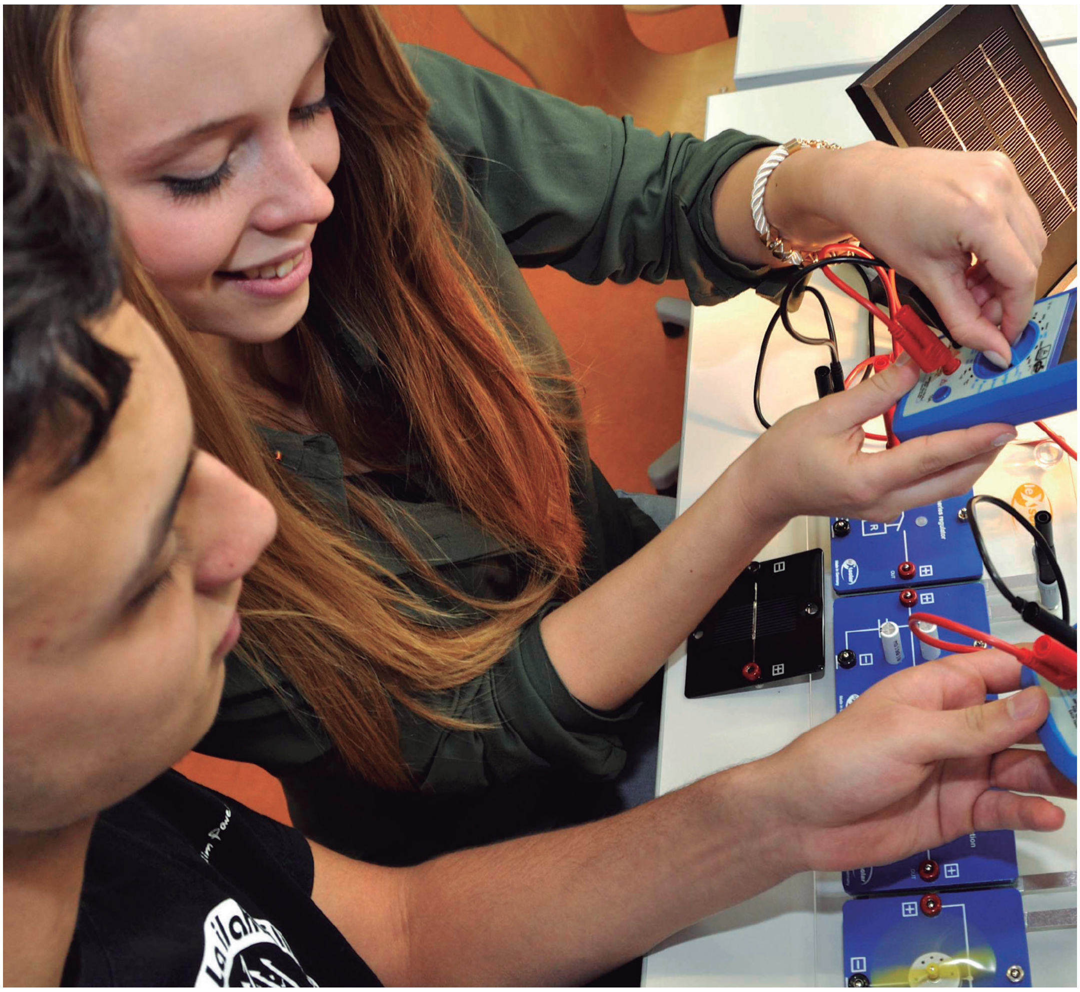
leXsolar-PV Professional



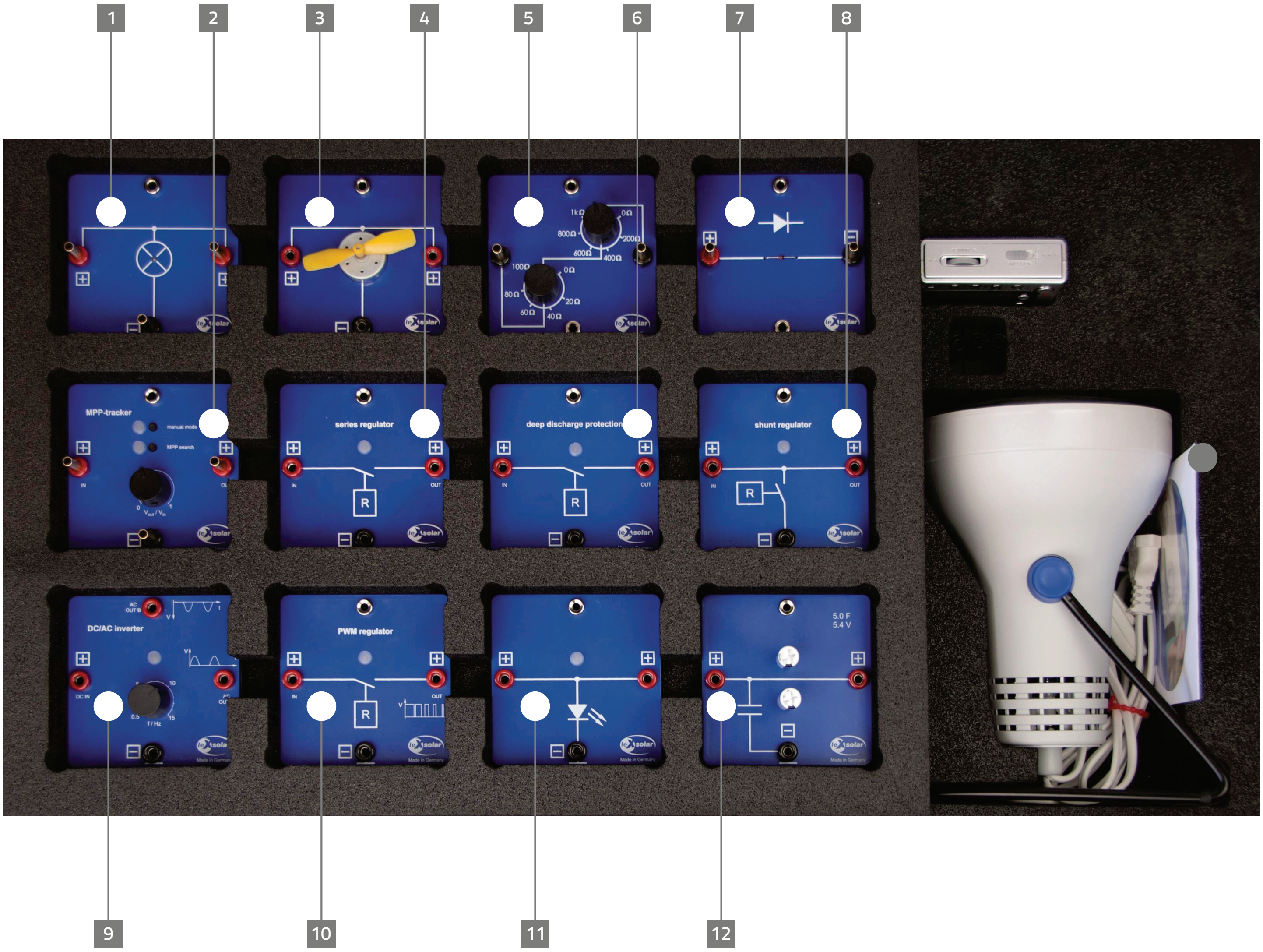
Experimental handbook

Layout diagram leXsolar-PV Professional

Item-No.1118

Bestückungsplan leXsolar-PV Professional

Art.-Nr.1118



1. 1118-01 Light bulb module Pro
   1118-01 Glühlampenmodul Pro
2. 1118-13 MPP-Tracker Pro
   1118-13 MPP-Tracker Pro
3. 1x 1118-02 Motor module Pro with L2-02-017 Propeller
   1118-02 Motormodul Pro mit L2-02-017 Propeller
4. 1118-10 Series regulator module Pro
   1118-10 Serienregler Pro
5. 1118-04 Potentiometer module Pro
   1118-04 Potentiometermodul Pro
6. 1118-07 Deep discharge protection module Pro
   1118-07 Tiefentladeschutzmodul Pro
7. 1118-05 Diode module Pro
   1118-05 Diodenmodul Pro
8. 1118-06 Shunt regulator module Pro
   1118-06 Shunt-Regler-Modul Pro
9. 1118-12 DC/AC-inverter module Pro
   1118-12 DC/AC-Inverter Pro
10. 1118-15 PWM regulator Pro
    1118-15 PWM-Laderegler Pro
11. 1118-08 LED module high brightness Pro
    1118-08 LED-Modul superhell Pro
12. 1118-11 Capacitor module Pro
    1118-11 Kondensatormodul Pro

