leXsolar-SmartGrid Professional

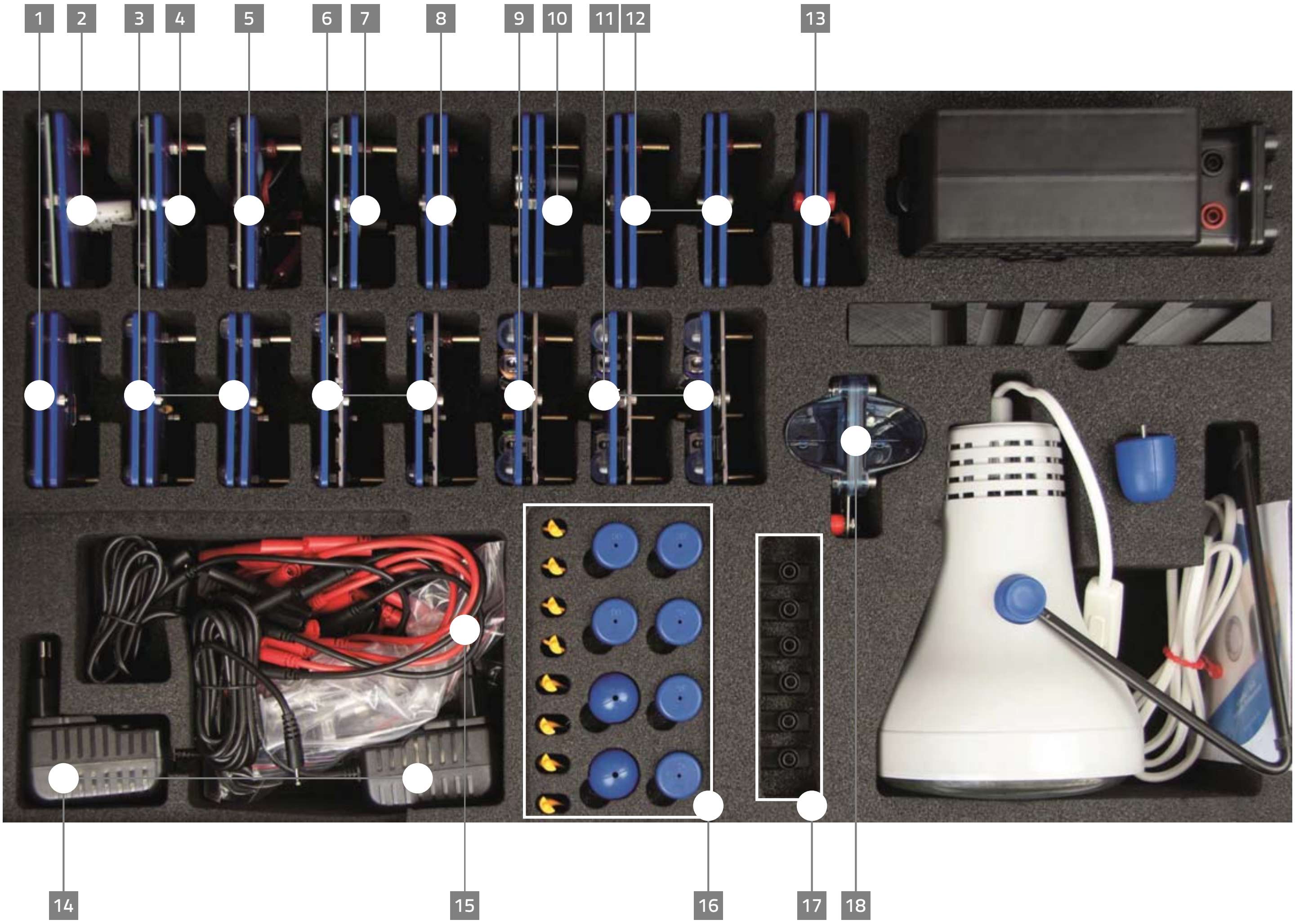
Experiment handbook

Layout diagram leXsolar-SmartGrid Professional

Item-No.1607

Bestückungsplan leXsolar-SmartGrid Professional

Art.-Nr.1607



1 1118-05 Diode module Pro
1118-05 Diodenmodul Pro

2 1118-11 Capacitor module Pro
1118-11 Kondensatormodul Pro

3 2x1607-01 Grid module Pro
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Version number
Versionsnummer

