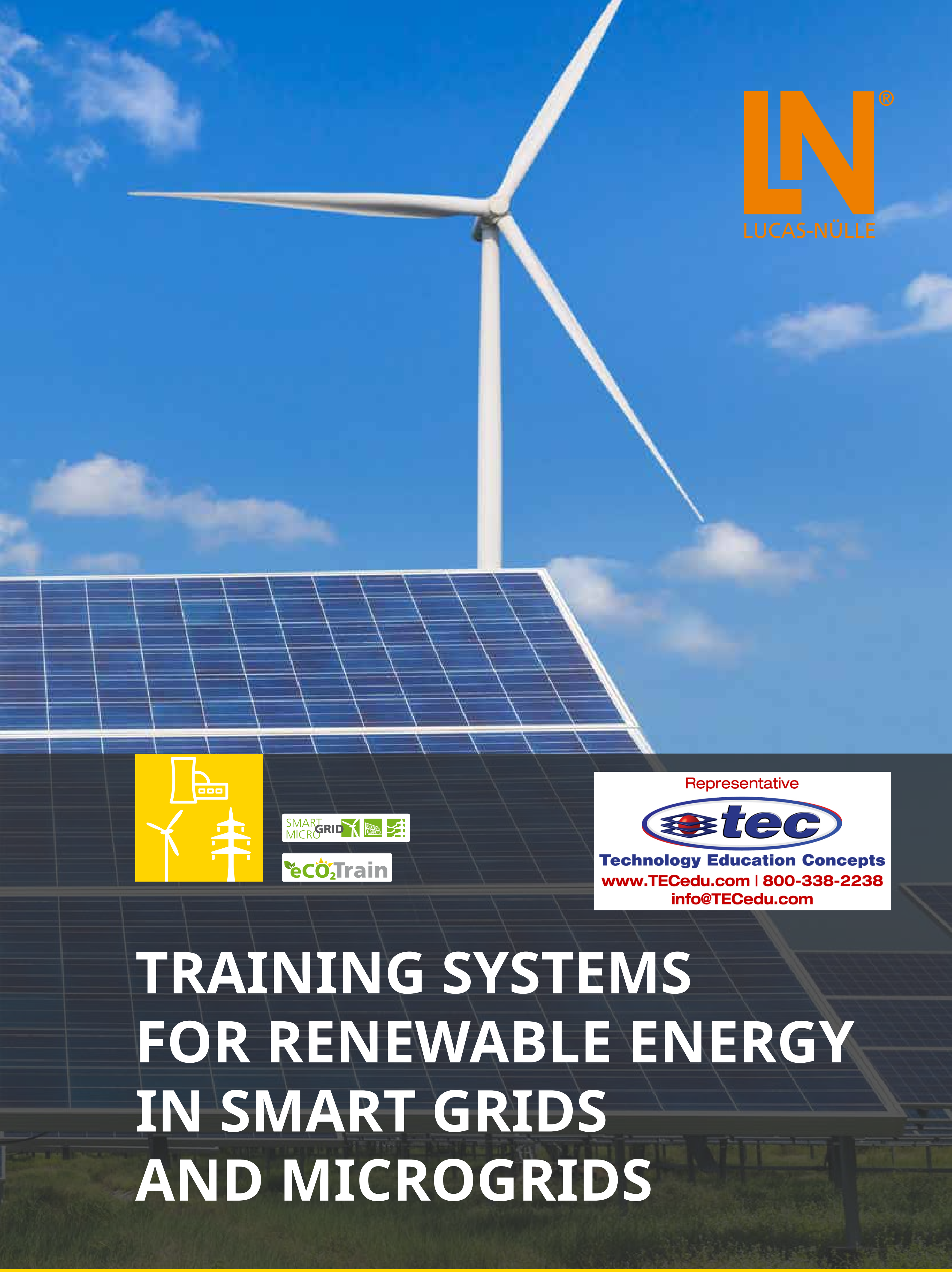

LUCAS-NÜLLE

SMART MICRO GRID

eCO2Train

Representative

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Technology Education Concepts

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TRAINING SYSTEMS FOR RENEWABLE ENERGY IN SMART GRIDS AND MICROGRIDS

3rd Edition

Qualification Through Quality

Inexhaustible, Sustainable, Real – the Future is Green

The move away from coal, oil and nuclear power to renewable forms of energy is gaining momentum. Today, technology has evolved to a point where solar energy, wind power, hydrogen fuel and biomass can be exploited as environmentally friendly energy sources. In order to sustain this trend, the search is on to find and train well-qualified technical staff worldwide.

