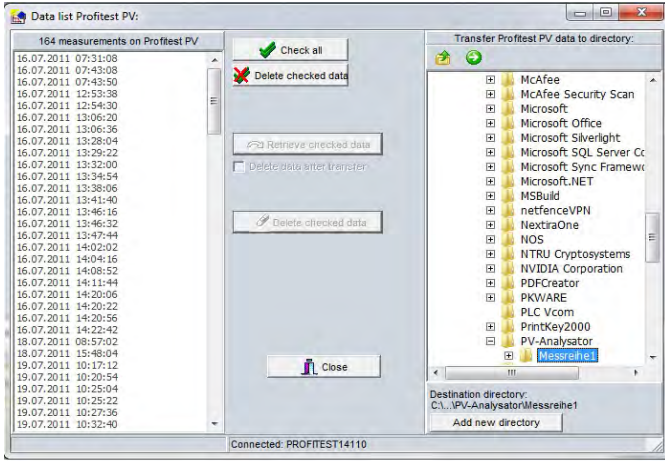
First of all, clock time at the PC and the PROFITEST PV is compared. If the difference is greater than 5 minutes, the application asks the user if the clock in the PROFITEST PV should be set to PC time.

After the time check has been completed, if data memory at the PROFITEST PV is empty a corresponding message appears or, if measurement data are available, a list of measurement series appears (the PROFITEST PV must be connected to this end). The displayed data can now be transferred to the PC for further processing.

Select the destination directory in the line which appears at the top of the window, to which the measurement data will be transferred. Click the folder icon at the right-hand side of the line to this end, after which a directory selection dialog box appears in which the desired directory can be selected.

Now select one or several measurements from the measurement series list (all of the displayed data records can be selected at once by clicking the "Select All" button), and then click the "Get Data" button.

The measurement series are now transferred, one after the other, and each data record is saved to the PC hard disk with a filename based on the following pattern: 04-01-2000 23_44_38.SUI (in this case a measurement conducted on 4 January 2000 at 23 hours, 44 minutes, 38 seconds).
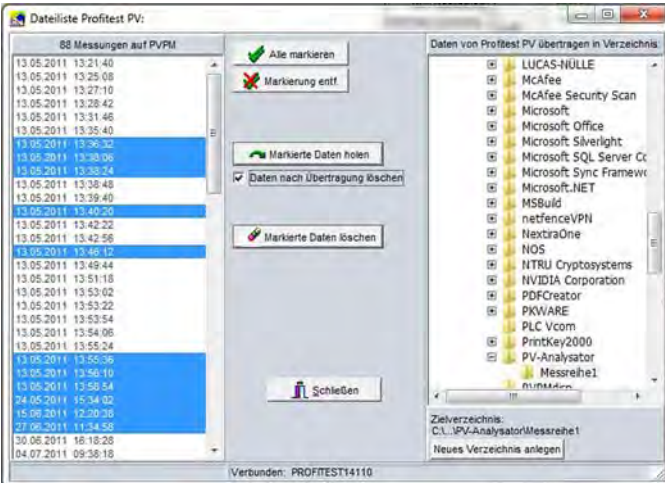

If the "Delete data after transfer" checkbox is activated, a prompt appears after data transfer asking the user to confirm that data should really be deleted from the PROFITEST PV. Do not respond with "Yes" unless you are absolutely sure that the data at the PROFITEST PV are not longer needed – the selected measuring series are then automatically deleted from the PROFITEST PV. Data can also be deleted from the PROFITEST PV by selecting the data to be deleted from the list and clicking the "Delete Data" button. **Caution: deletion cannot be undone!**

11.3.3 Transfer Date and Time to the PROFITEST PV

This function is included in the Profitest PV menu. The clock in the Profitest PV is set to current PC time and date.


11.3.4 Continuous Measurement
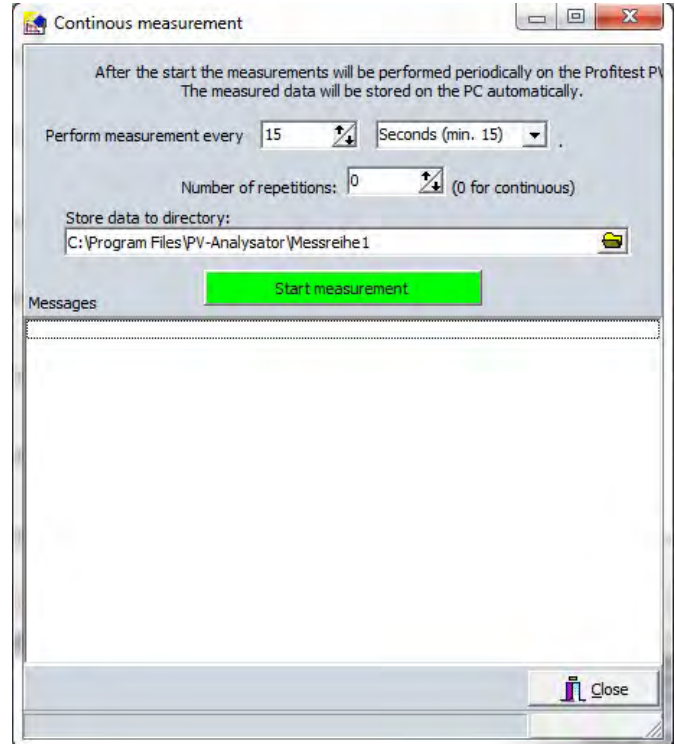
This function allows for automatic measurement with the PROFITEST PV, which is time-controlled by the PC.

Simply select the desired time interval (seconds, minutes, hours) at which the measurement will be repeated, as well as the number of repetitions (or 0 if the measurement is to be repeated indefinitely).

After clicking the "Start Measurement" button, measurement is performed automatically and can be stopped by clicking the "Stop" button. Measurement data are saved automatically to files in the specified directory, whose filenames include the date and time of measurement.
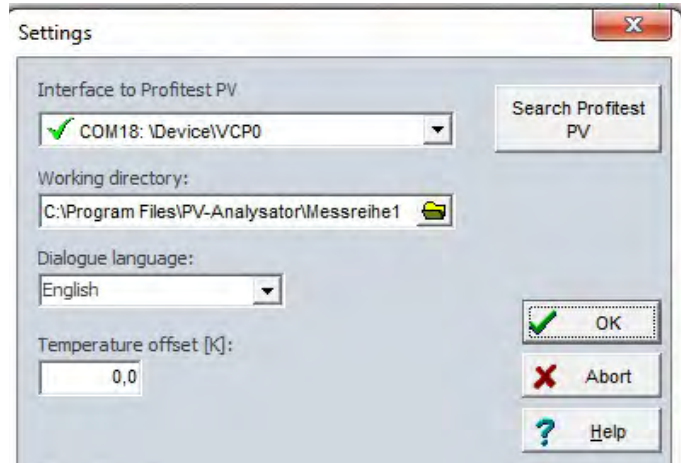
Automatic measurement is ended when the selected number of measurements has been completed, or in the event that a technical problem occurs (PROFITEST PV does not respond).

11.3.5 Editing the PROFITEST PV Sensor Database

Irradiation sensors from various manufacturers can be connected to PROFITEST PV instruments. Due to the fact that each sensor has a different calibration value, this value must be changed at the measuring instrument depending on which sensor is used. In order to simplify this procedure for on-site work, the PROFITEST PV supports a small database of up to 10 sensors, whose designations and calibration values can be entered or changed here. When sensors are changed, the desired sensor data can be selected at the PROFITEST PV with the help of the "PROFITEST PV" menu.
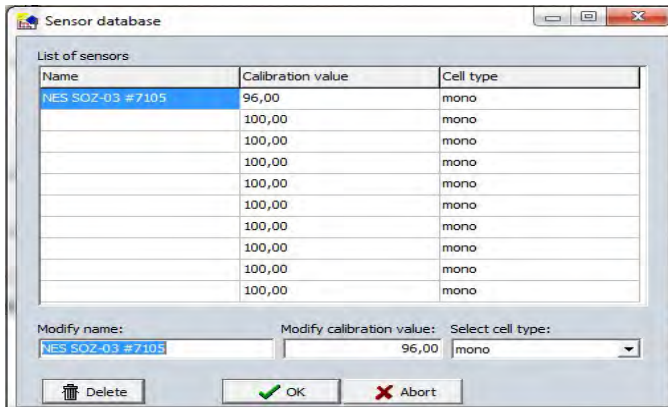
Attention: A PROFITEST PV must be connected to the PC for this function, and it must be ready for transfer. When the function is activated, the current database at the PROFITEST PV is loaded.