Version number
Versionsnummer

L3-03-181_07.06.2017

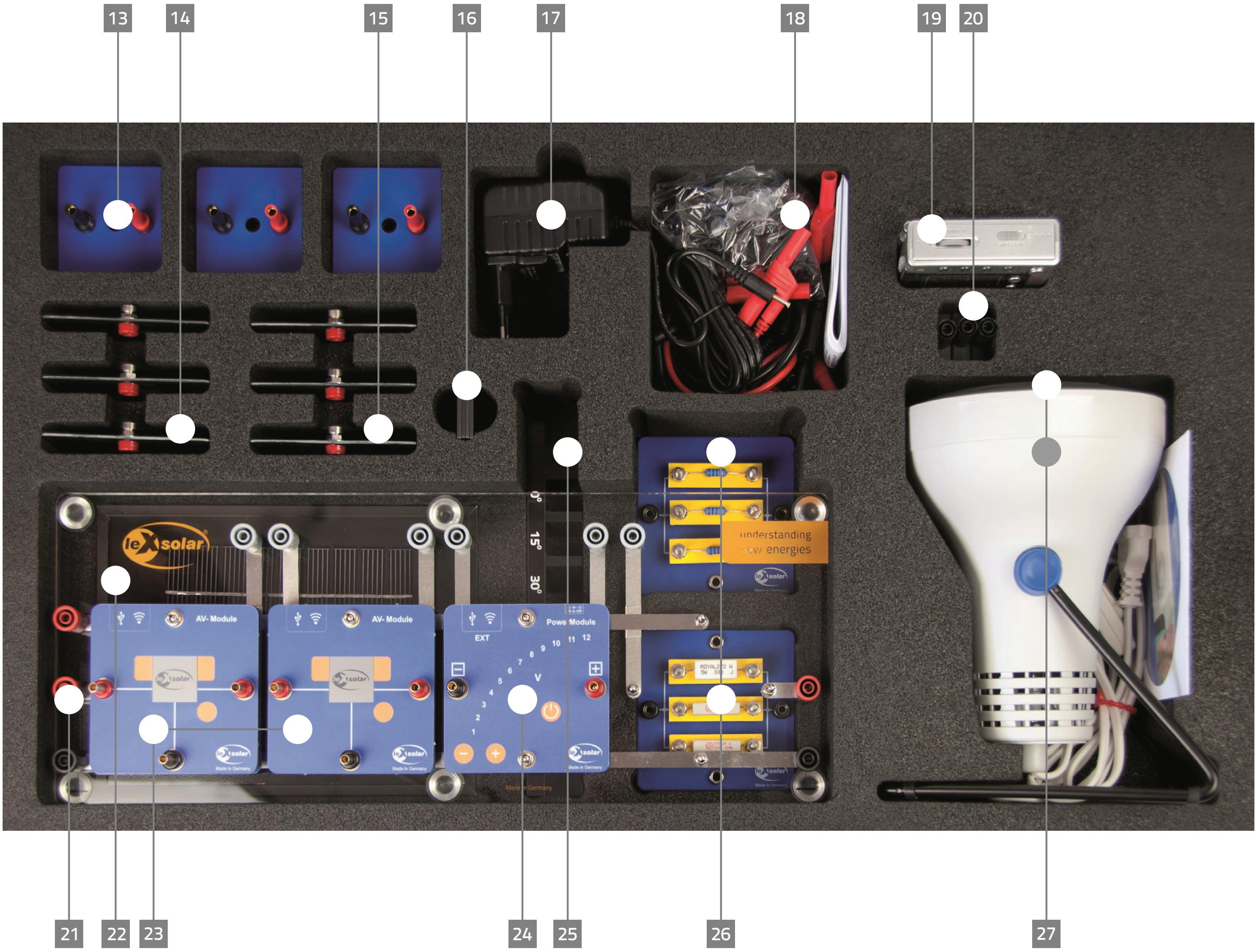
CE RoHS2

Layout diagram leXsolar-PV Professional

Item-No.1118

Bestückungsplan leXsolar-PV Professional

Art.-Nr.1118



13	3x 1100-20 Lighting module with 3xL2-05-035/036 Safety sockets 3x 1100-20 Beleuchtungsmodul Pro mit 3xL2-05-035/036 Sicherheitsbuchsen
14	3x 1100-02 Solar module 0,5 V, 840 mA 3x 1100-02 Solarmodul 0,5 V, 840 mA
15	3x 1100-01 Solar module 0,5 V, 420 mA 3x 1100-01 Solarmodul 0,5 V, 420 mA
16	1100-29 Solar cell cover set 1100-29 Satz Abdeckung f. Solarzelle
17	Power supply for 25 Stromversorgung für PowerModule für 25
18	4xL2-04-066/3xL2-04-067 Test lead red/black 25 cm 2xL2-04-059/1xL2-04-060 Test lead red/black 50 cm 4xL2-04-066/3xL2-04-067 Messleitung rot/schw. 25 cm 2xL2-04-059/1xL2-04-060 Messleitung rot/schw. 50 cm
19	1118-16 Radio module Pro 1118-16 Radiomodul Pro
20	3xL2-05-068 Safety short-circuit plug 3xL2-05-068 Sicherheits-Kurzschlussstecker
21	1400-13 leXsolar-base unit Professional 1400-13 leXsolar Grundeinheit Groß
22	1100-04 Solar module 5.22 V, 380 mA 1100-04 Solarmodul 5.22 V, 380 mA
23	2x9100-03 AV-Modul 2x9100-03 AV-Modul
24	9100-05 PowerModul 9100-05 PowerModul
25	1118-17 Base for solar panel 1118-17 Standfuß Solarmodul
26	2x 1800-01 Resistor module (triple) Pro with 3x 1800-04 Resistor plug element 100 Ohm 2x 1800-05 Resistor plug element 10 Ohm 1x 1800-06 Resistor plug element 33 Ohm 2x 1800-01 Widerstandsmodul 3-fach Pro mit 3x 1800-04 Widerstands-Steckelement 100 Ohm 2x 1800-05 Widerstands-Steckelement 10 Ohm 1x 1800-06 Widerstands-Steckelement 33 Ohm
27	L2-04-080 Lamp housing with L2-04-093 Illuminant 80W L2-04-080 Lampengehäuse mit L2-04-093 Leuchtmittel 80W

CE RoHS2

leXsolar-PV Professional

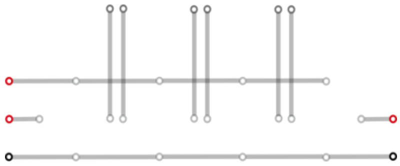
Experiment handbook

1. General Information

1.1 Components

The following part contains information about the components of the experimental system. There is sketched a photograph and a small pictogram how the modules are displayed in the experimental setup. Furthermore you get information about the handling of the components.

Base unit



Solar module, small

Specifications:

V=0.5 V

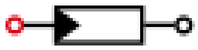
I=420 mA

Solar module, large

Specifications:

V=0.5 V

I=840 mA



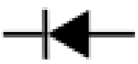
Solar module, extra large

Specifications:

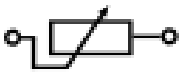
V=5 V

I=420 mA

Diode module



Potentiometer module

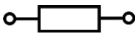


Radio module

Resistor plug module (triple) with resistor plug elements

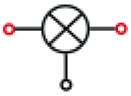
The following resistor plug elements are included:

2 x R=10Ω
1 x R=33Ω
3 x R=100Ω



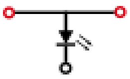
Light bulb module

The light bulb module starts lighting at a voltage of about 0.5V. However, the light bulb is more glowing, than lighting very bright. For an optimum visibility the light bulb should be shaded from other light sources.



LED module

The LED module corresponds to a LED lamp in a real solar off-grid system. For efficiency reasons nearly exclusively LEDs are used in such systems.