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CE RoHS2

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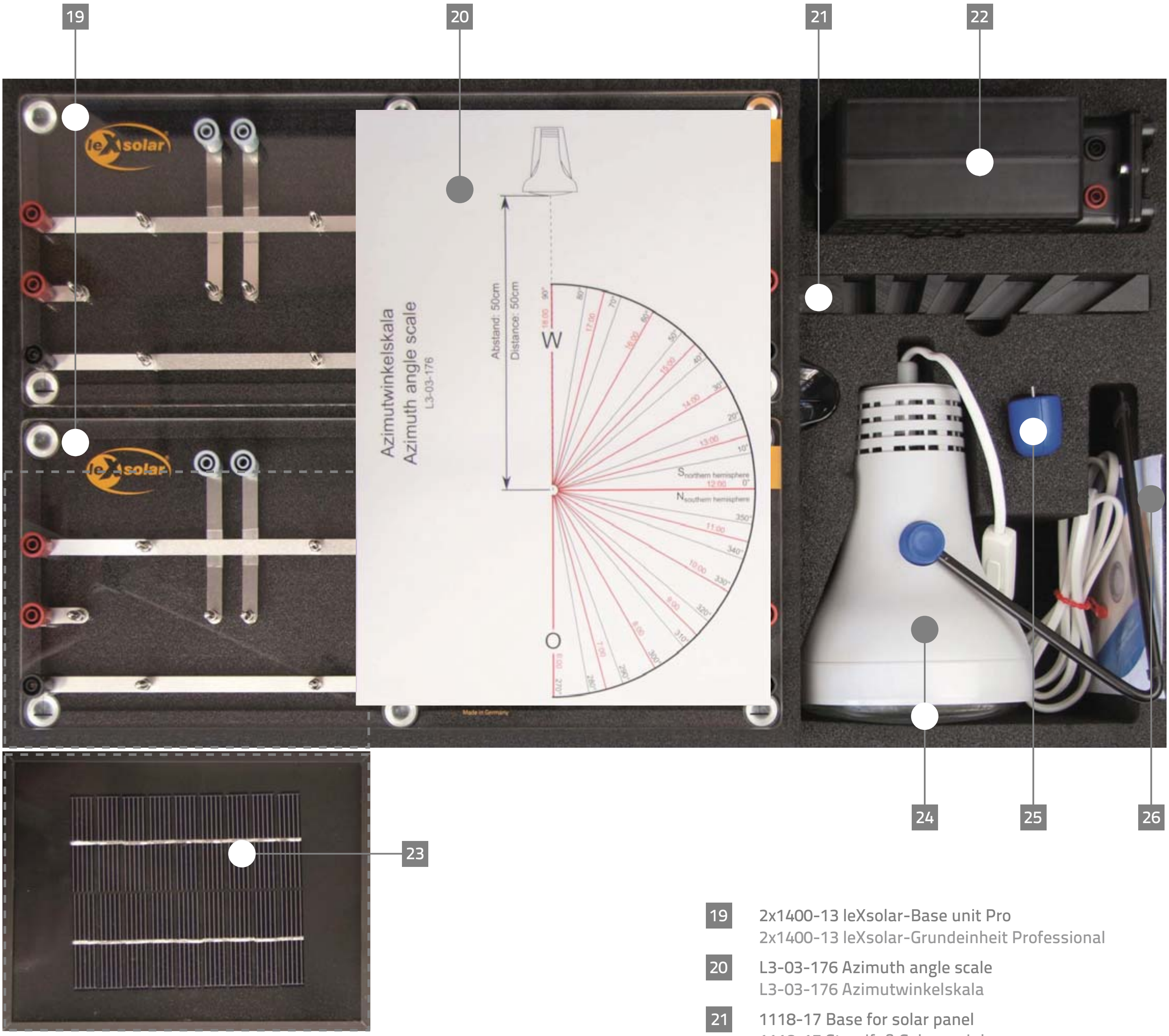

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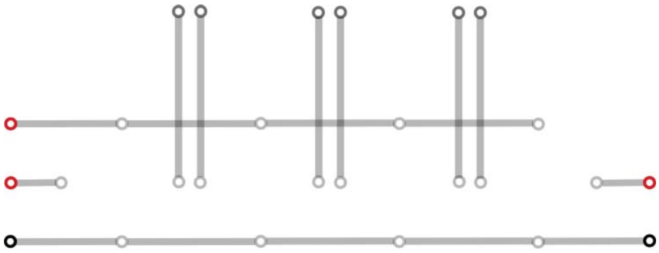
Chapter 1: Description of the experimental components of leXsolar-SmartGrid Professional

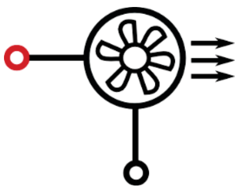
In the following schedule every component of the leXsolar-SmartGrid Professional case is listed. For every component there is the name with article number, a picture, the pictogram for the circuit diagram and operating instructions. With the aid of the article number it is possible to reorder a specific component.

Base unit Professional 1400-13



The base unit is a breadboard where up to 4 components can be plugged in a series and parallel connection. The current flows along the wires on the bottom side. At the head there are bypass slots to connect the components in the desired way.

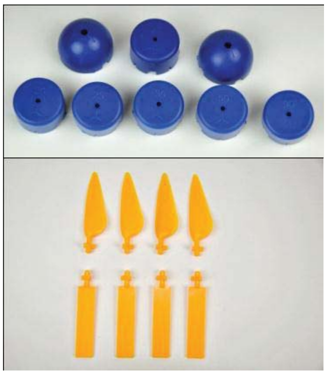
Wind machine 1400-19



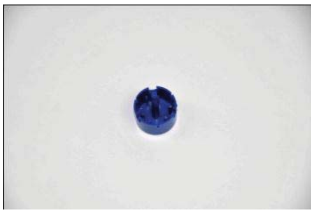
The wind machine is used to control the wind conditions during an experiment with the wind turbine. For those experiments the wind machine has to be connected to the PowerModule (voltage source). For this the negative (positive) pole of the PowerModule has to be connected to the black (red) connection. Towards the connections there is also a seperate on/off-switch. The wind direction is marked with arrows on the upside. The use of the wind machine is only permitted with the PowerModule or a stabilized voltage source. Misuse leads to termination of warranty.