In order to make a new entry, select an empty field with the mouse pointer and enter the designation and calibration value to the entry fields.

Click the "OK" button after completing your entries. You are then asked if the changed data should be transferred to the PROFITEST PV. As a rule, you should respond with "Yes". The new data are then immediately available at the PROFITEST PV.

11.3.6 Managing Modules at the PROFITEST PV ("Module List" button)

A module database with as many as 50 modules is included in the Profitest PV. This can be freely configured with the help of the module database in the software. This function makes it possible to add modules (Add Module) and delete modules (delete selected entry).
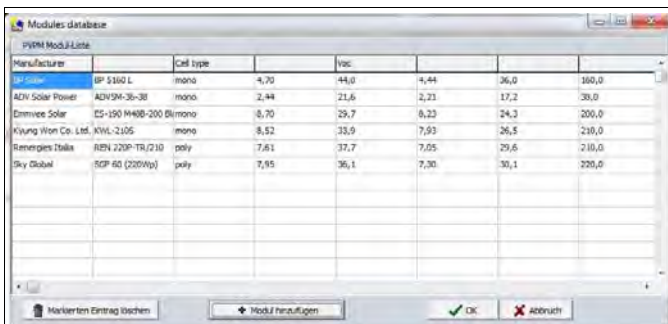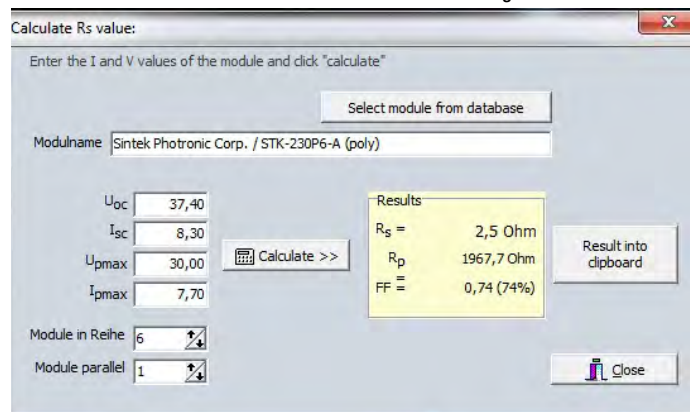

11.3.7 Managing Measuring Tasks at the PROFITEST PV ("Measuring Tasks" button)

Work orders can be managed at the PROFITEST PV with this function. The customer database is accessed directly. Customers, systems, system components and plans can be easily finalized.
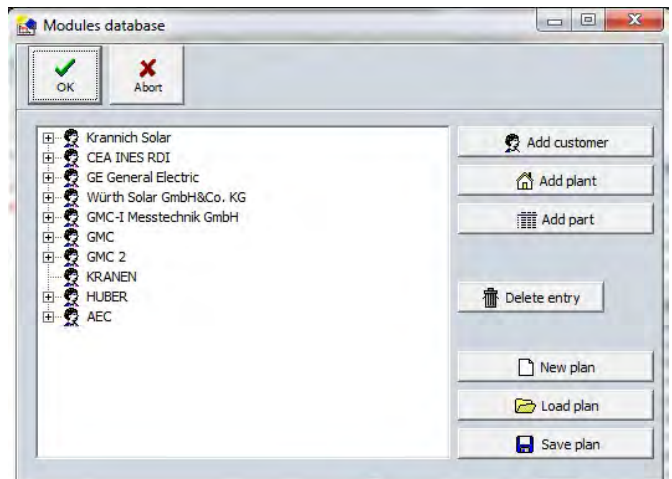
11.3.8 Calculating Internal Series Resistance R_S

In order to calculate, select the module to be compared from the database.

The PROFITEST PV can calculate the characteristic TRMS solar cell curve on the basis of STC values including short-circuit current, open-circuit voltage and current and voltage at the MPP, and determine expected internal series resistance R_S from the results. This theoretical value can be compared with other values which have been ascertained by means of measurement: If the measured value is higher than the theoretical value, the difference can be attributed to cable resistance.

11.3.9 Customer Database

All relevant customer data, system data and system components can be managed in the customer database.

11.3.10 Module Database

The module database is based on the database of the "Photovoltaik-Forum". All of the necessary characteristic values are included, which are required for comparison. The current data sheet is loaded directly from the Internet. Manual entry of characteristic values is possible at any time.


11.3.11 Settings

All of the changes entered here are saved automatically and remain valid until another change is entered.

Selecting a Serial Port

The serial port at the PC (COMn:) used to communicate with the PROFITEST PV can be selected here from the combo box. If the application can read the ports from the Windows registry, the designations contained therein are displayed in the combo box together with a note indicating whether or not the respective port is available. In the latter case, the respective port is already being used by another application. If the registry cannot be read (inadequate rights), the application displays simple port designations only (COMx). Selection of a port is nevertheless possible. If you don't know which port the PROFITEST PV is connected to, you can instruct the application to try all available ports by pressing the "Search" button, in order to establish connection with the PROFITEST PV.
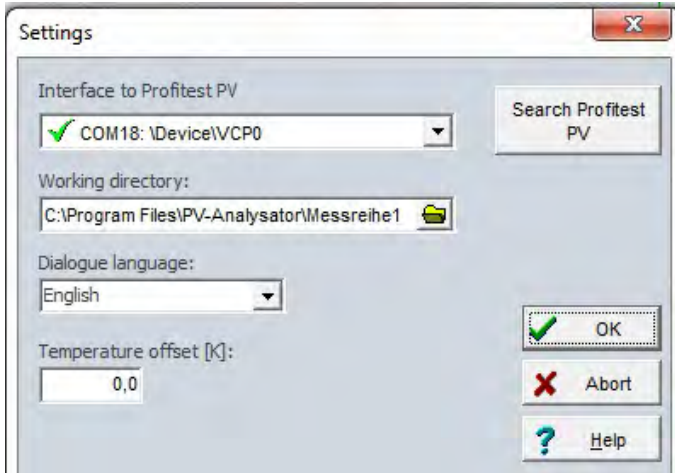
The PROFITEST PV must be connected to the PC to this end, and must be set to "Transfer". When the application receives a response from the PROFITEST PV, the search is stopped and the port found in this way is used for communication with the PROFITEST PV.

Configuring the Working Directory

The content of the working directory is displayed in the "file open" and "save" dialogs as a standard feature. Enter the directory to which you will normally save files. This directory will then also be used for automatic data storage (data transfer from the PROFITEST PV and continuous measurement). A directory selection window can be opened by clicking the button to the right of the entry field, from which a directory can be selected.

Changing the Dialog Language

The current version of PV Analyzer supports English and German as dialog languages. The language can be changed while the program is running. Select the desired language from the "Dialog Language" combo box to this end. The new language appears after closing the dialog box.

Please note that standard dialogs and system dialogs always appear in the language of the installed Windows version.

11.3.12 Setting Temperature Offset

If you are aware of the fact that there is a difference between temperature measured by the sensor and the actual temperature at the back of the module (for example in-roof systems), you can enter a correction factor by which measured temperature is then changed. The entered value is added to the measured temperature value, i.e. if you enter a negative value the measured temperature value is reduced. PV Analyzer uses the changed value for calculations. However, this value is not saved to the file!

11.3.13 Firmware Update

This function is currently only intended for service purposes and is not explained here.

11.4 Using the Graphic Interface
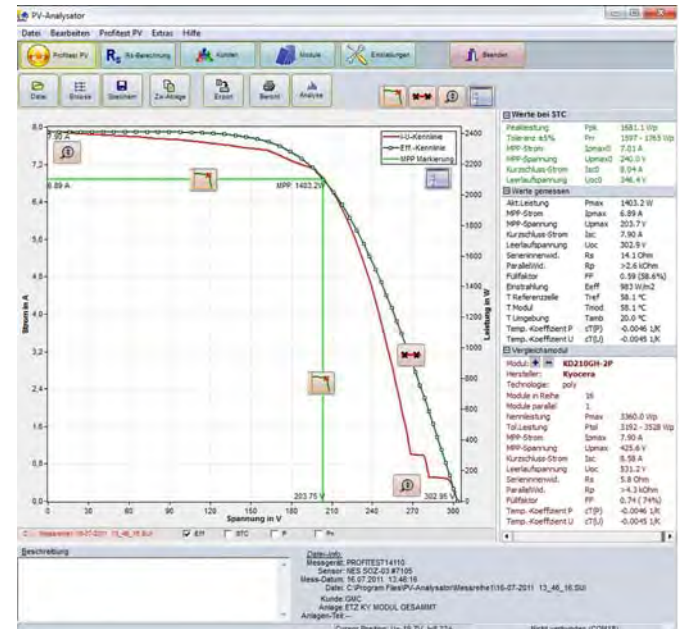
After loading a measurement or performing a new measurement, the graphic can be displayed by clicking the "Graphic" button (if it isn't already displayed).