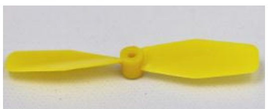


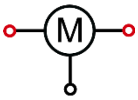
Motor module

Starting current I=20mA

Starting voltage V= 0.4V

Running voltage V=0.4V…12V





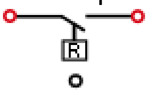
Capacitor module

Specifications:

Double module:	Single module:
V=5.4 V	Internal resistance R < 34mΩ
C=5.0F	Max. current I=10A

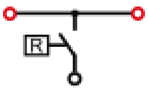
Deep discharge protection

A deep discharge protection is a device that protects an accumulator from dropping below the minimum charging voltage. Deep discharge is harmful for many types of accumulators; especially for lead accumulators, that are often used in off-grid systems; and leads to a drastic increase of their lifetime. In real systems the deep discharge protection is integrated in the charge control, but in this experimental system both devices are divided due to didactic reasons. The leXsolar deep discharge protection is a so called two-level controller that disconnects the consumer from the accumulator when the loading voltage is dropping below 2.8V. Only when the accumulator is charged again up to 3.16V, the consumer is switched on. The control LED is lighting, as long as the consumer is switched on.



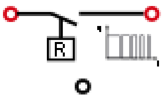
Shunt-regulator

The shunt-regulator is a charge controller that short circuits the input voltage when reaching the charge end voltage to protect the accumulator from overload. It is a two-level controller with an upper switching threshold of 4.2V and a lower switching threshold of 3.6V. The working principle of the control LED is identical to the series regulator. Before starting the experiment, the capacitor should be loaded up to 2V to ensure the correct operation of the control LED.



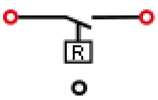
PWM-regulator

So called pulse width modulators do not load the accumulators continuously but with pulses of fixed frequency and different length. The ratio of pulse duration and pulse period – the so called duty cycle – determines how fast the accumulator is loaded. With this process one can ensure that the accumulator is kept on its maximum capacity as long as no consumer is connected. The advantage over the two-level regulators is that the loading voltage is not dropping to the lower switching threshold. The leXsolar PWM-regulator has two operating modes: Until a loading voltage of 3.7V the PWM regulator fully interconnects the input voltage. Accordingly it begins to pulse and reduces the duty voltage until a constant loading voltage of 4.1V is adjusted. The control LED is lighting as long as the PWM-regulator is loading.



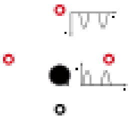
Series regulator

The leXsolar series regulator is a two-level regulator that disconnects the accumulator from the solar module when the charging voltage of 4.1V is reached. When discharging the accumulator the series regulator interconnects the input voltage of the solar module not before dropping below the lower threshold of 3.5V. The control LED is lighting as long as the series regulator is loading.



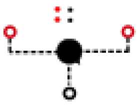
DC/AC inverter module

DC/AC inverters are used to convert the DC voltage of the solar module into an AC voltage to either feed the electricity into the grid or to operate customary domestic appliances in a smart-grid system. The leXsolar DC/AC inverter module does not produce mains voltage but an AC voltage with an amplitude of 2.5V and a variable frequency that can be adjusted with the potentiometer between 0.5 and 15 Hz. To reduce the power dissipation the process of inverting the voltage has been kept on a simple level. Therefore the output voltage is sinusoidal only in a first approximation.



MPP - Tracker

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

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.

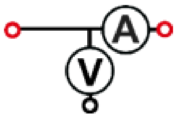
Specifications:

- 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)

AV-Module

The AV-Module is a combined voltage and current meter. It holds 3 buttons, whose features are described in the display respectively. By pushing a random button the module will switch on. In the disabled state the display shows the leXsolar emblem. When the display does not show anything or the word „Bat“ is shown, it is necessary to change the batteries in the back (2 x AA batteries 1.2 to 1.5V; Take care of the polarity marked on the bottom of the battery case! Do not touch the button while inserting the batteries).



With the top right button the measuring mode can be switched between voltage mode, current mode or combined voltage-current mode. Both measurement mode and required cable connection will be indicated by the circuit symbols on the display. Take care that in voltage mode no current is applied to the right jack. In the combined mode the voltage can be measured with the right jack as well as with the left one. The influence of the internal resistance of the current measurement is compensated internally. The measured values are signed. When the positive pole is connected to a red jack and the negative pole is connected to the black jack, the value of the voltage will be positive. When current is applied from the left to the right, the current value will be positive, as well. The other way around, the algebraic sign changes.

After 30 min without pushing a button or after 10 min of measuring a constant value, the module will switch off automatically. It can measure voltages up to 12 V and currents up to 2 A. In case of exceeding one of the values, the module interrupts the current flow and shows “overcurrent“ or “overvoltage”. This error message can be confirmed by touching a button. The module will resumes measuring, when the values attain acceptable values.

Specifications:

Voltage metering:
- range: 0...12 V
- accuracy: 1 mV
- automatic shutoff in case of overvoltage >12 V

Current metering:
- range: 0...2 A
- accuracy: 0.1 mA (0...199 mA) und 1mA (200 mA...1 A)
- automatic shutoff in case of overcurrent >2 A
- internal resistance <0.5 Ohm (0...200 mA); <0.2 Ohm (200 mA...2 A)

1

1.2 Handling and safety

Solar module with stand

The solar module is adjusted against the lamp and stabilized with the stand. The minimum distance between the lamp and the solar module should be **25cm**.

The angle of incidence can be varied by means of the stand. The following angles can be adjusted (printed on the stand):

0°,15°,30°,45° und 55°.

The short circuit current of the solar module can be adjusted by the variation of the angle or the distance between lamp and solar module.

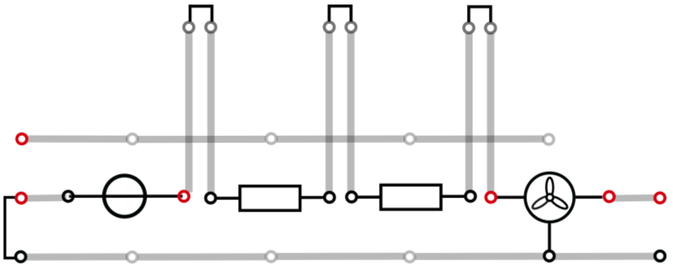
The lamp may become very hot during operation! After using it, the lamp should cool down and not be put back into the case before it is cold enough. Otherwise the foam insert could be damaged.

B.1 Setup of a simple circuit

Task

Set up a simple electrical circuit.

Setup



Required devices

- base unit
- 1 PowerModule (V=5V)
- 1 resistor module, triple
- 2 resistor plug elements (R=100Ω)
- 1 motor module

Execution

1. Set up the experiment according to the circuit diagram. Plug in every resistor module one resistor.
2. Open and close the electrical circuit by:
   a) Plug in/plug off a cable.
   b) Plug in/plug off a current bridge.
   c) Plug in/plug off a resistor
3. Note your observations.

Observation

The motor stops turning when the electrical circuit is interrupted. It is not an issue in which way the circuit is broken.

Evaluation

1. Formulate reasons for the behaviour of the motor.

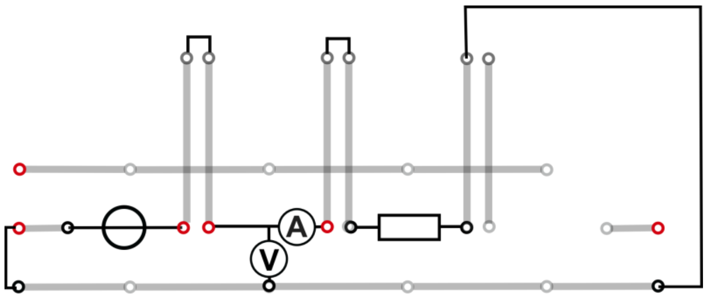
The motor needs a certain voltage and current to turn. When the circuit is interrupted no current is flowing and therefore the motor stops turning.

B.2 Ohm`s law

Task

Investigate Ohm`s law with several resistors.

Setup



Required devices

- base unit
- 1 PowerModule
- 1 resistor module, triple
- 3 resistor plug elements (R=100Ω, R=33Ω, R=10Ω)
- 1 AV-Module

Execution

1. Set up the experiment according to the circuit diagram.
2. Measure voltage and current for various resistances:
   - R=100Ω
   - R=33Ω
   - R=10Ω
3. Note your measured data in the table and calculate each the ratio V/I.