Specifications:
- Maximum voltage: 12 V DC (stabilized)
- Wind speed: 0 – 7 m/s

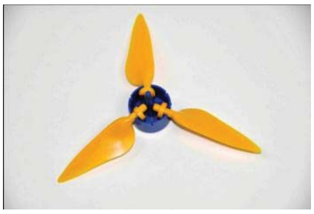
Wind rotor set 1400-12



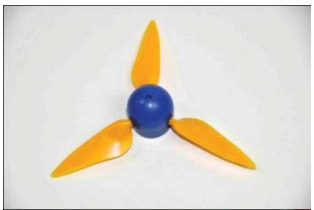
With the available components, rotors with 2, 3 or 4 blades and with a flat or an optimized profile can be created. There is a hub for 4 blades with a pitch angle of 25° and hubs for 3 blades with pitch angles of 20°, 25°, 30°, 50° and 90°. To assemble you should proceed in the following way:



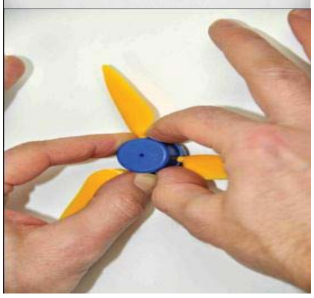
First, a hub with the desired rotor blade pitch and the number of blades should be selected. (The hubs are labelled on the back.) The Two-blade rotor and the Four-blade rotor can both be constructed with the Four-blade hub.



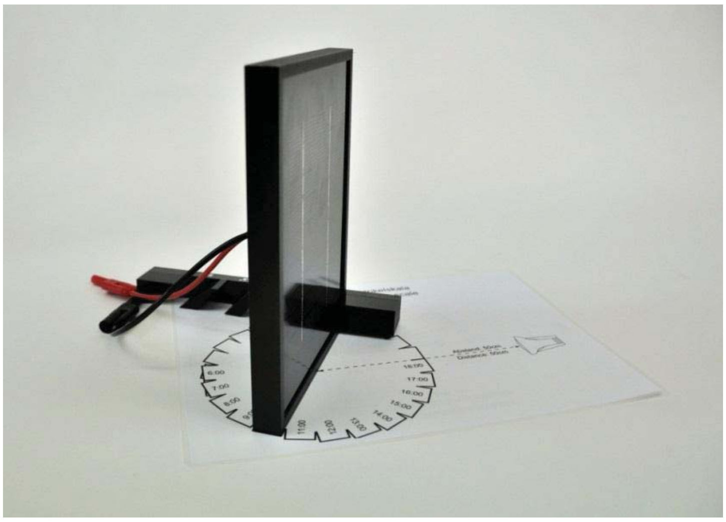
After that, the rotor blades are installed. During the insertion of the blades, make sure that they are installed with the rounded side up.



After installation of the rotor blades, the hub-cap will be mounted and lightly pressed against the hub.

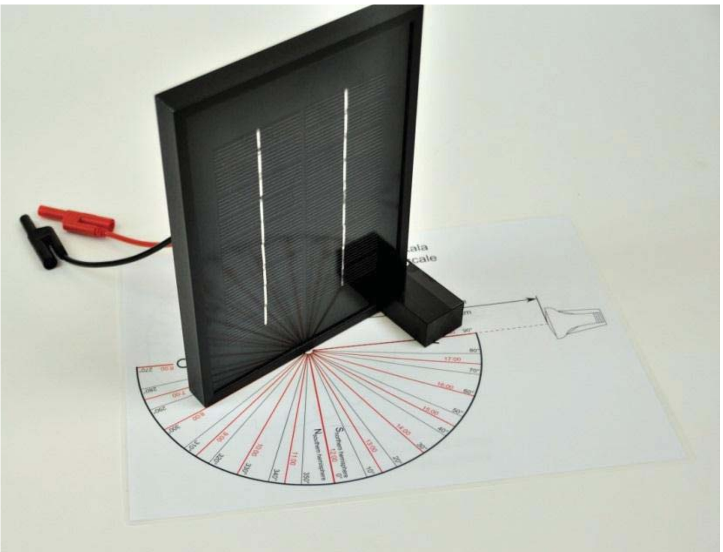


To replace the blades, a small nose is located on the head of the hub. If the nose is pressed lightly on a hard surface, the hub-cap can be removed easily.



Solar module in 10 o'clock position

With the azimuth angle scale it is possible to set up the azimuth angle between the solar module and the lamp. On one page there are rectangles arranged in a circle and labelled with corresponding times of day. If the solar module is placed in a certain rectangle, the azimuth angle is set up for the chosen time of day. For example, in the alongside figure the solar module is arranged in the 10 o'clock position.

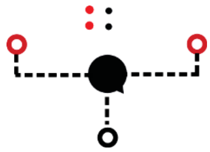


Solar module in 8 o'clock position

The second page can be used for a more exact configuration of a specific azimuth angle. The angle is set up, when the leading edge of the solar module is located at the corresponding line.
In the alongside figure the solar module is arranged in an azimuth angle of 300°. On both scales the position of the lamp is marked. The distance between the lamp and the center of the solar module has to amount to at least 50 cm.
The center of the solar module has to be located at the center of the angle scale.

Advice: The azimuth angle scale does not name the deviation angle of the solar module concerning the south, but name the azimuth angle of the sun in the astronomic meaning! In the experiment is assumed that the solar module is aligned to south (optimal direction). Therefore the used azimuth angle is not the term used in solar engineering, where 0° describe an aligned solar module to the south (-90° to the east, +90° to the west).