You can draw a rectangle within the graphic with the help of the mouse (move the mouse from top left to bottom right while pressing and holding the left mouse key). The selected range can then be enlarged. The normal display reappears after drawing a rectangle from bottom right to top left. The selected portion of the graphic can also be moved by right clicking and holding the mouse key depressed.

A pop-up menu appears after right clicking the graphic. the following options are then available (the same functions can also be executed with the buttons at the top of the graphic display):

11.4.1 Measuring Points On/Off ("Measuring Points" button)

Display measuring points on the traced characteristic curve.

 Measuring Points Button

11.4.2 MPP On/Off ("Show MPP" button)

You can either display a calculated MPP (maximum power point) or deactivate this display. The MPP is not taken directly from the measurement data values table, but rather interpolated.

 Show **MPP Button**

11.4.3 Display Theoretical Curve On/Off

If possible, a theoretical characteristic curve approximation is executed, and the resulting curve (TRMS curve) is additionally displayed with this function. This display can also be deactivated.

11.4.4 Display Characteristic STC Curve On/Off

If possible, the characteristic curve converted to STCs is displayed with this function. This display can also be deactivated. The scale range is automatically enlarged if applicable.

11.4.5 Power Display On/Off

The characteristic PU curve can be displayed in addition to the characteristic IU curve with this function. The right scale is used as a reference axis for power.

11.4.6 Key On/Off ("Key" button)

A key can be displayed for the diagram if desired. The key appears in the upper right-hand portion of the graphic.

Key Button

11.4.7 Stretch On /Off ("Max. Zoom" button)

The graphic is scaled so that it takes up as much space as possible in the graphic display.

Max. Zoom Button

11.4.8 To Clipboard ("Clipboard" button, main toolbar)

The current graphic is copied to the Windows clipboard with this function, and can then be inserted directly into, for example, an MS Word document.

11.5 Results

Measured values, values converted to STC and values of the module to be compared are displayed in a clear-cut fashion next to the characteristic curve.
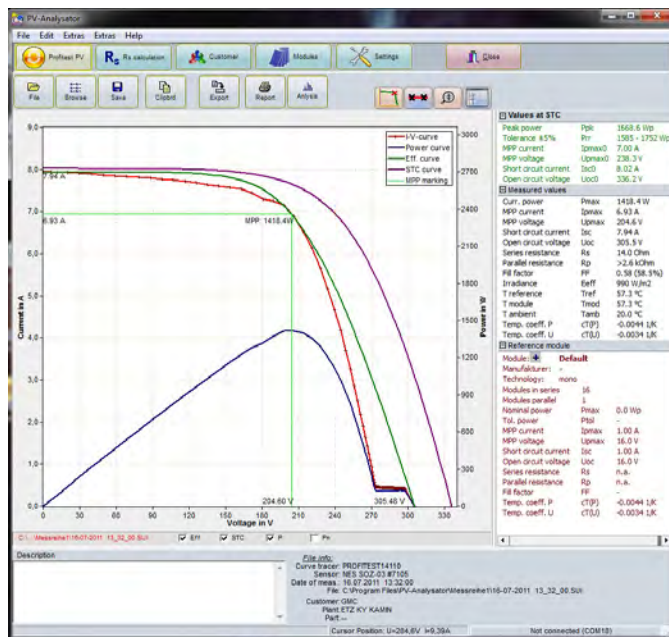
11.6 Help

11.6.1 Contents

The "Contents" option included in the help menu opens the table of contents for the PV Analyzer help function.

11.6.2 Search

Individual terms can be searched for with the help of this menu option.

11.6.3 Using Help

This option provides you with pointers for working with the MS Windows help system.

11.6.4 Info

This menu option opens an information window in which the revision level of the installed program is displayed.

12 Technical Data

12.1 Unit of Measure

Sampling rate: max. 100 kHz
Resolution: 0.01 to 0.25 V, 0.005 to 0.001 A
(depending on selected measuring range)
Measuring accuracy: better than 1%
Peak power tolerance: ±5%
Reproducibility of peak power results: ±2%
Measurement duration for separate measurement of individual modules: > 20 ms (approx. 100 pairs of measured values) – the capacitive characteristics of the device under test have no influence on measurement.

The irradiation reference sensor (Phox) with integrated Pt100 or Pt1000 temperature sensor ascertains irradiation and cell temperature. Other commercially available reference sensors such as the ISET-Sensor® can be connected via interference-free cables.

4-conductor measurement cable to the generator prevents systematic voltage measuring errors.
Irradiation reference sensor (Phox) with integrated Pt100/ Pt1000 temperature sensor
Supplementary measurement of temperature at the back of the module is possible (a second Pt100 input is provided).
Commercially available reference sensors such as the ISET-Sensor® can be connected via interference-free cables.
Connection is only permissible to direct voltage sources with current limiting (e.g. photovoltaic generators).

12.2 Sensor Connection Pin Allocations

Temperature (external): 4 pin female chassis socket, Lumberg KFV40
Pin 1 = current source + (~1 mA)
Pin 2 = Pt100 +
Pin 3 = Pt100 -
Pin 4 = current source - (~1 mA)

Irradiance: 8 pin female chassis socket, Lumberg KFV81 (plug: SV81)
Pin 1 = irradiance+
Pin 2 = Pt1000 (reference) +
Pin 3 = irradiance-
Pin 4 = current source + (~1 mA)
Pin 5 = current source - (~1 mA)
Pin 6 = unused (do not connect)
Pin 7 = unused (do not connect)
Pin 8 = Pt1000 (reference) -

PROFITEST PV **Measuring Ranges (subject to change):**

Std. Measuring Ranges	Voltage [V]	Current [A]	Temperature	Irradiation
PROFITEST PV	25/100/500/1000	2/5/10/20	-40° to +100° C with Pt1000	0 to 1300 W per sq. meter (standard sensor)

Measuring ranges can be combined with each other.
The measuring instrument automatically selects the ideal measuring range.

12.3 Computer Unit

Miniature industrial PC, real-time clock, no moving mechanical parts such as hard disks, fans etc.
A-D sampling rate: max. 100 kHz, resolution: 12 bit
Measuring accuracy for characteristic IU curve better than 1%, peak power ±5%
Data from several thousand measurements are automatically saved at the instrument permanently (flash memory).

12.4 Display

Color LCD panel, LED backlit, resolution: 480 x 272 pixels
Daylight-compatible

12.5 Operation

Menu driven via touch-screen directly at the instrument
Operation and evaluation alternatively with Windows software
Connection to PC: USB, standard B socket
USB cable: standard USB 2.0 cable

12.6 Power Supply

Lead-acid accumulator, 12 V/3.4 Ah (cont. operation approx. 3 hr.), optional: 12 V/7.2 Ah (cont. operation approx. 6 hr.),
power consumption: approx. 40 W
External power pack, input: 90 to 263 V AC, 47 to 63 Hz, 40 W, output: 16 V DC, UL approved
Integrated charge controller for protection against overcharging and excessively depleting the batteries
Charge level indication by means of LED on the housing

12.7 Dimensions

Width: 480 mm, height: 315 mm, depth: 226 mm,
weight: approx. 9.5 kg

12.8 Operating Conditions

	Temperature	Humidity
Operation	0 to 40° C	10 to 90% (non-condensing)
Storage	-10 to 85° C	5% to 95%,

12.9 Optionally Available

Measurement cable, e.g. 15 or 25 meters long (other lengths upon request)