Measurement

R (Ω)	100	33	10
V (V)	5.0	5.0	5.0
I (mA)	50	140	480
V/I (Ω)	100.0	35.7	10.4

Evaluation

1. Deduce a connection between resistance R and ratio V/I. Which lawfulness can be derived?

The resistance R is matching the ratio V/I. Therefore the equation of Ohm`s law can be deduced:

R=V/I

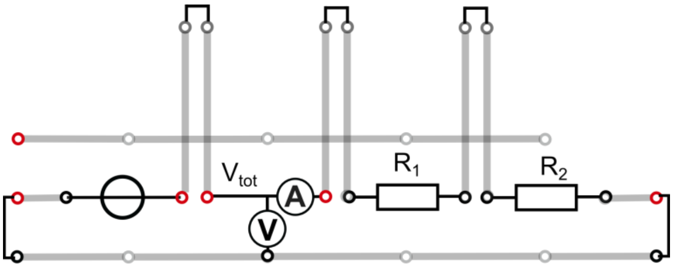
B.3 Series connection of ohmic resistances

Task

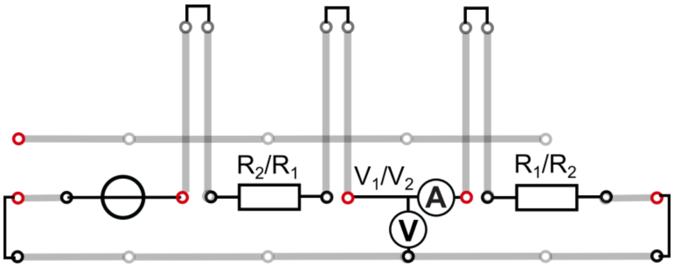
Examine the series connection of ohmic resistances.

Setup

Setup to measure the total voltage



Setup to measure the single voltage



Required devices

- base unit
- 1 PowerModule
- 1 resistor module, triple
- 4 resistor plug elements (2x R=100Ω, 2x R=10Ω)
- 1 AV-Module

Execution

1. Start with a series connection of 2x100Ω. Measure each voltage and current over both resistances (V_{tot} and the single voltage (V_1, V_2) for the following circuits:
   - R_1=100Ω / R_2=100Ω
   - R_1=100Ω / R_2=10Ω
   - R_1=10Ω / R_2=10Ω

   Set up the experiment according to the voltage measurement. To measure the single voltage over each module, it is necessary to change the position of the resistor modules intermediate.

3. Note your measured data in the table.

Measurement

	R_1=100Ω / R_2=100Ω	R_1=100Ω / R_2=10Ω	R_1=10Ω / R_2=10Ω
V_1 (V)	2.5	4.54	2.5
V_2 (V)	2.5	0.46	2.5
V_{tot} (V)	5.0	5.0	5.0
I (mA)	24.3	42.7	180.1
R_{tot}=V_{tot}I (Ω)	205.8	117.1	27.7

B.3 Series connection of ohmic resistances

Evaluation

1. Calculate each the ratio $R_{tot}=V_{tot}/I$ and note your values in the table above.
2. Calculate each the sum of the single voltages ($V_1 + V_2$) and compare it the voltage over both resistances (V_{tot}).
3. What is the influence of the resistance on the current I and the voltages $V_1 + V_{2\text{ and }}V_{tot}$?
4. What is the connection between the total resistance R_{tot} and the single resistances?
5. Formulate a law for the calculation of the total resistance in a series connection of resistances.

2.

	$V_1 + V_2$	V_{tot}
R_1=100Ω / R_2=100Ω:	5.0	5.0
R_1=100Ω / R_2=10Ω:	5.0	5.0
R_1=100Ω / R_2=10Ω:	5.0	5.0

→ $V_{tot}= V_1+V_2$

3.

The higher the resistance, the lower the current.

The higher the sum of the resistances, the lower the current

If both resistances are equal, the voltage over the resistances is also equal.

If one resistance is higher, a higher voltage can be measured at the higher resistance.

The total voltage remains constant.

4. + 5.

The total resistance is nearly matching the sum of the single resistances.

Therefore the equation for the total resistance in a series connection can be written as:

$R_{tot}= R_1+ R_2+\ldots+R_n$ (n…number of resistances)

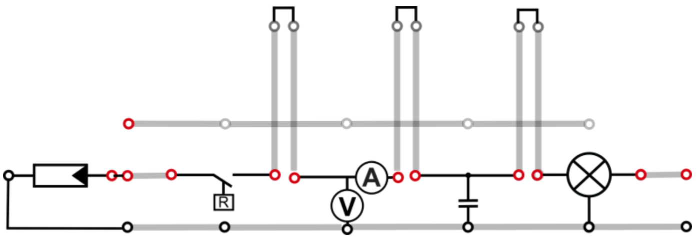
10. Mode of operation of the deep discharge protection module

Task

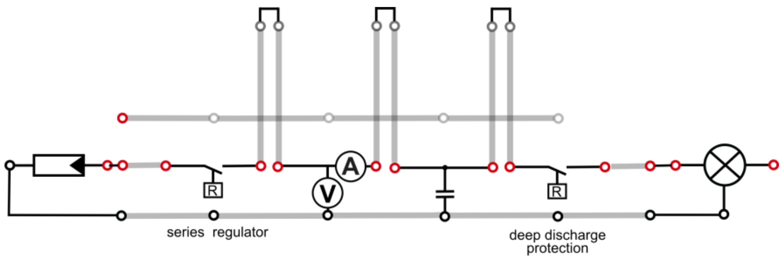
Investigate systems with and without deep discharge protector, and conclude what the mode of operation of the product is from it!

Setup

without deep discharge protection module:



with deep discharge protection module:



Required devices

- base unit
- 1 filament bulb module
- 1 solar module
- 1 halogen lamp
- 1 deep discharge protection module
- 1 AV-Module
- 1 stopwatch
- 1 capacitor module
- 1 charge regulator

Execution

1. First interconnect the capacitor (voltage at capacitor approximately 3 V) with the bulb (see setup without deep discharge protector) and illuminate the solar module.
2. Measure the voltage every 10 seconds and enter the measurements in the table.
3. Repeat the measurement ($V_{capacitor}$ = 3 V) now with deep discharge protector (see setup with deep discharge protector). Measure the voltage here every 10 seconds too and enter the values in the table. Illuminate the solar module again!

10. Mode of operation of the deep discharge protection module

Evaluation

1. Plot the U-t curve for the system with and without deep discharge protector on a chart (use different colours)!
2. Determine the switching thresholds of the deep discharge protector from the second characteristic!
3. Describe the mode of operation and role/task of the deep discharge protector!

Measured values

a) without deep discharge protector

t [s]	0	10	20	30	40	50	60	70	80	90	100	110	120
V [V]	3.01	2.99	2.96	2.94	2.92	2.90	2.88	2.86	2.84	2.82	2.80	2.78	2.76

t [s]	130	140	150	160	170	180	190	200	210	220	230	240	250	260
V [V]	2.74	2.73	2.71	2.70	2.68	2.66	2.65	2.63	2.62	2.61	2.59	2.58	2.57	2.55

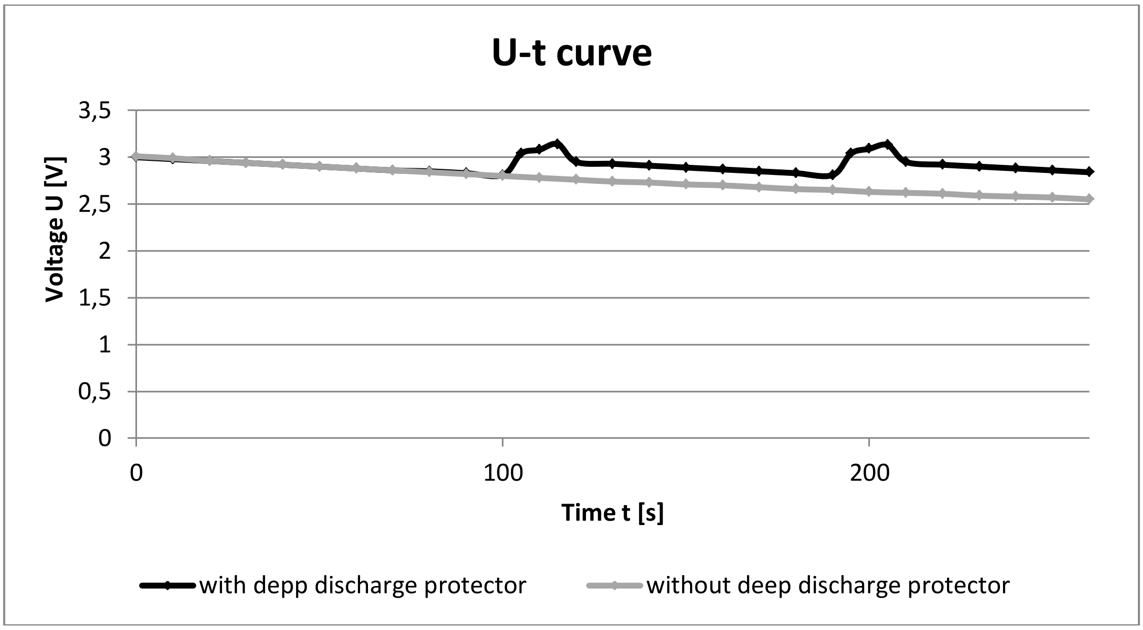
b) with deep discharge protector

t [s]	0	10	20	30	40	50	60	70	80	90	100	110	120
V [V]	3.00	2.97	2.95	2.93	2.91	2.89	2.87	2.86	2.84	2.82	3.04	3.13	2.93

t [s]	130	140	150	160	170	180	190	200	210	220	230	240	250	260
V [V]	2.91	2.89	2.87	2.85	2.82	3.04	3.13	2.92	2.88	2.84	2.82	3.03	3.14	2.95

10. Mode of operation of the deep discharge protection module

Diagram



Evaluation

The recorded characteristic curve without deep discharge protector corresponds to the conventional discharge characteristics of the capacitor. Through the additional solar module current the discharge cycle is slowed down.