MPP-Tracker 1118-13



When connecting an arbitrary consumer to the solar module, it will commonly not operate at the MPP (Maximum Power Point) of the module. Therefore, often a part of the solar cell power is lost because of not using the possible maximum power. An MPP-Tracker is a so called DC/DC inverter which can increase or decrease the input voltage. The power as the product of voltage and current remains constant but the operating point can be adapted to a more convenient part of the I-V-characteristic. The leXsolar MPP-Tracker module has two operation modes that can be chosen with pushbuttons. When choosing the "automatic mode" the output voltage is varied in a broad range (LED is blinking) and the operating point with the maximum output power is automatically selected (LED shines continuously). Afterwards, the operating point is slightly shifted, to ensure that the consumer always extracts the maximum power from the solar module (dissipation power is disregarded). When using the "manual mode", the ratio between output and input voltage can be adjusted manually with the potentiometer and a manual tracking is possible. To reduce the power dissipation of the MPP-Tracker module, it is only possible to reduce the output voltage against the input voltage. This is an advantage when the consumer has a lower internal resistance than the solar module.

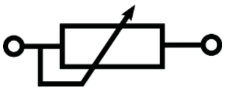
PowerModule 9100-05

The PowerModule is a compact and intuitively usable voltage source. First, the attached power adapter has to be connected to a power outlet and to the top right input jack. The voltage can be chosen with the „+"- and „-" -buttons and will be displayed by LEDs. When the desired voltage is chosen, the voltage will be applied by using the yellow on/off- button. In case of a short circuit or currents greater than 2 A the PowerModule will switch off immediately.
In the Smart Grid experiments the PowerModule is on the one hand used as voltage source for the wind machine or the electrolyzer or on the other hand as a simulation of a power plant or a transformer station.

Specifications:

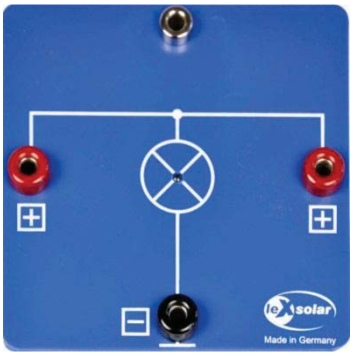
- Output voltage: 0-12 V
- Output power: max. 24 W
- Adjustable in 0.5 V steps
- Overcurrent detection >2 A and automatic shutoff
- Input voltage: 110-230 V, 50-60 Hz (with enclosed power adapter)

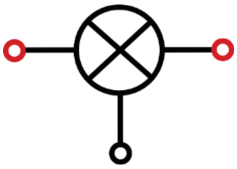
Potentiometer module 1100-62



The potentiometer module holds a 0-10-Ω-potentiometer and a 0-100-Ω-potentiometer. Both are serially conneted, so that the potentiometer can attain resistances between 0 Ω bis 110 Ω. The measuring error amounts to 0.5 Ω for the small resistor and 5 Ω at other one.

Light bulb module 1118-01



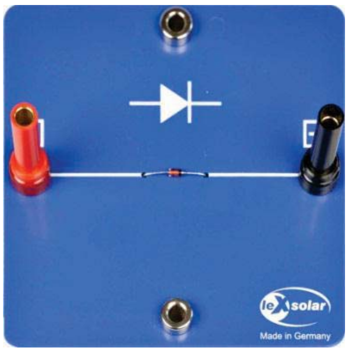


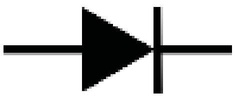
The light bulb module acts as a consumer in SmartGrid experiments.

Specifications:

Light bulb P_{typ} = 200 mW (at 3.5 V)
Fuses work up to maximum voltage of 6 V

Diode module 1100-21





The diode module is used to avoid a return current to the wind turbine in SmartGrid experiments with many voltages sources. Without the diode the turbine could act as a motor.

Chapter 2: Sample solutions of the experiments

Primary notes

The details for every experiment are separated into preparation, implementation and follow-up procedure.
The advice for preparation contains information about the educational objectives of the experiment, necessary prior knowledge, previous experiments and detailed advice about the procedure and evaluation. This information assists in

- the classification of the experiment in a sequence of lessons,
- the classification of the experiment as of a lesson,
- the preparation of the experiment concerning necessary knowledge of the students,
- an effective implementation of the experiment to get the best measurement results,
- the avoidance, recognition and correction of errors during the procedure,
- the decision, whether the experiment can be conducted by the teacher or the students
- the preparation of follow-up topics about smart grid

The implementation is separated into the subchapters: task, primary notes, setup and equipment, procedure and measured values. The instructions are conceptualized a way, that an immediate usage by students without given measured values is possible. This means, that the students are able to do the experiment on their own, make an appropriate evaluation and understand the physical processes, given they possesses of the required knowledge.

The evaluation consists of

- exercises in comprehending the measured values
- exercises in elucidating the physical processes of the experiment and the real situation
- exercises in suggesting tasks for the following lessons

Every task consists of sample solutions and is considered a suggestion for your own lesson. With the given foreknowledge the students should be able to solve every task on their own. Nevertheless, it could be necessary for students to solve some tasks in groups or that intermediate tasks are given. Furthermore, there are (German) references so that students are enabled to solve the task by investigations of their own.

The experiments are subdivided in preliminary experiments and smart grid experiments. The preliminary experiments should impart technical knowledge about the main components, which is necessary for the smart grid experiments. Moreover the preliminary experiments are important to become acquainted with the handling of the leXsolar components.
Some of the smart grid experiments are quite complex and will require 3 to 4 students to do the experiment. The complex setups consist of many different components, so that there are many potential sources of error. Therefore it is important that the setups and the procedures are implemented conscientiously. This limits the liberty of experimenting, but it is necessary to get sensible and comparable results.