13 List of Symbols Used in Formulas

AM	Air mass, relative travel distance of sunlight through the atmosphere
E	Irradiance
E_0	1000 W per sq. meter (irradiance under STC)
E_{TRMS}	Momentary, effective irradiance with spectral evaluation through the cell material
FF	Fill factor, ratio of $I_{sc}*U_{oc}/I_{pmax}*U_{pmax}$, for crystalline modules roughly 0.75 = 75%, smaller values may indicate reduced power
I	Current
I_m	Abbreviation for I_{pmax}
I_{ph}	Photoelectric current
I_{pmax}	Current at maximum power point
I_{pmax0}	I_{pmax} under STC
I_{sc}	Short-circuit current
I_{sc0}	I_{sc} under STC
MPP	Maximum power point, another designation for P_{max}
NOCT	Nominal operating cell temperature, cell operating temperature where $T_{ambN} = 20°$ C and $E_N = 800$ W per sq. m.
P	Power
P_{max}	Instantaneous peak power of a solar cell
P_{pk}	Peak power, rated peak power of the solar cell under STC, $P_p = I_{sc0} * U_{oc0}$
PV	Photovoltaic
R	Resistance
R_{pv}	Photovoltaic resistance
R_s	Internal series resistance, in addition to resistance in the module, e.g. cable/plug resistance, inherent resistance of about 0.5 Ohms in crystalline modules, or 2 to 3 Ohms in thin-film cells. Within the string, R_s is greatly influenced by line resistance.
R_p	Parallel resistance
R_{pv}	Photovoltaic resistance (calculated value only, not true resistance)
STC	Standard test conditions for determining P_{pk}: AM 1.5, T = 25° C, E0 = 1000 W per sq. meter
T_{mod}	Module temperature
U	Voltage
U_m	Abbreviation for U_{pmax}
U_{oc}	Open-circuit voltage
U_{oc0}	U_{oc} under STC
U_{pmax}	Voltage at maximum power point
U_{pmax0}	U_{pmax} under STC

14 Causes of Reduced Output and Yield

Error	Can be detected by:	Possible Cause / *Remedy*
System is not ideally configured	Measurement of match losses	Planning error / *new configuration*
Incorrect adaptation of strings to inverter	Too little power fed to the location and too little generator power	Planning error / *new configuration*, replacement of the inverter
Shaded by cast shadows	Characteristic IU curve has "bumps", too little **peak power**, visual inspection	Obstruction in direct proximity to the module (e.g. bird droppings) / *remove obstacle*
Diffuse shading (possibly undetectable with the naked eye!)	Characteristic IU curve is "dented", too little **peak power**	Obstacle at some distance (high diffuse light component) / *remove obstacle*
Corrosion on plugs/terminals	**Internal series resistance R_s too high**	Material, planning or installation error / *clean, replace*
Peeling of the cell embedding	Same as **diffuse shading**	Material or manufacturing defect / *replace*
Formation of bubbles in the resin	Same as **diffuse shading**	Material defect / *replacement by supplier*
Cover material becomes opaque (glass, plastic, resin)	Visual inspection, **peak power** too low (see also **diffuse shading)**	Material defect / *replacement by supplier*
Discoloring of the transparent cover material (plastic, resin)	Visual inspection, too little **peak power** (see also **diffuse shading**)	Material defect / *replacement by supplier*
Penetration by moisture between the laminate, leads to other damage (corrosion, discoloring)	Visual inspection	Material or manufacturing defect / *replacement by supplier*
Defective crystal structure in individual cells (hot spot effect)	Same as **diffuse shading**	Manufacturing defect / *price reduction, replacement by supplier*
Module contaminated with dust	Visual inspection, same as **diffuse shading**	Extremely dusty (usually not a problem in Germany), inspect at regular intervals / *clean*
Moss and algae growth on the module, bird droppings	Same as **shaded by cast shadows**	Normal, depending on region and location / *clean*
Broken cover glass, leads to other damage (corrosion, discoloring)	Visual inspection	Damage caused by hail, installation error, transport / *replacement by supplier*
Broken individual cells in the module	Too little **peak power,** characteristic IU curve may be distorted	Material defect / *replacement by supplier*
Poor electrical connections inside the module	Too little **peak power**, **internal series resistance R_s** higher than calculated	Soldering error, material defect, corrosion / *replacement by supplier*
Defective bypass diode (short-circuit)	**Peak power** reduced by amount equal to module power	Overloading, material defect / *repair*
Bypass diode installed in the wrong direction	**Peak power** reduced by amount equal to module power	Installation error / *repair*
No bypass diode or defective bypass diode (high impedance)	Shading of just one module may dramatically reduce the power of the entire string	Planning or installation error / *repair*
Cables are inadequately dimensioned	**Internal series resistance R_s too high**	Planning error / *replace cabling*
Defective cable (e.g. broken, corrosion)	**Internal series resistance R_s too high**	Installation error / *repair*
Plug connectors incorrectly connected	**Internal series resistance R_s too high**	Installation error / *repair*
Corrosion in screw of plug connectors	**Internal series resistance R_s too high**	Installation error / *clean, repair*
Bad preliminary selection of modules according to peak power (good/bad modules all in one string)	Too little **peak power** for the overall system	Planning or installation error (match losses) / *match up modules again after peak power measurement*
Bad preliminary selection of individual cells according to power during module manufacturing	Too little **peak power** for the module	Manufacturing defect / *price reduction, replacement by supplier*
Short-circuit between individual cells in the module	Too little **peak power** for the overall system, open-circuit voltage U_{oc} to small, characteristic curve course	Manufacturing defect / *replacement by supplier*
Manufacturing tolerances in cell production	Too little **peak power**, characteristic curve course	Manufacturing defect / *price reduction, replacement by supplier*

Source: PVE
Please note: Errors might only become apparent under certain operating
conditions, e.g. high module temperatures.
No claims are made regarding the completeness or correctness of this list.

15   Characteristic IU Curves: Contexts

The diagrams shown below have been taken from the following books with the kind permission of their authors:
Quaschning, 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
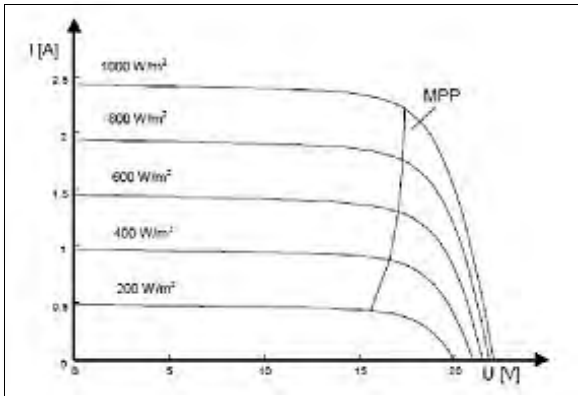

Figure: Characteristic current-voltage curves with irradiation of 1000 W per sq. meter and other irradiation values
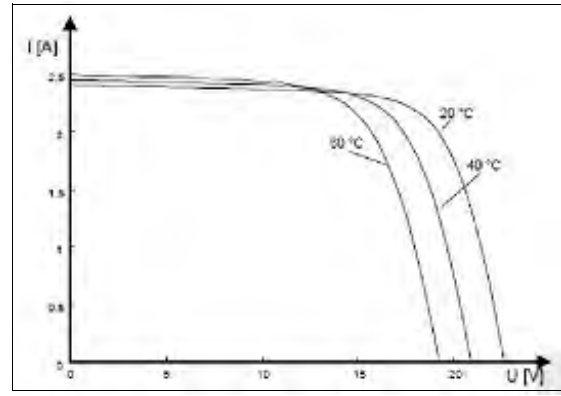

Figure: Characteristic current-voltage curves with irradiation of 1000 W per sq. meter and various cell temperatures
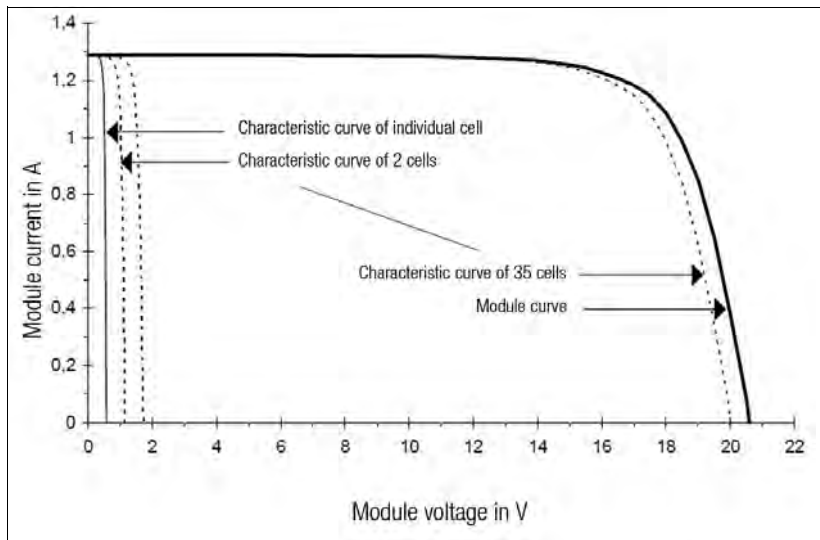