The lower switching threshold of the deep discharge is 2,81V, the upper threshold is 3,16V.

Mode of operation and role of the deep discharge protector:

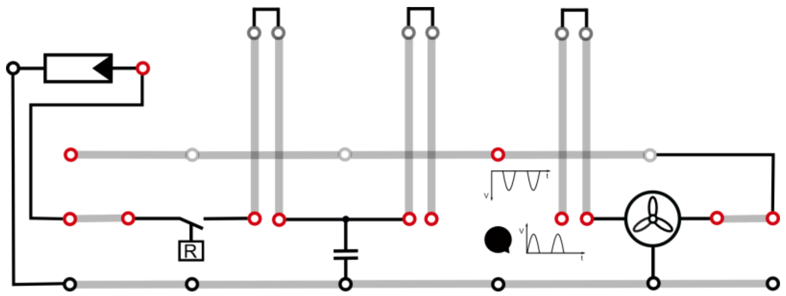
The deep discharge protector protects the battery against harmful deep discharge by switching off the consumer load when it has reached its lower voltage limit. The restart occurs automatically when the upper threshold of the deep discharge is exceeded.

11.1 Working principle of a DC/AC inverter module

Task

Determine the working principle of a DC/AC inverter.

Setup



Required devices

- base unit
- 1 solar module
- 1 halogen lamp
- 1 series regulator
- 1 capacitor module
- 1 DC/AC inverter module
- 1 LED module
- 1 lamp module
- 1 motor module

Execution

1. Set up the experiment as shown in the circuit diagram, initially without the DC/AC inverter. Charge the capacitor completely until the charging control LED of the series regulator turns off.
2. Now plug in the DC/AC inverter module and connect the motor module to both outputs of the DC/AC inverter module.
3. Adjust the frequency initially to the minimum (0.5Hz). Observe the behaviour of the motor module.
4. Now slowly increase the frequency, what do you observe?
5. Apply the lamp module and the LED module instead of the motor module. Compare the behaviour of both modules.

Evaluation

1. Describe the behaviour of the motor module and name reasons for this!

The ventilator rotated with the adjusted frequency alternating to the left and to the right, because the applied motor is a DC motor that follows a change in polarity with a change of the direction of rotation. By increasing the frequency the rotation is turning into a trembling movement because of inertia effects.

2. What is the difference between the lamp module and the LED module?

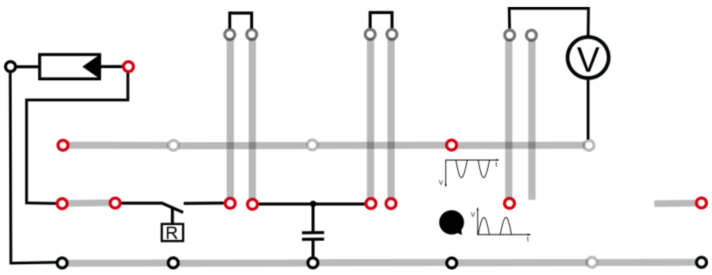
The flash frequency of the light bulb is twice the frequency of the LED. The LED only lights at the half-cycle of the alternating direction, which corresponds to the forward biased condition.

11.2 Determination of the output voltage course at the DC/AC inverter

Task

Determine the voltage course at the output of the DC/AC inverter module.

Setup



Required devices

- base unit
- 1 solar module
- 1 halogen lamp
- 1 capacitor module
- 1 DC/AC inverter module
- 1 shunt regulator
- (potentiometer module)
- data logging system and PC

Execution

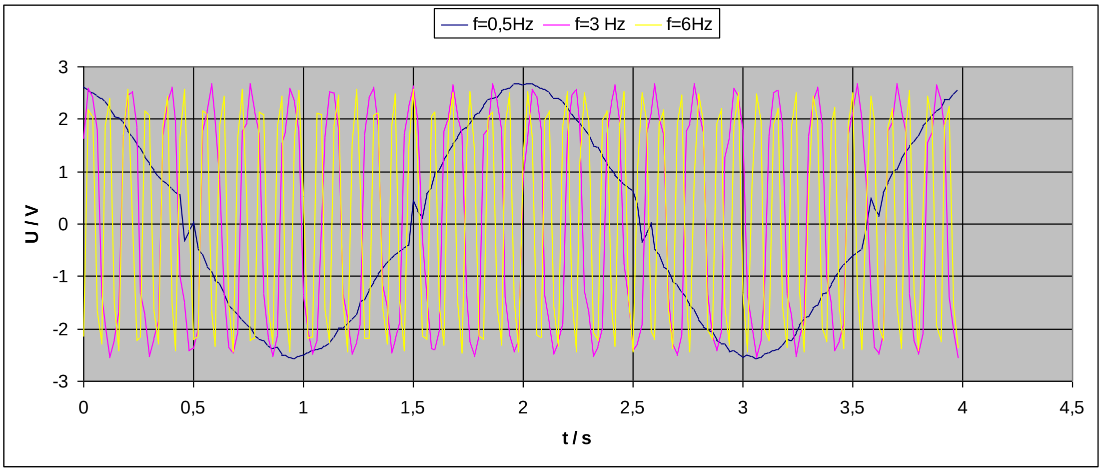
1. Set up the experiment as shown in the circuit diagram, initially without the DC/AC inverter. Charge the capacitor completely until the charging control LED of the shunt-regulator turns off.
2. Now plug in the DC/AC inverter module and connect the voltage sensor of the data logging system to both outputs of the DC/AC inverter module.
3. Start the data logging and consider the course of voltage. Adjust slowly the frequency of the DC/AC inverter module and observe the course.
4. Record the course of voltage respectively for three frequencies for 10 seconds. (Interval: 50 samples per second)

Addition:

Connect the potentiometer module in series to a current sensor with both outputs of the DC/AC inverter module. Adjust the 1kΩ–potentiometer to the minimum and the 100Ω-potentiometer to the maximum. Record voltage and current with the data logging system.

Evaluation

1. Mark the three measurements at different frequencies in a diagram and calculate the frequencies.



12. Curriculum: Fundamentals and Applications of Photovoltaic Technology - One Semester Lab course

12.1 Introduction

This curriculum defines how to teach fundamentals and applications of photovoltaic technology at universities for beginners. Following this teaching course ensures that students gain expertise about photovoltaics and its common applications from scratch. The curriculum is meant to be used as an accompanying lab course for photovoltaic lectures using leXsolar-PV Professional. This means tutors have to elaborate lectures which satisfy their desired intensity. The topics of the experimental sections and units can of course be taken as a reference for the content and a reasonable order. Prospective tutors should attend the leXsolar-Academy modules for photovoltaics as teach-the-teacher courses to gain all needed expertise in a comprehensive and effective way.

Structure:

The course is divided in four sections which consist of a various number of units. The approach of the structure is to group the content and experiments in clusters beginning from a small perspective on single solar cells and ending at a broad view of complete power supply systems. This is not only a good choice because it follows the intrinsic structure of the topic, but also because this procedure fulfills the method of learning helixes. This assures a consolidation of the learned content. E.g. analyzing the IV-characteristics of solar modules reactivates the knowledge about the characteristics of single cells.
Each unit includes one or more experiments and is designed for a duration of 90 minutes. The actual needed time varies lightly in order to the experimental skills of the students and the actual unit.
The objectives and topics of each section and unit are listed on the following pages.