Bright outlook with photovoltaics

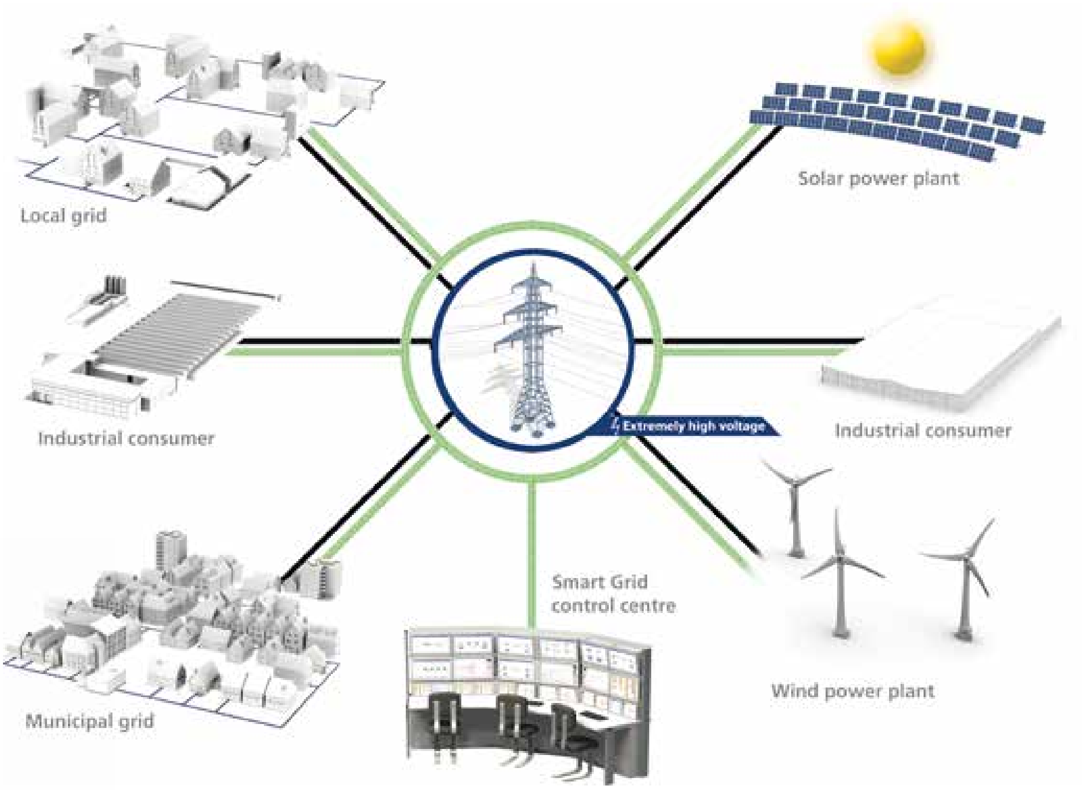
- Abu Dhabi has announced it will invest about two billion US dollars in technology for manufacturing thin-film photovoltaic modules in Masdar.
- The USA's largest solar power plant with a rated output of 25 megawatts is being built in Silicon Valley.
- Photovoltaic facilities capable of generating a total of 38.5 gigawatts have already been realised in Germany. This output is equivalent to that of 38 modern power plant units.

A clean future with wind energy

- Forecast for Germany: By 2030, 25% of electricity will be produced by means of wind power.
- A 3.0-megawatt wind farm annually saves 13,000 barrels of oil or 10,000 tons of CO_2.