Figure: String layout based on characteristic cell curves (irradiance E = 400 W per sq. meter, T = 300 K)
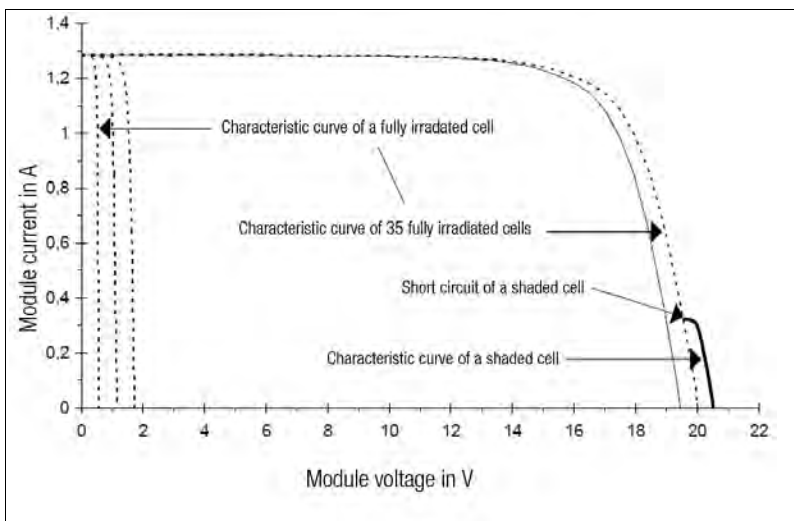

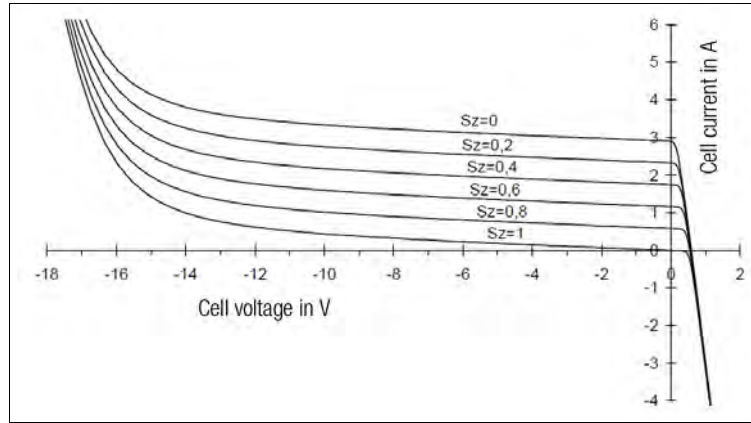Figure: Partial layout of the string with a partially shaded cell

Figure: Characteristic curve of a polycrystalline solar cell over the entire voltage range with varying degrees of shading ($E_0 = 1000$ W per sq. meter, T = 300 K)
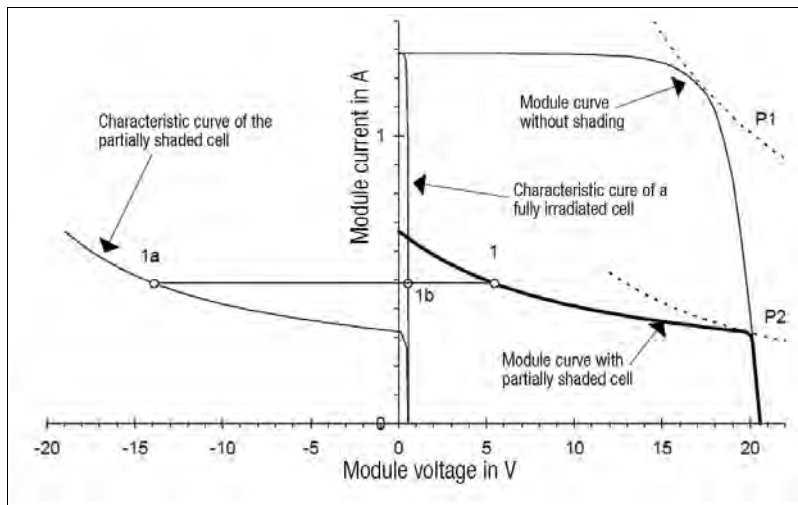

Figure: Layout of an SM50 module string with a 75% shaded cell
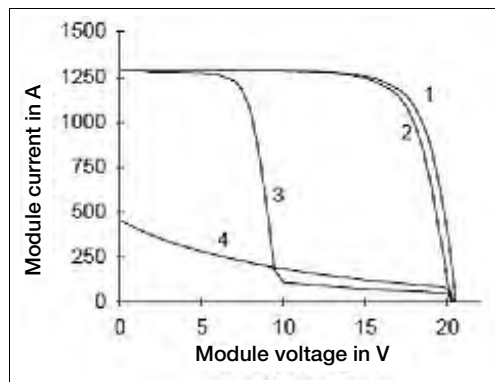*(E = 407 W per sq. meter, T = 300 k)*

Figure: Solar module curve: (1) fully irradiated; (2) one cell fully covered with bypass diode over the cell; (3) with bypass diodes over half of the cell string; (4) without bypass diode
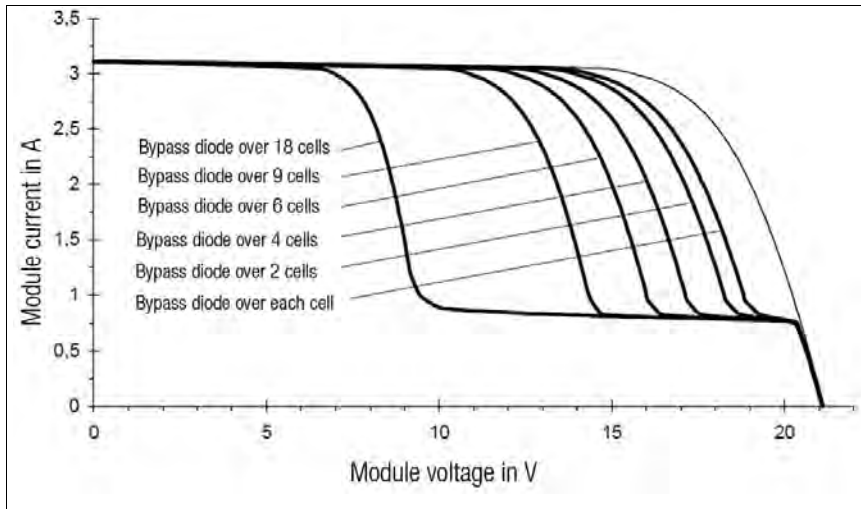
Figure: Simulation of various characteristic module curves with bypass diodes over varying numbers of cells (E = 1000 W per sq. meter, T = 300 K)
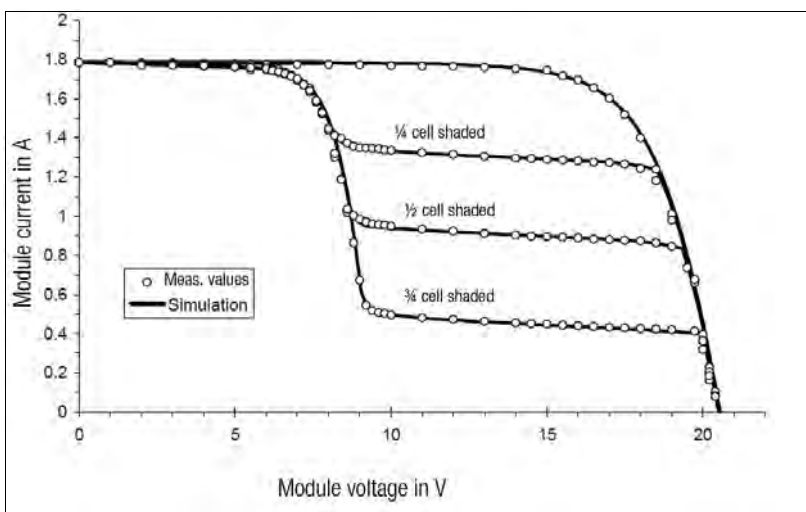
Figure: Comparison of simulation and measured values using an example with the SM50 module, 36 cells with two bypass diodes over 18 cells each. Once cell was shaded variously, the others were fully irradiated (E = 574 W per sq. meter, T = 300 K).