Duration:

4 Sections, 15 units, 22.5 hours total

Strategic objectives:

The Students …

- gather knowledge about the characteristics and performance of solar cells at different conditions.
- are able to plan and build up optimized solar modules from given cells and can estimate their response to various conditions.
- gain exemplary insight of possible applications for photovoltaic with off-grid systems.
- know different peripheral parts and their characteristic for a technically mature use of photovoltaic.

Flow chart:

Fundamental Basics [optional]

- 1.5 hours
- topics: electrical Basics
- objectives: describing and reasoning the behavior of basic electrical circuits; calculate and measure systems of resistors

Basic Solar Cell Properties

- 7.5 hours
- topics: solar cells and environmental conditions; characteristics of solar cells
- objectives: determining basic properties of solar cells; analyzing electrical characteristics of solar cells; measuring and describing the influence of environmental conditions on solar cell parameters

Solar Cells in use

- 6 hours
- topics: connecting solar cells to modules; solar cells as supply
- objectives: building up solar modules; dimensioning and tuning reasonable parts of solar cell modules

Off-Grid systems: Parts and Properties

- 7.5 hours
- topics: Off-grid systems; charge regulators; electrical storage, deep discharge regulators, DC/DC and DC/AC inverter
- objectives: problems and tasks at the designing of photovoltaic power supply systems; different peripheral parts of off-grid systems; reasonable choosing from different standard solutions when building up a system

12.2 Section 0: Fundamental basics [Optional]

Overview

This section ensures that the students possess some minimal basic knowledge about electrical circuits and values. Depending on the previous knowledge of the students, this section can be taken as optional. But it is anyway a good exercise to get used to the leXsolar-experimental system and materials.

Previous knowledge:

- Voltage: value, unit and measurement
- Current: value, unit and measurement

Tactical objectives:

The Students

- can handle the leXsolar-experimental System
- can describe and reason the behavior of basic electrical circuits
- can calculate and measure systems of resistors

Topic:

Ohm’s law, basic electric circuits, electric motors (inrush current, cutoff current)

Duration:

1 unit; 1.5 hours

Units:

1. Fundamental electrical basics
   G.1 Setup of a simple circuit
   G.2 Ohm‘s law
   G.3 Series connection of ohmic resistances
   G.4 Parallel connection of ohmic resistances
   G.5 Start-up and idling behavior of a motor

12.2.1 Unit 1 Fundamental electric basics

G.1 Setup of a simple circuit
G.2 Ohm's law
G.3 Series connection of ohmic resistances
G.4 Parallel connection of ohmic resistances
G.5 Start-up and idling behavior of a motor

Duration: 90'

Previous knowledge:

- Voltage: value, unit and measurement
- Current: value, unit and measurement

Operational objectives:

The Students
- can handle the leXsolar-experimental system.
- measure resistors.
- measure and calculate serial resistors.
- measure and calculate parallel resistors.
- can describe and reason the behavior of basic electrical circuits
- can explain the difference between inrush current and cutoff current.

12.3 Section 1: Basic solar cell properties

Overview

This section has the goal to research the basic properties of inorganic solar cells. The students get to know solar cells from a practical view. As one key aspect, the influence of environmental conditions will be determined by short targeted experiments. Therefor the focus is set to the most significant environmental values for the practical use of photovoltaic, such as temperature, intensity of the incoming light and the angle of incident. A second part gives the students an understanding of the electrical properties of solar cells e.g. the IV-curve and belonging parameters. At the end both aspects are researched in combination.
These are elementary topics for a solid knowledge of solar cells and crucial for an ongoing research of a more application-oriented use of solar cells.

Previous knowledge:

- Voltage: value, unit and measurement
- Current: value, unit and measurement
- Power: value, unit and measurement

Tactical objectives:

The Students
- determine the basic properties of solar cells.
- analyze the electrical characteristics of solar cells.
- can measure and describe the influence of environmental conditions on solar cell parameters.

Topic:

The influence of environmental conditions on solar cells and solar cell characteristics

Duration:

5 units; 7.5 hours

Units:

1. Geometrical aspects
   3.3 Dependence of the power of the solar cell on its area
   3.4 Dependence of the solar cell power on the angle of incident of the light
2. Environmental conditions
   3.5 Dependence of the solar cell power on the illumination intensity
   3.9 Dependence of the power of the solar cell on the temperature
3. Solar cell characterization
   4.1 I-V-characteristics under dark conditions
   4.2 I-V-characteristics, MPP and filling factor of the solar cell
4. Influence of environmental conditions on solar cell characteristics I
   4.3 Dependence of the I-V-characteristics on the illumination intensity
5. Influence of environmental conditions on solar cell characteristics II
   4.4 Dependence of the I-V-characteristics of the solar cell on the temperature

Flow chart:

1 Geometrical aspects

- relationship between the area of a solar cell and its power
- relationship between the angle of incident and the solar cell power

↓

2 Environmental conditions

- relationship between light intensity and the solar cell power
- influence of temperature on solar cell performance

↓

3 Solar cell characterization

- IV-characteristics
- dark and illuminated solar cells

↓

4 Influence of environmental conditions on solar cell characteristics I

- Dependence of the I-V-characteristics on the illumination intensity

↓

5 Influence of environmental conditions on solar cell characteristics II

- Dependence of the I-V-characteristics of the solar cell on the temperature

12.3.1 Unit 1 Geometrical aspects

3.3 Dependence of the power of the solar cell on its area
3.4 Dependence of the solar cell power on the angle of incident of the light

Duration: 90'

Previous knowledge:

- Voltage: value, unit and measurement
- Current: value, unit and measurement
- Power: value, unit and measurement

Operational objectives:

The Students
- can explain the relationship between the area of a solar cell and its power.
- transfer their knowledge of the relationship between solar cell area and power to interpret the relationship between the angle of incident and the power.
- can explain the relationship between the angle of incident and the solar cell power.

Content information:

The content of this unit are the geometrical aspects of solar cells and the solar cell orientation.

12.3.2 Unit 2 Environmental conditions

3.5 Dependence of the solar cell power on the illumination intensity
3.9 Dependence of the power of the solar cell on the temperature

Duration: 90'

Previous knowledge:

- Voltage: value, unit and measurement
- Current: value, unit and measurement
- Power: value, unit and measurement

Operational objectives:

The Students

- can explain the relationship between light intensity and the solar cell power.
- identify the V_{OC} as nearly independent from light intensity.
- interpret the relation between light intensity and solar cell power as the relation between luminous flux and generated electron hole pairs.
- specify the relationship between solar cell temperature and I_{SC} and U_{OC}.
- deduce the worsening of solar cell power at higher temperatures from the temperature coefficients.

Content information:

The topics of this unit are the influence of environmental conditions on solar cell performance, the dependency on charge carrier generation of the luminous flux and the influence of temperature.

12.3.3 Unit 3 Solar cell characterization

4.1 I-V-characteristics under dark conditions
4.2 I-V-characteristics, MPP and filling factor of the solar cell

Duration: 90'

Previous knowledge:

- Voltage: value, unit and measurement
- Current: value, unit and measurement
- Power: value, unit and measurement
- Diode characteristics

Operational objectives:

The Students

- record IV-characteristics.
- identify a fully shaded solar cell as a diode.
- can describe IV-characteristics of illuminated solar cells.
- can name and explain the characteristically parameters of solar cells, as maximum power point, fill factor, U_{OC} and I_{SC}.

Content information:

This unit takes the focus on the electrical characteristics of solar cells: IV-curve, parameters (illuminated/shaded device)

12.3.4 Unit 4 Influence of environmental conditions on solar cell characteristics I

4.3 Dependence of the I-V-characteristics on the illumination intensity

Duration: 90'

Previous knowledge:

- Voltage: value, unit and measurement
- Current: value, unit and measurement
- Power: value, unit and measurement
- Dependence of the solar cell power on the illumination intensity
- record IV-characteristics

Operational objectives:

The Students

- determine the influence of different illumination intensities on IV-characteristics of solar cells.
- can describe the influence of illumination intensities on the position and value of the MPP.

Content information:

The topic of this unit is the influence of the light intensity on the electrical characteristics of solar cells.