The protocols without sample solutions can be found in the separate instruction manual or on the leXsolar-CD as pdf- or word-file (docx). With the purchase of the product you acquire the right to a free usage of the protocols for the purposes of education. This includes variation of text passages or figures within the word-file (providing the source is acknowledged).

1.1 – 1.5 Basic experiments on photovoltaic

Educational objectives

Experiment 1.1: The I-V-caracteristic of a solar module

- The students measure, plot and describe the I-V curve and the V-P curve of a solar module.
- The students interpret the intersection between the I-V-characteristic of a solar module and a resistor as operating point.
- The students realize by reference to the I-V curve, that voltage, current and power of a solar module depend on the connected resistor.
- The students calculate the resistance of the MPP at room temperature. Hereby, the students know approximately where the operation point is located for certain resistances

Experiment 1.2: The I-V characteristic of a solar module depending on illuminance.

- The students measure and plot the I-V- and V-P-characteristic curves of a solar module.
- The students compare voltage, current and power output to the results of experiment 1.1 using the same resistance and ascertain a decrease of every value.

Experiment 1.3: The I-V-characteristic of a solar module depending on temperature

- The students measure and plot the I-V- and V-P-characteristic curves of a solar module.
- The students compare voltage, current and power output of the solar module to the measurement results of experiment 1.1 using the same resistance. They observe, that the maximum power decreased, however the power does not decrease for every resistance.

Experiment 1.4: The I-V-characteristic of the solar module with MPP-tracker

- The students measure and plot the I-V and V-P- curve by usage of an MPP-tracker
- The students compare voltage, current and power output of the solar module to the results of experiment 1.1 using the same resistance. They observe that the solar module with MPP-tracker releases a higher power for certain resistances.

Experiment 1.5: The functionality of the MPP-tracker

- The students measure the voltage and the current between the solar module and the MPP-tracker and the power at a consumer using different resistances.
- The students plot the power of the solar module and the consumer depending on the resistance in an R-P-diagram.
- The students observe, that the power output conforms with the maximum power when the resistance is lower than the MPP-resistance.
- The students observe that the energy conversion efficiency is higher, the lower the resistance.
- The students conclude that the MPP-tracker is a DC-DC-converter, which is only able to reduce the voltage.

Foreknowledge

- The students know, that a solar cell converts light energy into electric energy.
- The students know, that power is the product of voltage and current.
- The students can plot the I-V-characteristic curve of an ohmic resistance.
- The students know the function principle of a DC-DC-converter.

1.1 The I-V-characteristic of a solar module

2. Describe the behavior of the curves.

   The current between 0 V and 4.2 V is approximately constant at 180 mA. Up to 4.2 V the current decreases fast, so that it is zero at 5.3 V.
   The power is depending of the voltage. The highest power is achieved at a voltage of 4.2 V and amounts to 769 mW. The lowest power is reached at 0 V and 5.3 V and amounts to 0 mW. In the interval [0 V; 4.2 V] the power rises linearly and in the interval [4.2 V; 5.3 V] it decreases rapidly.

3. Draw the I-V-characteristic of a 10 Ω- and a 100 Ω-resistance into your diagram. Explain the meaning of the intersection points between the characteristic curves of the solar module and the resistances.

   At the intersection points you can read out the voltage and the current of the solar module depending on the resistance.