Figure: Characteristic module curves for the SM50 module without bypass diodes, first cell variously shaded (degree of shading S_{ZI} = 0 to 1), E = 407 W per sq. meter, T = 300 K

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Figure: Resultant characteristic curve using series connection with bypass diode

16 Sample Characteristic Curves from Actual Practice (source: PVE)
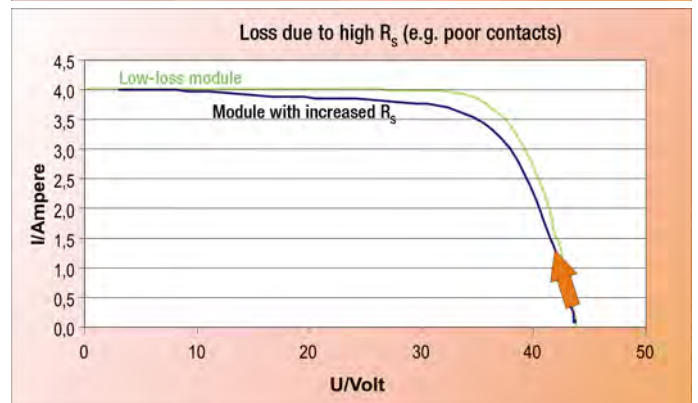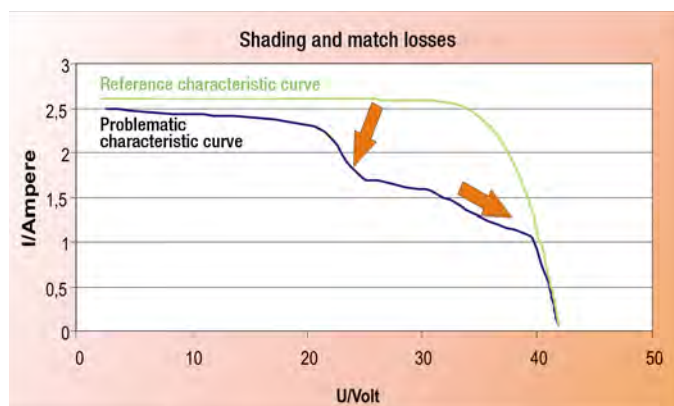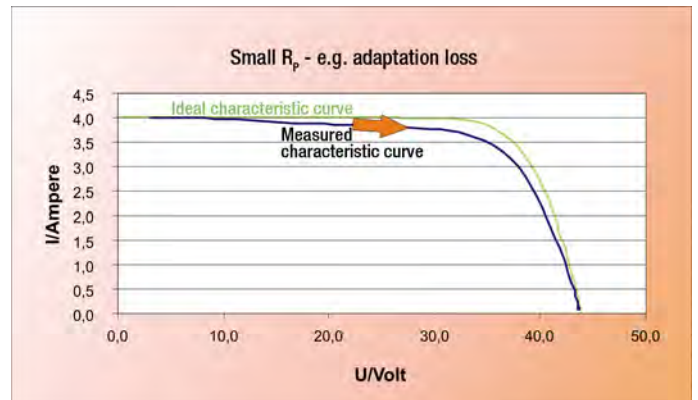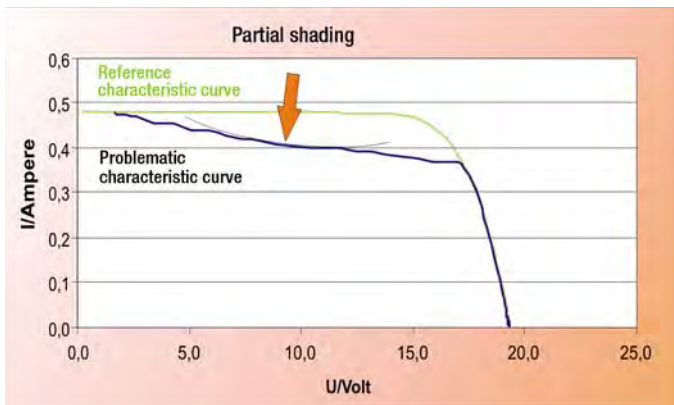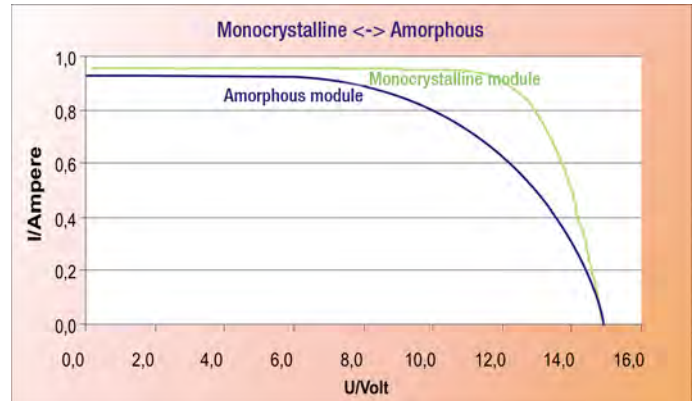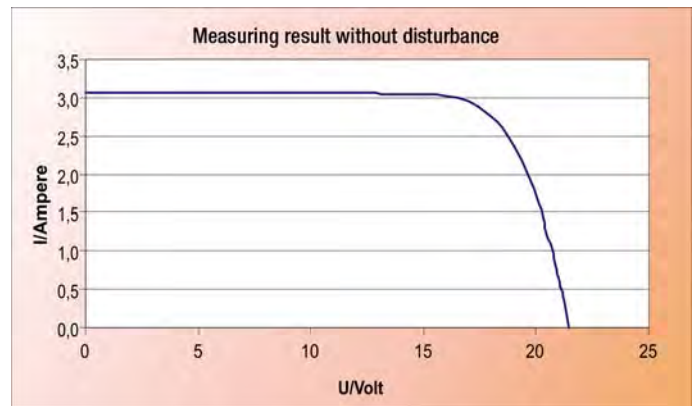
4-Wire Measurement (Kelvin measurement)

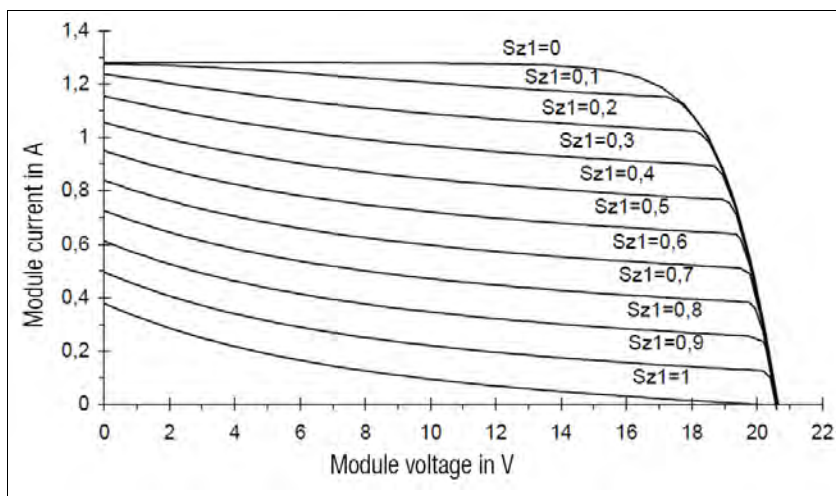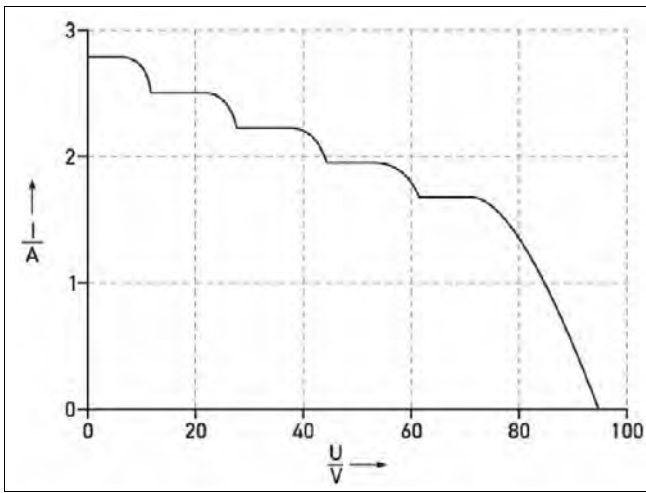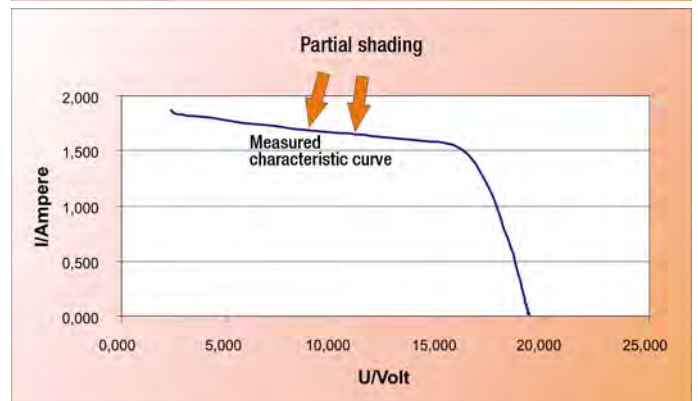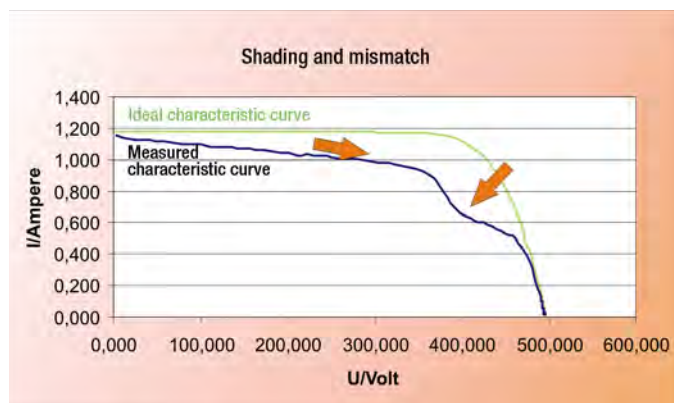When current flows through an electrical conductor, voltage drops due to specific resistance. This phenomenon is known as Ohm's law ($R = U/I$). Voltage at the end of the conductor is not as high as it was at the beginning (the measuring point). The 4-wire method is used in order to be able to determine the exact voltage value at the measuring point. In this case, current flows through two conductors (plus and minus) und and a low impedance load, and voltage drops as a natural result. Two additional cables are connected to the current conductors at the point of measurement, and a high impedance measuring instrument is hooked up. Due to the fact that nearly no current flows at this point, there is no voltage drop in the cable: Measured voltage is precisely the voltage which prevails at the measuring point.
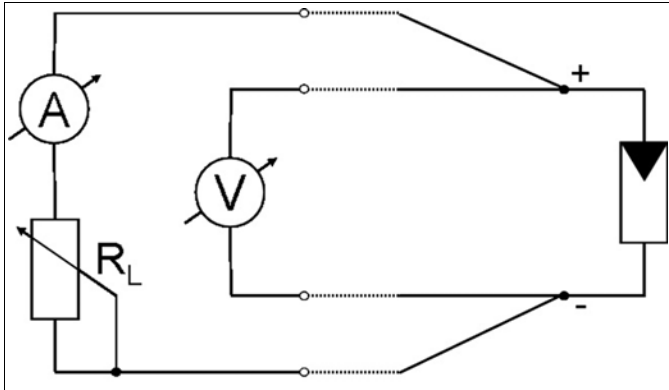
Azimuth Angle (ß) and Inclination Angle (α)