12.3.5 Unit 5 Influence of environmental conditions on solar cell characteristics II

4.4 Dependence of the I-V-characteristics of the solar cell on the temperature

Duration: 90'

Previous knowledge:

- Voltage: value, unit and measurement
- Current: value, unit and measurement
- Power: value, unit and measurement
- Dependence of the power of the solar cell on the temperature
- record IV-characteristics

Operational objectives:

The Students
- determine the influence of temperature on IV-characteristics of solar cells.
- can describe the influence of temperature on the position and value of the MPP.

Content information:

The topic of this unit is the influence of temperature on the electrical characteristics of solar cells.

12.4 Section 2: Solar cells in use

Overview

The main goal of the third section is the examination of solar cells as a component part in electrical circuits. Based on the knowledge of the behavior and characteristic of a single solar cell, the students investigate the properties of solar modules. The students will be introduced to typical problems and solutions of this topic, e.g. how to connect a couple of single cells reasonable to build up a module or how to avoid problems caused by shadows. Also very important for the application of solar cells is the knowledge of the behavior and performance on load when used as power source.
In a nutshell the content of this section is the fundament to understand the realization of photovoltaic power plants and their output.

Previous knowledge:

- Section 0
- Section 1

Tactical objectives:

The Students
- can build up solar modules.
- are able to dimension and tune reasonable parts of solar cell modules.

Topic:

Building up solar modules with single cells; solutions for real life problems in photovoltaics (bypass diode); characterizing solar modules; solar cells as power supply.

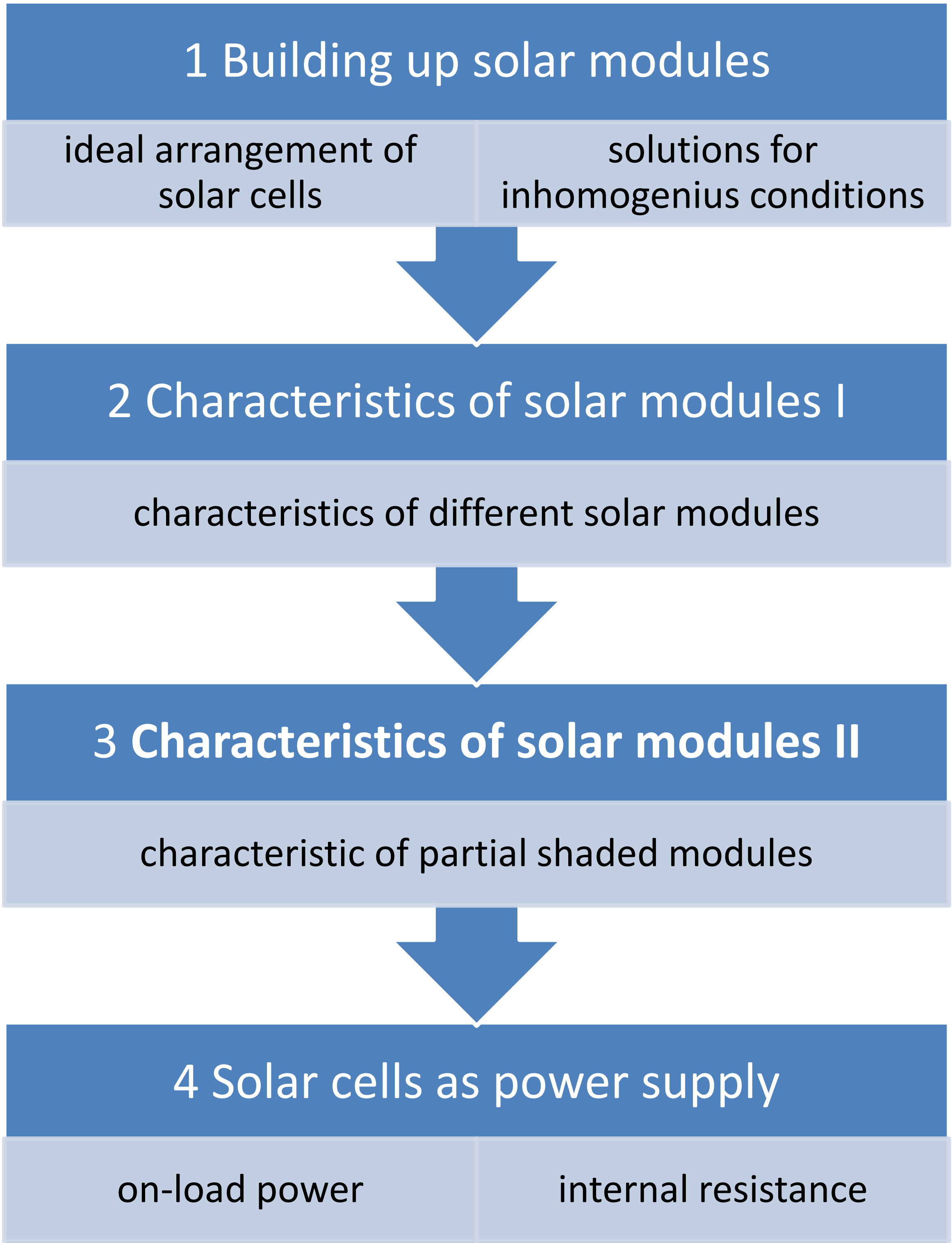
Duration:

4 units; 6 hours

Units:

1. Building up solar modules
   3.1 Series and parallel connection of solar cells (phenomenological)
   3.2 Series and parallel connection of solar cells (quantitative)
   3.8 Partial shading of series-connected solar cells
2. Characteristics of solar modules I
   4.5 I-V-characteristics of different solar modules
3. Characteristics of solar modules II
   4.6 I-V-characteristics of partial shaded solar modules
4. Solar cells as power supply
   3.6 Dependence of the on-load power on the illumination intensity
   3.7 Dependence of the internal resistance on the illumination intensity

Flow chart:


1 Building up solar modules
ideal arrangement of solar cells
solutions for inhomogenius conditions
2 Characteristics of solar modules I
characteristics of different solar modules
3 Characteristics of solar modules II
characteristic of partial shaded modules
4 Solar cells as power supply
on-load power
internal resistance

12.4.1 Unit 1 Building up solar modules

3.1 Series and parallel connection of solar cells (phenomenological)
3.2 Series and parallel connection of solar cells (quantitative)
3.8 Partial shading of series-connected solar cells

Duration: 90'

Previous knowledge:

- Section 0
- Section 1

Operational objectives:

The Students

- can build up solar modules with multiple solar cells.
- can calculate the open circuit voltage and the short circuit current of a solar module by the values of the included cells.
- can explain the influence of a shaded solar cell in a solar module on the performance of the module.
- compare modules with and without bypass diodes.

Content information:

This unit discusses the construction of solar modules. Different possible interconnections and additional parts are integrated.

12.4.2 Unit 2 Characteristics of solar modules I

4.5 I-V-characteristics of different solar modules

Duration: 90'

Previous knowledge:

- Section 0
- Section 1
- Basic properties of solar modules

Operational objectives:

The Students
- measure IV-characteristics of different modules.
- compare the performance (position and value of maximum power point) of different possible solar modules.
- can explain expected performance of modules.
- can consider a reasonable installation of solar modules.

Content information:

The topic of this unit is the IV-characteristic of solar modules.

12.4.3 Unit 3 Characteristics of solar modules II

4.6 I-V-characteristics of partial shaded solar modules

Duration: 90’

Previous knowledge:

- Section 0
- Section 1
- Basic properties of solar modules

Operational objectives:

The Students

- measure IV-characteristics of a partly shaded solar module with and without different bypass diode installations.
- can describe and explain the shape of the different IV-curves and give reasons how the bypass diode influence the module characteristic.
- can estimate the expected performance of modules at different conditions.
- can consider a reasonable use of bypass diodes in solar modules.

Content information:

The bypass diode is an important part of solar modules. Different solar modules with bypass diodes over one or multiple cells feature highly different IV-characteristics.

12.4.4 Unit 4 Solar cells as power supply

3.6 Dependence of the on-load power on the illumination intensity
3.7 Dependence of the internal resistance on the illumination intensity

Duration: 90'

Previous knowledge:

- Section 0
- Section 1

Operational objectives:

The Students

- analyze the dependency of on-load power on different illumination intensities.
- measure the internal resistance of solar cells.

Content information:

This unit is about solar cells as power supply. The internal resistance and the on-load power are important parameters for the use of solar cells.