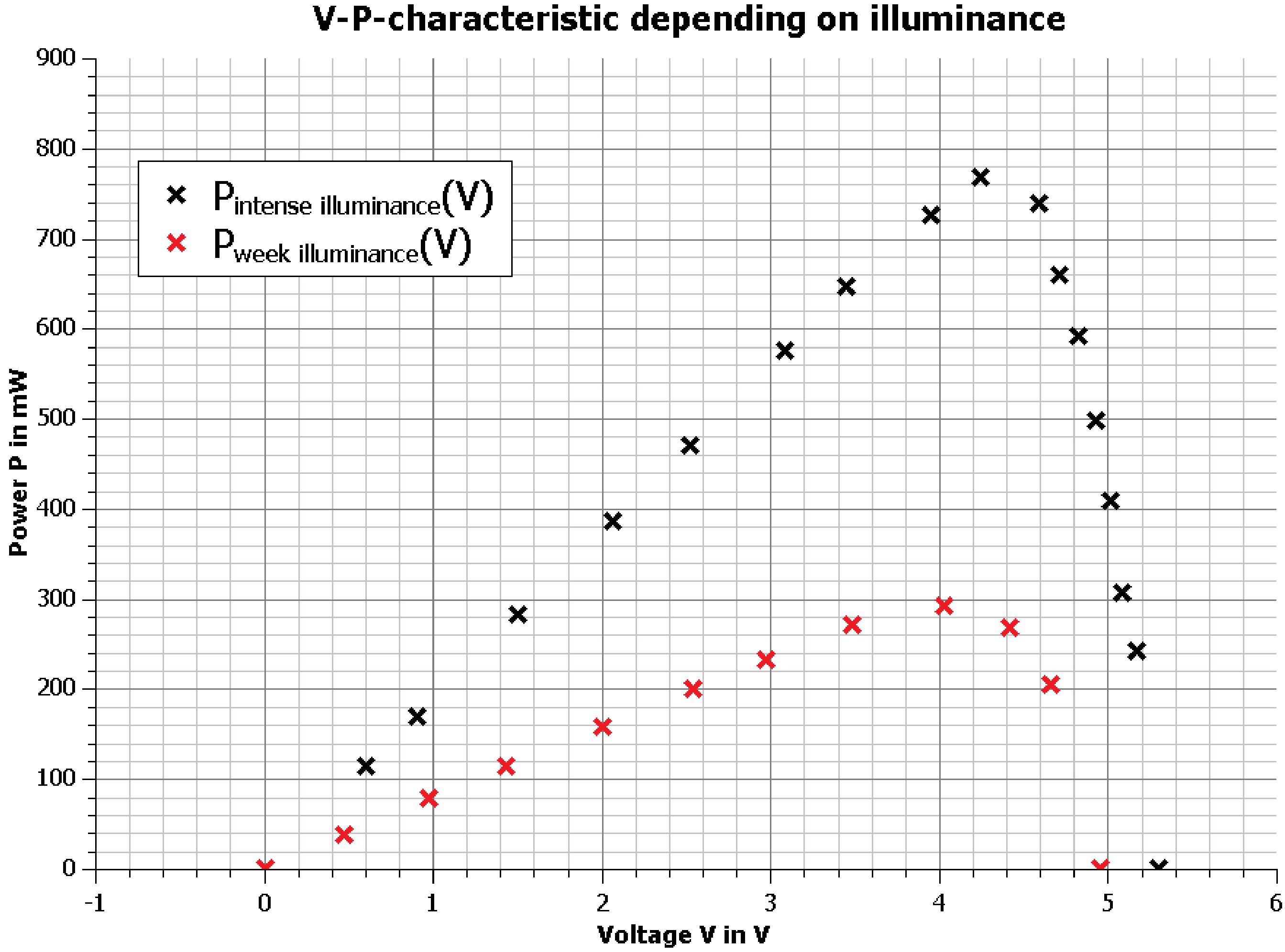
4. Evaluate the voltage and energy output of the solar module depending on the connection of a certain consumer.

   Depending on the resistance of the consumer, there will be a different voltage and power. Therefore, the solar module is neither a voltage source, which provides the same voltage for every consumer, nor a power source, which releases the same power to every consumer.

5. Calculate the resistance, which generates the highest power of the solar module.

   The Maximum Power Point (MPP) is achieved at a voltage of 4.2 V and a current of 182 mA. Therefore the resistance has to amount to: $R_{MPP} = \frac{V}{I} = \frac{4{,}2\ V}{0{,}182\ A} \approx 23\ \Omega$.

1.2 The I-V -characteristic of a solar module depending on the illuminance



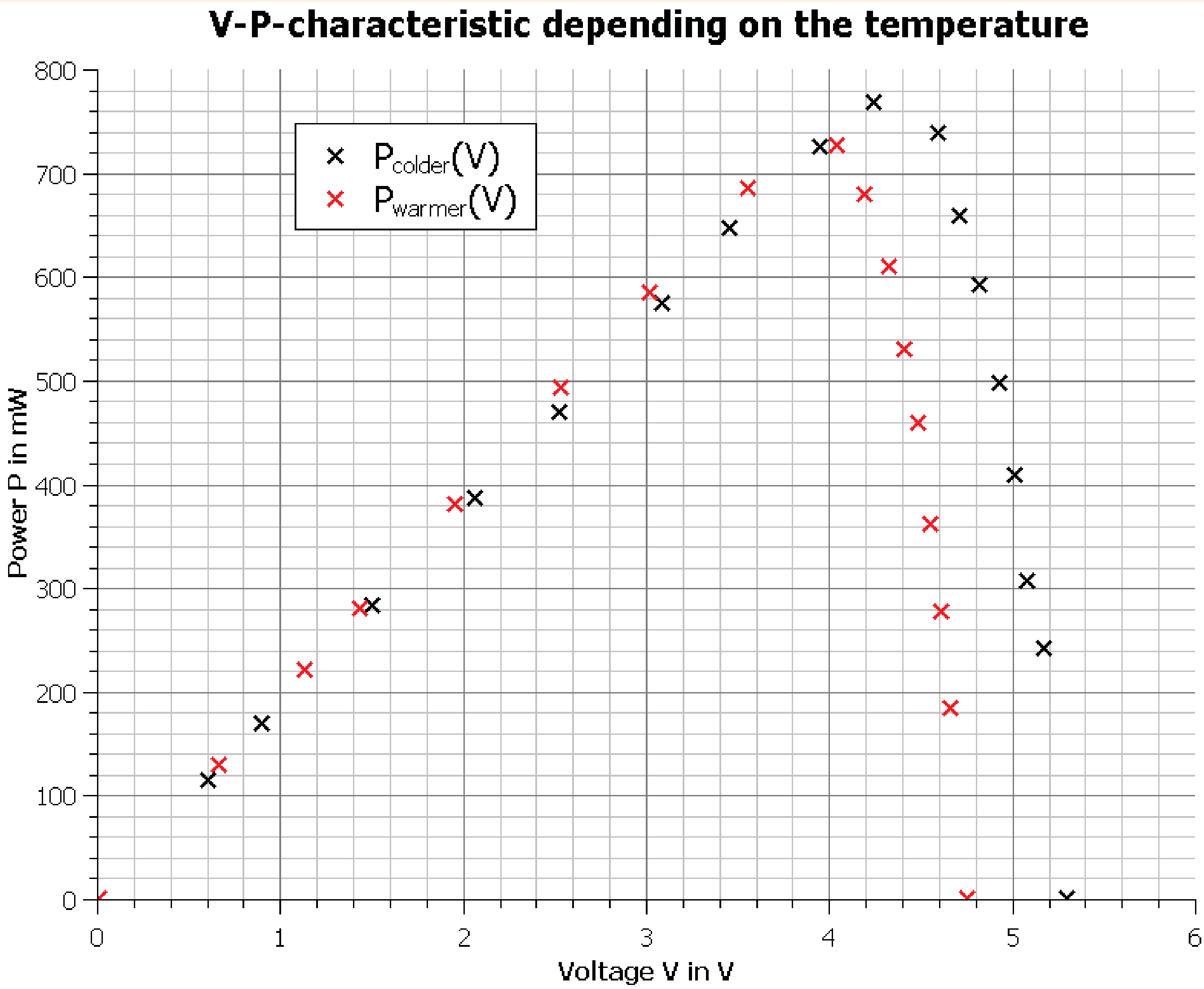
2. Compare the I-V- und V-P- curves with different illuminance.