In order to take effective advantage of solar irradiation, modules and collectors are aligned to assure the greatest possible solar harvest. In addition to the sun's incident angle, the azimuth angle and the inclination angle of the modules or collectors play a role as well. The azimuth angle (ß) indicates how many degrees the surfaces of the modules or collectors deviate from an exact southern alignment. The inclination angle (α) specifies deviation from the horizontal. Investigations reveal that solar systems with an azimuth angle of approximately 0° and an inclination angle of 30° are ideally aligned. However, small deviations are not necessarily problematic: With a southeast or southwest orientation, it's still possible to bring in about 95% of the full harvest. Large systems are equipped with electric motors for tracking the sun in order to increase yield (see also tracking).

When conducting measurements with the PROFITEST PV, precise alignment of the irradiation sensor to the modules is extremely important. The sensor and the modules must be "looking at the same sky". The fact that ambient reflections (caused by the walls of houses or other bright surfaces) may greatly influence the incidence of light at the module and the sensor must be taken into consideration.

Characteristic Current-Voltage Curve
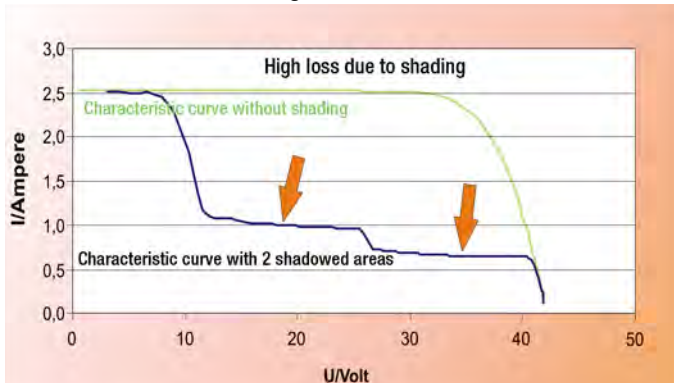
The characteristic current-voltage curve of a PV generator indicates its various attributes and problems, and serves as a basis for several essential, characteristic values. For example, partial shading in the form of diffuse or cast shadows show up in the characteristic curve, as do high internal resistance values and any missing or incorrectly installed bypass diodes. Recognizing these details necessitates a certain amount of experience in interpreting the characteristic curves, as well as basic knowledge of the physics of the PV cell (from a semiconductor standpoint).

In addition to short-circuit current Isc and open-circuit voltage Uoc, as well as current and voltage at maximum power point (MPP) Ipmax and Upmax, these data also serve as a basis for determining fill factor using the formula Isc*Uoc/(Ipmax*Upmax).

Additionally, the characteristic curve is also the basis for calculating TRMS solar cell curves, by means of which peak power and internal series resistance can also be calculated.

DC

Abbreviation for direct current, as generated by solar cells or modules and stored in accumulators. If several solar cells are connected in series into a module, their voltage values are added up.

Degradation Characteristics

The efficiency of amorphous solar cells drops greatly at the beginning of the phase with prolonged exposure to sunlight, and doesn't stabilize until after a period of 3 weeks to 5 months. In addition to this irreversible degradation, reversible degradation takes place as well. This means that amorphous solar cells demonstrate a greater degree of efficiency in the spring and summer months than they do in fall and winter.

Direct Radiation / Diffuse Radiation

Direct (shadow casting) radiation strikes a surface without scattering through components of the Earth's atmosphere. Scattering (due to fog, haze or clouds) results in diffuse/indirect radiation.

Efficiency

General: The relationship between potentially usable energy and actually used energy. For instance, conventional light bulbs transform about 3 to 4% of the used energy into light, solar cells reach efficiencies of about 11 to 17% when converting light into electricity, and a solar heating system can transform 25 to 40% of the solar radiation into usable heat.

Generator

Generators convert other forms of energy into electrical current. In the field of solar technology, only the complete system of interconnected photovoltaic modules is called a generator or solar power plant.

Global Radiation

Designation for solar irradiation which strikes a horizontal surface on the Earth. It's comprised of direct radiation and reflected radiation (e.g. from snowfields).

Internal Series Resistance R_S

This resistance is the physical result of the material used to manufacture the module, as well as its layout and wiring connections, and normally has a constant value. For example, it amounts to roughly 1 Ohm for crystalline modules and more than 2 Ohms for thin-film modules.

As of recently, measurement of internal series resistance can be performed with instruments from the PROFITEST PV product range. Only a single characteristic IU curve has to be traced at the module for this purpose. On the basis of this characteristic curve, the instrument automatically calculates R_S, as well as peak power P_{PK} and parallel resistance R_P.

Theoretically anticipated internal series resistance R_S can be calculated. For example, this is possible with PV Analyzer software if the following characteristic STC values are known for the module: U_{oc}, I_{sc}, U_{Mpp} and I_{Mpp}.

The calculated R_S value can then be compared with the measured value, which is read out by the PROFITEST PV measuring instrument after curve tracing. If the measured value is too high, wiring must be inspected for interruptions, corrosion, connection errors and underdimensioning.

Mismatching

Connection of worse and better modules into a single string – the worst module in a string dictates current and thus reduces overall power.

MPP

Abbreviation for maximum power point. A solar cell has a maximum power point in its characteristic UI curve for every possible irradiation value, in combination with a certain temperature and light spectrum value. The product of usable voltage and associated current is not always the same.

Peak Power

In order to assure comparability of power ratings for PV modules, it has been generally agreed that the nominal power of a module is to be measured with a cell temperature of 25° C, irradiation amounting to 1000 W per square meter and a light spectrum corresponding to AM = 1.5, and that the resulting value shall be called "peak power" (some manufacturers call this the "nominal value"). The above specified conditions are known as standard test conditions (STC).