Smart grid – Networked systems in the power engineering laboratory

Using the Lucas-Nülle equipment sets, it is possible to model an entire power supply grid from power generation all the way to ultimate consumption. Accordingly, you can, for example, take the power obtained from renewable energy sources and transmit this power via a line model, use a transformer to step it up or down and distribute it to any number of consumers using the double busbar. Additionally, the bus systems of the measurement and protective equipment can all be interconnected, centrally evaluated and controlled using our SCADA Power-LAB software. It makes it safe and easy to design and investigate intelligent power grids in the lab.



Fuel cells – Long-term energy storage elements

- Used widely as a standby power source
- Used in zero-emission vehicles
- Used by co-generation units

Photovoltaics

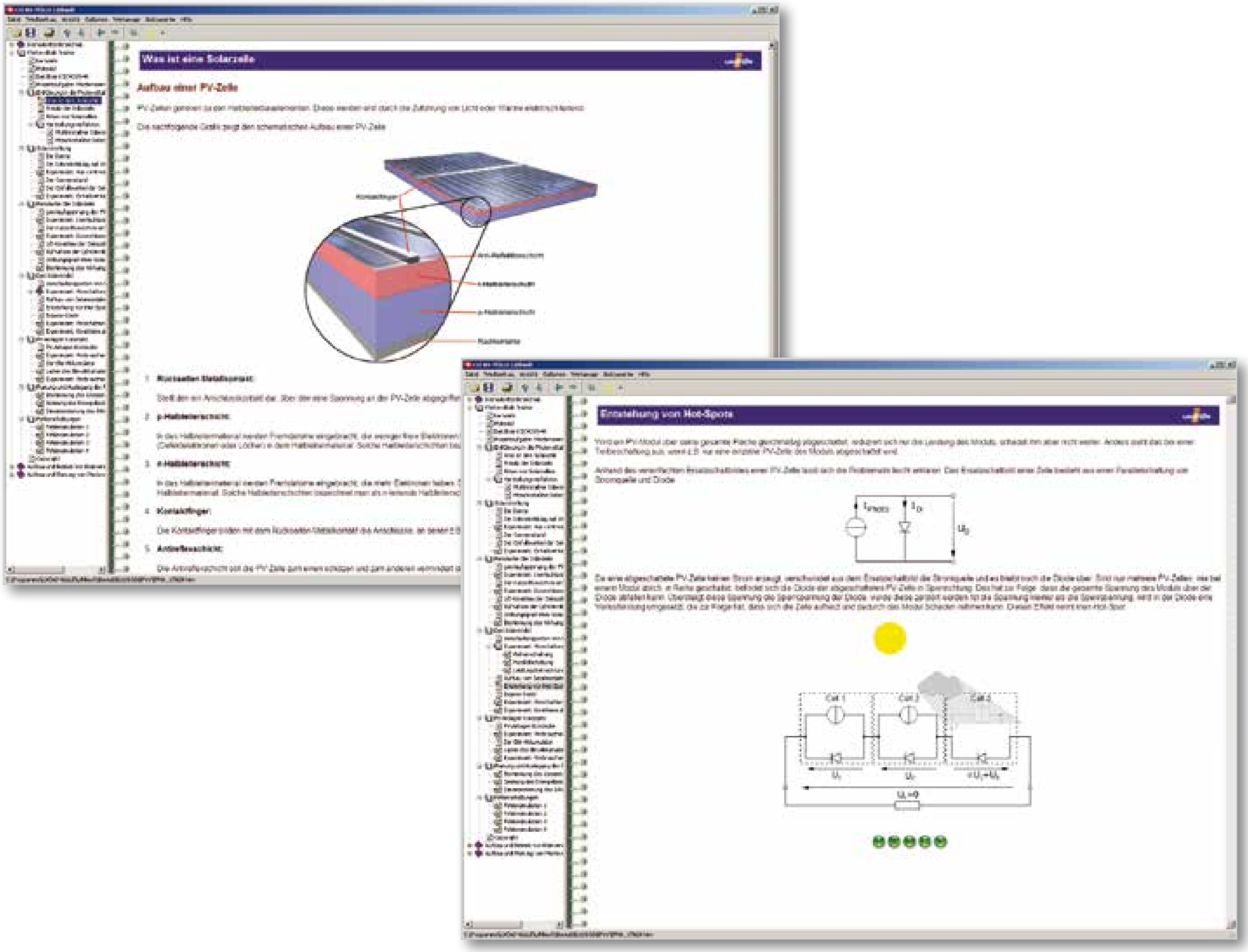
Sunny Prospects with the Photovoltaics Course