   The qualitative behavior of both I-V-curves is nearly the identical. The characteristic curve with lower illuminance shows a smaller off-load voltage (V = 4.95 V). The current is nearly constant in the same voltage interval as before. The biggest difference is the lower current at the same voltage with a lower illuminance. It seems as if the curve is shifted along the y-axis.
   The qualitative behavior of the power is also similar the previous experiment. However, the power decreases to more than half at the same voltage. The MPP is still located at a voltage of 4.2 V.

3. Draw the characteristic curves of a 10 Ω and a 100 Ω resistance into the I-V-diagram. Explain the variance of voltage, current and power for the same resistance depending on the illuminance.

   For both resistors there is a higher applied voltage and a higher current for higher illuminances. Therefore, the power is also increasing with a more intense illuminance.

1.3 The I-V -characteristic of a solar module depending on the temperature



2. Compare the characteristic curves at different temperatures.

   The qualitative behavior of both I-V-characteristic curves is nearly the same. The maximum voltage will be lower when the temperature increases. The maximum current, however, increases, due to the warming more electrons are released within the semiconductor material.
   The qualitative behavior of both power curves is nearly identical, as well. Up to a voltage of 3.9 V the power is slightly higher for the higher temperature. After this the relation is reversed.

3. Add the I-V-characteristic curves of a 10 Ω- and 100 Ω- resistance into the I-V-diagram. Explain the influence of the temperature on the MPP and the power drain by using a constant resistance.

   The maximum power decreases when the temperature increases. Depending on the resistance the power will increase or decrease.