Unfortunately, STCs occur only rarely in nature, and thus it has been necessary to perform respective measurements in the laboratory thus far, where it is quite costly to create the specified conditions.

With new processes offered by PROFITEST PV peak power meters and curve tracers, it's now possible to perform measurements under actual ambient conditions because the measuring instrument converts results to STC. And thus after just a single curve tracing procedure, the user is provided with immediate results including peak power P_{pk}, internal series resistance R_s and parallel resistance R_p. Compared with the setpoints for the system under test, these values indicate various defects in the PV generator and simplify power monitoring as well as troubleshooting.

Performance Ratio

In the field of photovoltaic, the term performance ratio refers to the relationship between actual yield and target yield. The performance ratio of a photovoltaic system is the quotient of alternating current yield and the nominal yield of the generator's direct current. It indicates which portion of the generated current can actually be used. High performance photovoltaic systems can achieve performance ratios of greater then 70%. The performance ratio is frequently called the quality factor (Q) as well. Solar modules based on crystalline cells can even reach quality factors of 0.85 to 0.95 (i.e. performance ratios of 85 to 95%).

Phox Sensor

The principle of the Phox sensor (p**ho**tovoltaic Lu**X**) is based on the fact that current generated by a photovoltaic cell, which has a nearly linear relationship to radiation striking the cell, is fed through a so-called shunt, i.e. a very accurate resistor. The voltage, which drops over the resistor is, in turn, linearly dependent on irradiation and can be acquired with simple voltage meters. Disadvantage: Each and every sensor must be separately calibrated: The calibration value is the voltage generated by the sensor when subjected to standard test conditions (STC).

Roof Pitch

Even if roof pitch is asked for when planning a solar system (for example for an online calculation), roof pitch is insignificant: It's the inclination of the collectors that matters. Even if roof pitch or alignment is unfavorable, collectors can be suitably positioned by means of appropriate supports and holders.

The sun's rays should strike collectors at a right angle in order to take best advantage of solar irradiation. The ideal inclination angle corresponds to the terrestrial latitude of the installation site (for example, Freiburg is at the 48th degree of latitude and Lübeck at the 54th). Due to the fact that the sun is higher above the horizon in the summer than in the winter, it depends on the season during which the solar system will be used primarily. For example, photovoltaic systems generate best possible yield during the long summer days, whereas thermal solar systems are needed to support heating during the winter. As a rule of thumb for the inclination angle, degree of latitude minus 10 applies for summer use, and degree of latitude plus 10° applies to winter use.

Alignment to the south (azimuth angle) must not be confused with inclination angle. In actual practice, small deviations from ideal alignment result in only minimal yield reductions. Shading of the collectors from time to time impairs yield to a greater extent.

Short-Circuit Current with regard to Solar Cells

Current which flows when the cell's plus and minus poles are connected to each other, i.e. when no resistance or power consumer is connected between the plus and minus poles. This is not dangerous for the solar cells themselves, but a dangerous electric arc may occur when the poles are disconnected!

Solar Constant

The solar constant is the amount of solar irradiation which perpendicularly strikes a surface outside of the atmosphere (s = 1.37 kW per sq. meter). Solar irradiation is nearly constant in outer space; on the Earth it fluctuates during the course of the day and from season to season, and it varies depending upon latitude and weather conditions. The maximum value on the Earth is between roughly 0.8 and 1.2 kW per square meter. Average annual solar irradiation in Germany lies within a range of 850 to 1100 kWh per square meter depending on region.

Solar Irradiation

Solar irradiation is comprised of direct irradiation from the sun, as well as several indirect components. Amongst others, the indirect components include reflected irradiation from the environment. Snow surfaces, for example, reflect irradiation from blue skies, as well as other diffuse irradiation, especially well. The angle of the sun's rays to the respective surface is decisive for accurate calculation of the amount of energy which strikes the surface. This angle changes according to time of day and season. Various websites provide information concerning exact calculation. Even with bright sunshine and blue skies, only about 90% of the sun's energy arrives at the surface of the Earth.

Standard Test Conditions

According to IEC 60904-3, standard test conditions (STC) are fulfilled with irradiation amounting to 1000 W per square meter, a spectrum corresponding to AM = 1.5 and a module temperature of 25° C.

Tracking

In the case of tracking photovoltaic systems, the module surface follows the position of the sun during the course of the day. Tracking can be executed via one or two axes – yield is higher with 2-axis tracking. As opposed to a system which is aligned to the south in a fixed manner, annual yield can be increased in this way by roughly 30% at our latitudes. Mast supports for tracking solar systems allow for ideal positioning. Regardless of construction conditions, a shade-free swivel angle of 180° is thus made possible.

18   Appendix A

18.1   Indicator lamps on the front panel:

Labeling	Function
Charge level	Lights up red when the battery is depleted (immediate charging required) Lights up green when the battery is ready for use Lights up yellow when the battery is fully charged
External power supply	Lights up when the external power pack is connected and switched on

18.2   Acoustic Signals

The PROFITEST PV indicates errors and operating states by means of acoustic signals: Low pitch tones are designed in the following as "da", and high pitch tones as "di".

Signal	Meaning	Response
Clicking	Keyboard clicking sounds are simulated when the membrane keypad is used.	--
di	During operation: indicates that a function has started or stopped	--
da	General error indication	Observe further messages generated by the instrument regarding the error.
di	If this signal is generated when the main menu appears, the instrument is ready for operation.	Instrument ready
da or da-da	Shortly after switching on: processor OK	--
da or da-da followed by da-da	Shortly after switching on: The processor's lithium backup battery is presumably depleted.	Customer service required
di-di-da-da	The LCD panel cannot be addressed.	Switch the instrument off, wait briefly and then turn it back on. If the error persists: customer service required.
di di	After transferring a file to the PROFITEST PV (service only)	File transfer OK
da-di-da	After transferring a file to the PROFITEST PV (service only)	File transfer failed, target file is deleted
di-di-di-di	During measurement: irradiation is fluctuating / is not strong enough.	Measurement is inaccurate and must be discarded.
di-di-di- da-da-da- di-di-di	A-D converter could not be initialized.	Customer service required

19 Maintenance and Recalibration

19.1 Return and Environmentally Sound Disposal

The instrument is a category 9 product (monitoring and control instrument) in accordance with ElektroG (German electrical and electronic device law). This device is not subject to the RoHS directive.

We identify our electrical and electronic devices (as of August 2005) in accordance with WEEE 2002/96/EC and ElektroG using the symbol shown at the right per DIN EN 50419.

These devices may not be disposed of with the trash. Please contact our service department regarding the return of old devices.

If the batteries used in your instrument are depleted, they must be disposed of properly in accordance with valid national regulations. Batteries may contain pollutants and heavy metals such as lead (Pb), cadmium (Cd) and mercury (Hg).

The symbol to the right indicates that batteries must not be disposed of with the trash, and must be brought to a designated collection point.

Pb Cd Hg

19.2 Recalibration

The measuring tasks performed with your instrument, and the stressing it's subjected to, influence aging of its components and may result in deviation from the specified levels of accuracy.

In the case of strict measuring accuracy requirements, as well as in the event of use at construction sites with frequent stress due to transport and considerable temperature fluctuation, we recommend a relatively short calibration interval of once per year. If your instrument is used primarily in the laboratory and indoors without considerable climatic or mechanical stressing, a calibration interval of once every 2 to 3 years is sufficient as a rule.

During recalibration* at an accredited calibration laboratory (DIN EN ISO/IEC 17025), deviations from traceable standards demonstrated by your measuring instrument are documented. Ascertained deviations are used to correct displayed values during later use of the instrument.

We would be happy to perform DKD or factory calibration for you at our calibration laboratory. Further information is available at our website: www.gossenmetrawatt.com (→ Services → DKD Calibration Centre or → FAQs → Questions and Answers Regarding Calibration).

Recalibration of your instrument at regular intervals is essential for the fulfillment of requirements according to quality management systems per DIN EN ISO 9001.

* Examination of the specification, as well as adjustment, are not included in calibration. However, in the case of our own products, any required adjustment is performed and adherence to the specification is confirmed.

19.3 Repair and Replacement Parts Service Calibration Center* and Rental Instrument Service

If required please contact:

PV Engineering GmbH
Augustastr. 24
58644 Iserlohn
Germany

20 Product Support

If required please contact:

GMC-I Messtechnik GmbH
Product Support Hotline
Phone: +49-911-8602-0
Fax: +49-911-8602-709
e-mail   support@gossenmetrawatt.com

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