In times of soaring energy costs and increased environmental awareness, photovoltaic technology constitutes a very interesting alternative to traditional power generation. With the photovoltaics course, you can not only research the fundamentals of solar cells, but also simulate operation of a photovoltaic system in direct or storage mode.

Training contents

- Functions and operating principles of solar cells
- Recording the characteristics of a solar module
- Dependency of a solar module's current and voltage on temperature, irradiance and angle of incidence
- Series, parallel and other types of circuit for solar cells
- Manufacture of solar cells
- Various types of solar cell
- Design of a photovoltaic battery
- Various types of solar plant
- Setup of an off-grid power system with rechargeable solar cells

Multimedia Course Consolidates the Experiment



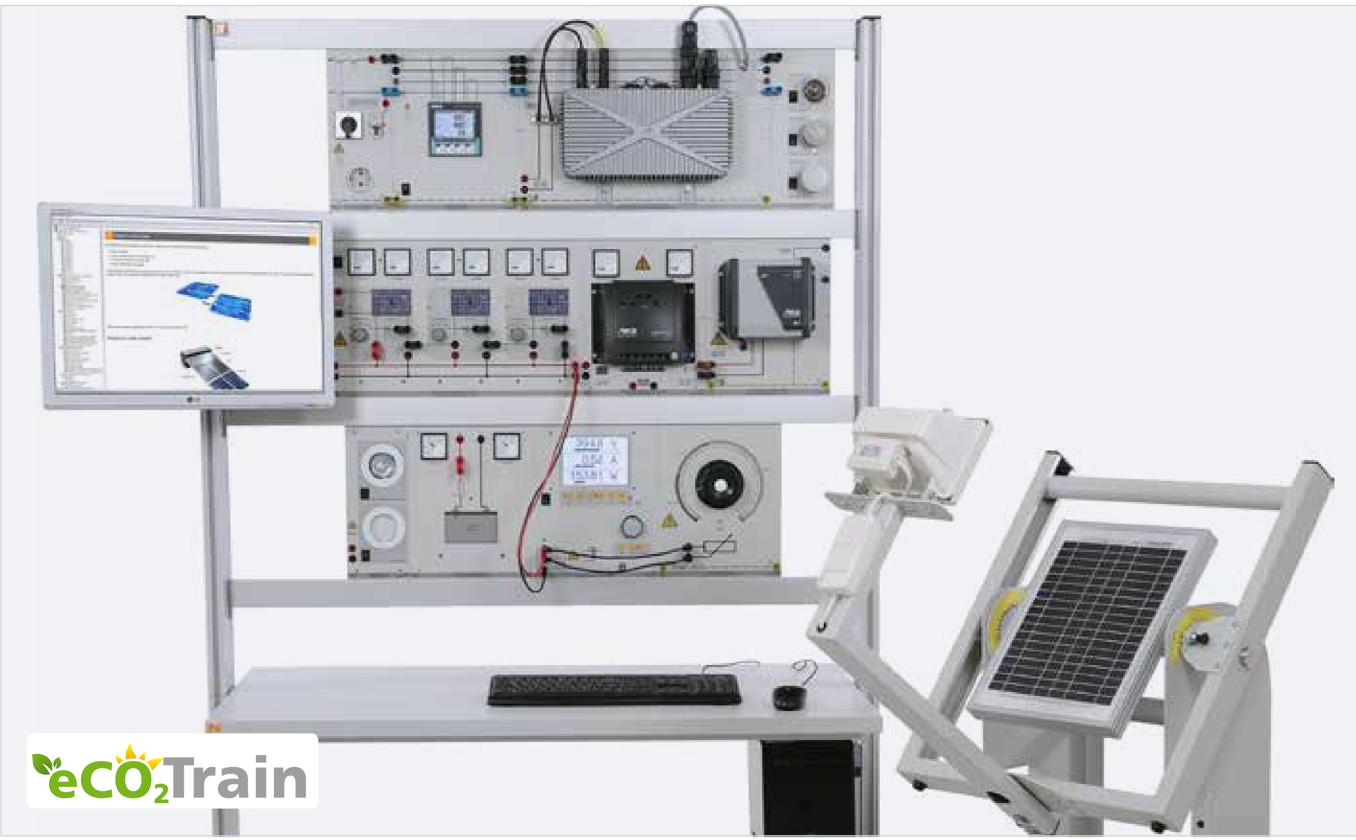
Your benefits

- Theoretical knowledge and practical know-how are conveyed using the UniTrain-I multimedia course
- Complete equipment set including all relevant components
- PC-supported evaluation of measurement data
- System operates with secure extra-low voltage of 12 V
- System supports fault simulation
- Course duration: 4.5h approx.

Advanced Photovoltaics

Project Work with Industrial Components