1.4 The I-V -characteristic of a solar module with MPP-tracker

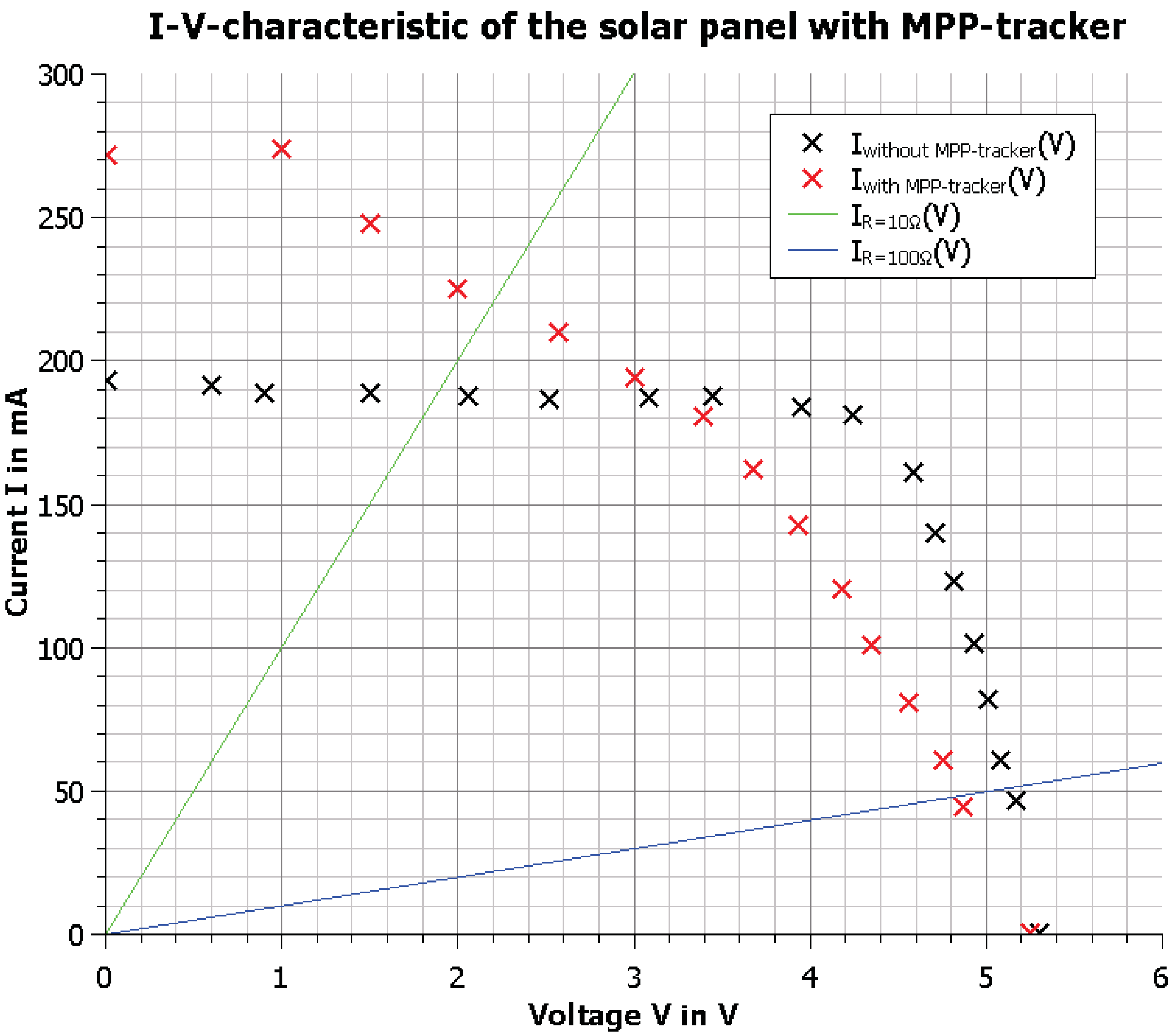
Measured values

V in V	5.25	4.87	4.75	4.56	4.35	4.18	3.93	3.68	
I in mA	0	44,6	60.6	81	101.1	120.2	142.5	162.3	
P in mW	0	217,2	287.9	369.4	439.8	502.4	560	597.3	

V in V	3.39	3	2.57	2	1.5	1	0		
I in mA	180.6	194	210.1	225.4	248	274	272		
P in mW	612.2	582	540	450.8	372	274	0		

Evaluation

1. Plot your measuring points in the I-V- and V-P-diagram and add the results from experiment 1.1 and draw the according curves.



1.5 The functionality of the MPP-tracker

2. Describe the voltage and power release of the solar module and the power at the consumer depending on different resistances.

   Voltage and power of the solar module are constant at V = 4.1 V and P = 790 mW up to a resistance of 15 Ω. This is the maximum power of the solar module under these conditions (see experiment 1.1). By starting from a resistance between 15 Ω and 20 Ω the voltage increases and the power decreases.
   The consumption of the potentiometer is the highest at a resistance of 20 Ω. The curve is monotonically increasing in the interval [0 Ω; 20 Ω] and monotonically decreasing in the interval [20 Ω; 100 Ω]. The lowest value amounts to 250 mW and is generated with a resistance of R = 0 Ω and R = 100 Ω.

3. Describe the power loss of the MPP-tracker.

   The power loss increases with a rising resistance. At R = 0 Ω it amounts to P = 550 mW. Up to R = 100 Ω it remains constant at P = 30 mW.

4. Conclude the scope of the MPP-tracker from your measured values. Note that the MPP-tracker is a DC-DC-converter. Involve the measured values of experiment 1.1 and 1.4, if necessary.

   For a certain voltage interval, the MPP-tracker ensures MPP-power release by the solar module.. In this interval the DC-DC-converter reduces the voltage. If the resistance is higher than the MPP-resistance, the MPP-tracker is no longer efficient. Obviously, the MPP-tracker can not raise the voltage. The released power is lower than without the MPP-tracker, because the MPP-tracker uses part of the energy generated by the solar module.

2.1 – 2.3 Basic experiments on wind power

Educational objective

Experiment 2.1: The dependence of the power on the pitch angle and the blade design

- The students measure voltage and current of a wind turbine with different pitch angles and blade designs.
- The students calculate the respective power values and plot the values in an angle-power-diagram for both blade designs.
- The students describe the power values and realize, that the maximum power is reached with an angle of 25° and the optimized profile.
- The students elucidate the reasons for the different power values.
- The students elucidate the importance of the pitch angle of wind turbines.

Experiment 2.2: The dependence of the power on the number of blades

- The students measure voltage and current of a wind turbine depending on the number of blades.
- The students calculate the power and plot the measured values in a wind speed-power-diagram depending on the number of blades.
- The students describe the relation between wind speed, power and number of blades and realize, that rotors with 3 blades achieve maximum power.
- The students elucidate the advantages of wind turbines with 3 blades.

Experiment 2.3: The dependence of the power on the wind direction

- The students measure voltage and current of a wind turbine depending on the wind direction.
- The students calculate the power and plot the measurement results in a wind direction-power-diagram.
- The students elucidate the necessity of a motor to control the alignment of the rotor.
- The students elucidate the advantages and disadvantages of upwind rotors.

Foreknowledge

- The student know, that the power is the product of voltage and current.
- The students know the essential setup of a wind turbine.
- The students know, that there is a motor to control the alignment of the rotor and blades as well as a breaking device inside the wind turbine.
- The students know the advantages and disadvantages of upwind rotors.

Experimental and reworking advices

- The summary of all experiments should emphasize that wind turbnines with 3 blades, an optimized profile and a pitch angle of 25° release the maximum power when the wind blows strongly and from the front. For that reason, this configuration is used in the smart grid experiments. In reality, this is not correct, because for example the pitch angle has to be adjusted to the wind speed in order to achieve an optimal power output.
- Experiment 2.1 can be used as an introduction of the streaming behavior of wind for different pitch angles and profiles.
- Additional theoretical facts and fundamental experiments on wind power can be found in the experimental handbook wind professional on the leXsolar-CD..