12.5 Section 3: Off-Grid systems - parts and properties

Overview

When it comes about to use photovoltaic for a practical purpose one needs more than just a solar cell or a solar module. Off-Grid systems are a typical application scenario for photovoltaic. Their aim is to provide stationary or mobile electrical supply in areas far away from an electrical infrastructure. They consist only of a few electrical components like load-regulators, storage etc. Therefore are they ideal subjects for students to get to know important tasks in power supply technique and different components which can be used as a solution for them.

Previous knowledge:

- Section 0
- Section 1
- Section 2
- Capacitor characteristics

Tactical objectives:

The Students

- are aware of possible existing problems and tasks at the designing of photovoltaic power supply systems.
- can name different peripheral parts of off-grid systems.
- choose reasonable from different standard solutions when building up a system.

Topic:

Off-grid systems; charge regulators; electrical storage, deep discharge regulators, DC/DC and DC/AC inverter.

Duration:

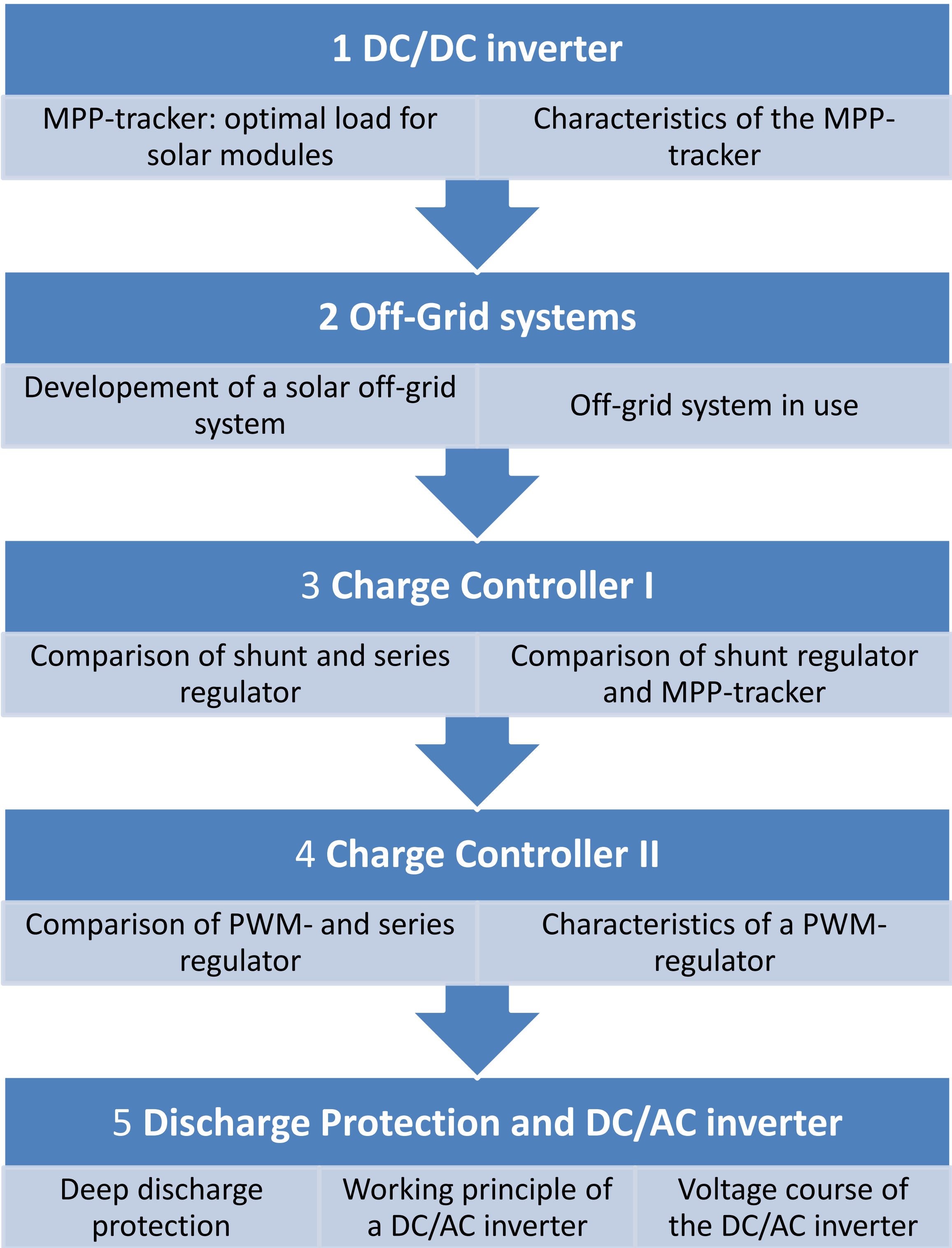
5 units; 7.5 hours

Units:

1. DC/DC inverter
   9.1 Working principle of the MPP-tracker module
   9.2 Characteristics of the MPP-tracker
2. Off-Grid systems
   5. Components of a solar off-grid system
   6. Possible operating conditions of an off-grid system
3. Charge Controller I
   7. Mode of operation of a shunt regulator and a series regulator
   9.3 Comparison of shunt regulator and MPP-tracker for the capacitor charge curve
4. Charge Controller II
   8.1 Comparison of a PWM-regulator and a series regulator
   8.2 The charge characteristics of a PWM-regulator
5. Discharge Protection and DC/AC inverter
   10. Mode of operation of the deep discharge protection module

11.1 Working principle of a DC/AC inverter module
11.2 Determination of the output voltage course at the DC/AC inverter

Flow chart:



12.5.1 Unit 1 DC/DC inverter

9.1 Working principle of the MPP-tracker module
9.2 Characteristics of the MPP-tracker

Duration: 90'

Previous knowledge:

- Section 0
- Section 1
- Section 2

Operational objectives:

The Students

- can reason the need of a DC/DC inverter.
- record the IV-curve of a MPP-Tracker.
- can describe the working principle of a MPP-Tracker

Content information:

The content of this unit is the use of DC/DC inverter to maximize the output power for different loads.

12.5.2 Unit 2 Off-Grid systems

5. Components of a solar off-grid system
6. Possible operating conditions of an off-grid system

Duration: 90’

Previous knowledge:

- Section 0
- Section 1
- Capacitor characteristics

Operational objectives:

The Students

- transfer their theoretical knowledge about solar cells to application problems.
- deduce different operation conditions of off-grid systems and fit the system to handle them.
- can name necessary parts of photovoltaic off-grid systems.
- can reason the need and the purpose of the basic elements of off-grid systems.

Content information:

This unit is about photovoltaic off-grid systems and therefore about technical applications of solar cell technology. Elements: Solar module, electrical storage, charge controller, discharge protection, load.

12.5.3 Unit 3 Charge Controller I

7. Mode of operation of a shunt regulator and a series regulator
9.3 Comparison of shunt regulator and MPP-tracker for the capacitor charge curve

Duration: 90’

Previous knowledge:

- Section 0
- Section 1
- Section 2
- Capacitor characteristics

Operational objectives:

The Students

- analyze the work principle of shunt and series regulator.
- compare pros and cons of different charge regulator principles.
- explain the different performance of shunt regulator and MPP-Tracker with their previous knowledge.

Content information:

All regulators have their advantages and disadvantages. This unit compares different types of regulators for overload protection (shunt and series regulator) and for optimized efficiency (MPP-tracker).

12.5.4 Unit 4 Charge Controller II

8.1 Comparison of a PWM-regulator and a series regulator
8.2 The charge characteristics of a PWM-regulator

Duration: 90'

Previous knowledge:

- Section 0
- Section 1
- Section 2
- Capacitor characteristics

Operational objectives:

The Students

- analyze the behavior of a PWM-regulator in comparison to a two-point regulator.
- measure the charge characteristic of a PWM-regulator.
- can explain the effort of a PWM-regulator against a two-point regulator.

Content information:

The PWM-regulator extends the lifetime of a battery, because it keeps the fill level constant if possible.

12.5.5 Unit 5 Discharge Protection and DC/AC inverter

10. Mode of operation of the deep discharge protection module
11.1 Working principle of a DC/AC inverter module
11.2 Determination of the output voltage course at the DC/AC inverter

Duration: 90'

Previous knowledge:

- Section 0
- Section 1

Operational objectives:

The Students

- record the U-t-curve of a deep discharge protection module.
- can explain and reason the task of a deep discharge module.
- analyze the effect of a DC/AC inverter on different polar and nonpolar modules.
- measure and analyze the U-t-curve of the DC/AC inverter at different frequencies.

Content information:

This unit researches on the one side the deep discharge protection used in the off-grid system. Also DC/AC inverters are introduced giving an outlook on on-grid systems.

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