The training system permits realistic simulation of paths taken by the sun. Emulators make it possible to conduct practical experiments in the laboratory without the sun.
Permitting PC-supported evaluation of measurement data, the advanced photovoltaics multimedia course is designed to convey both theoretical information and practical know-how.



Sample experiment "Advanced photovoltaics" EPH 2

Training contents

Investigating solar modules

- Testing the optimum alignment of solar modules
- Recording the characteristics of solar modules
- Investigating response to partial shading
- Investigating how bypass diodes operate
- Learning about various types of wiring for solar modules

Setting up photovoltaic systems for off-grid operation

- Installing PV systems
- Setting up and testing an off-grid PV system in direct mode
- Setting up and testing an off-grid PV system in storage mode
- Setting up and testing an off-grid PV system for generating 230-V alternating voltage

Setting up photovoltaic systems for grid-parallel operation

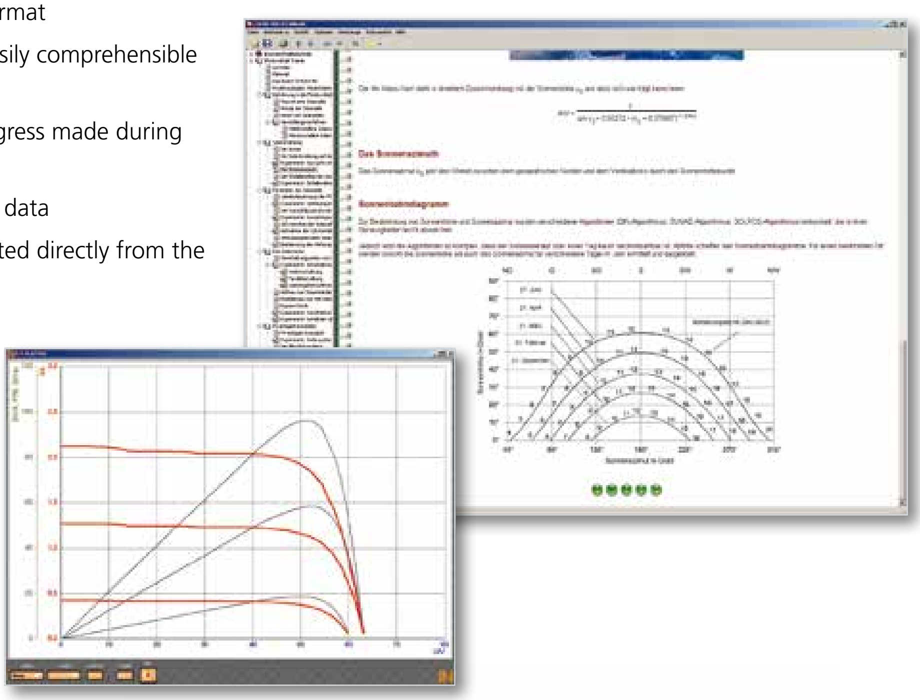
- Installing, setting up and testing a PV system with network feed
- Measuring the energy produced by a PV system
- Determining a grid-connected inverter's efficiency
- Investigating a PV system's response to a power outage on the electricity grid

Advanced Photovoltaics

A Little Sunshine for Your Lab

Interactive Lab Assistant

- Step-by-step instructions in multimedia format
- Explanation of physical principles using easily comprehensible animations
- Quiz and assessment tools for testing progress made during the course
- PC-supported evaluation of measurement data
- Virtual measuring instruments can be started directly from the experiment manual



Solar module with altitude emulator

- The sun's angle can be adjusted as a function of position (latitude), date and time
- The solar module's inclination can be adjusted
- 10-W polycrystalline solar module
- 500-W halogen lamp with dimmer
- Realistic emulation of the sun's path

Professional Photovoltaics

Modern Photovoltaic Systems Operating Parallel to the Grid

The design of photovoltaic systems operating in parallel with the electric power grid is realistic. In order to stabilise the electricity grid, the techniques of derating the power inverter and controllable local transformers are used. Knowledge and practical skills along with computer-based assessment of measured data are made possible by the advanced photovoltaics multimedia course along with SCADA Power Lab software.

Example experiment: "Setup for photovoltaic systems operating parallel to the grid" EPH 3

Training contents

Investigation of solar modules

- Recording of module response over days and years
- Testing optimum alignment of solar modules (to increase energy output)
- Recording characteristics of solar modules

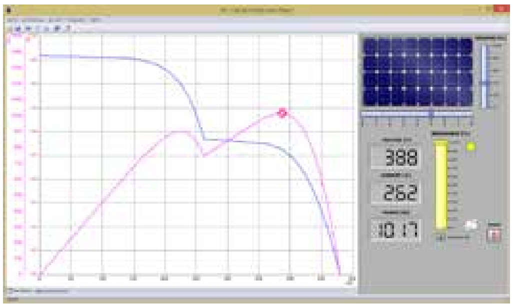
Configuration of photovoltaic systems to operate in parallel with the power grid

- Measurement of energy generated by photovoltaic systems
- Limiting the power of the photovoltaic inverter (derating)
- Determining the efficiency of the power grid inverter
- Response to control of the power grid inverter, MPP Tracking
- Recording output data using sun passage emulator
- Investigating the response of a photovoltaic system when there is a power outage on the grid
- Economic benefits of photovoltaic systems

Voltage control in a local power grid

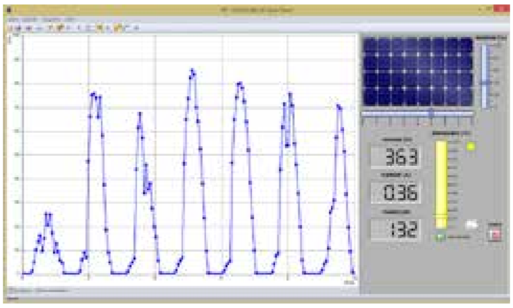
- Local-area network transformer
- Limiting the power of the photovoltaic inverter (derating)
- Automatic voltage control in a local power grid
- Operation and monitoring using SCADA

Professional Photovoltaics



Photovoltaic emulator with shadow

Emulation of solar illumination via solar emulator



Sunshine over the course of a week

Industrial inverter for photovoltaics with SCADA control

SCADA with derating of photovoltaic inverter

Your benefits

- Solar illumination emulator
- Latest technology featuring derating
- 3-phase feed into electricity grid
- Operation, observation and control via SCADA
- Use of industrial components
- Provision of reactive power
- Teaching via "Interactive Lab Assistant" course
- Flexible experimenting thanks to actual solar module or solar emulation

Investigation of battery storage units in conjunction with photovoltaic systems

An electrochemical energy storage device with a photovoltaic system is intended as a means of shifting or transferring power generation to periods of consumption or peak consumption periods to power generation periods. For this purpose, existent and available (solar) energy must be generated and subsequently stored so that it can be used in times of energy demand. The most important objectives of an electrochemical energy storage device are therefore:

- To increase own or private consumption
- To ensure dependable supply through backup power

Training contents

- Design and installation of the battery storage unit
- Putting the storage unit into operation
- Interaction between PV systems and storage units
- Boosting intrinsic consumption thanks to energy storage units

Wind Power Plants

Double-Fed Induction Generator (DFIG)

This equipment set is designed for investigating modern wind power plants incorporating double-fed induction generators. The wind can be emulated realistically by means of a servo machine test stand and WindSim software. A PC can be connected for convenient operation and visualisation during the experiments. The associated multimedia course titled "Interactive Lab Assistant" imparts theory besides supporting experiment procedures and evaluation of measurement data.

Sample experiment "Wind power plant" EWG 1

Training contents

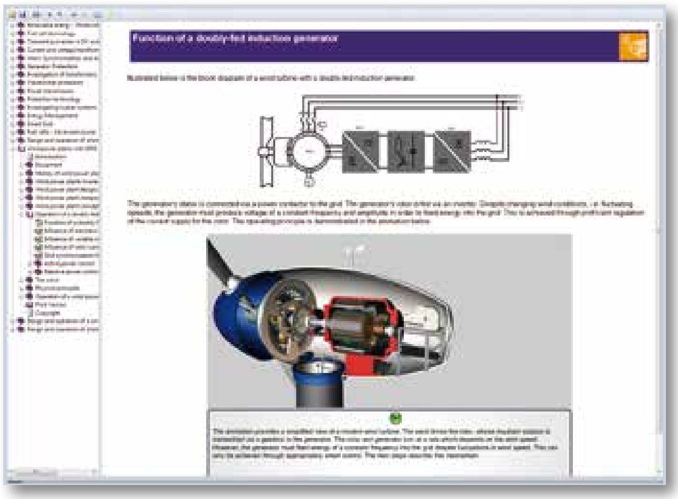
- Understanding the design and operation of modern wind power plants
- Exploring physical fundamentals from "wind to shaft"
- Learning about different wind power plant concepts
- Setting up and operating a double-fed asynchronous wind generator
- Operating the generator at varying wind force levels as well as adjustable output voltages and frequencies
- Determining optimum operating points under changing wind conditions
- Investigating responses to "fault ride-through" grid malfunctions

Wind Power Plants

Fresh Wind in the Laboratory

Interactive Lab Assistant

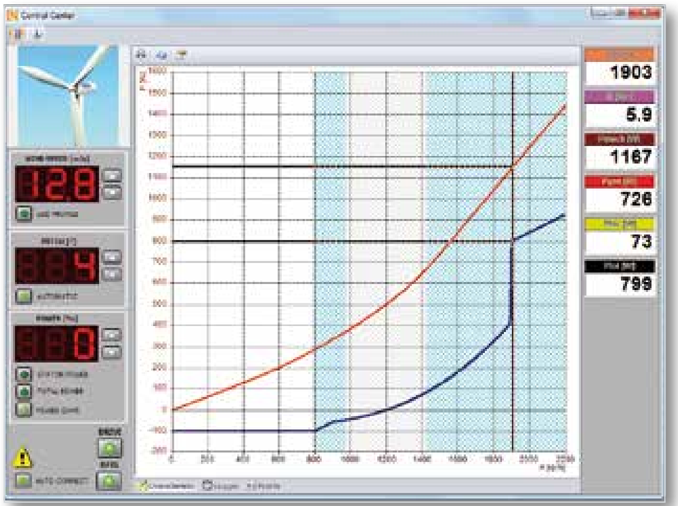
- Step-by-step instructions in multimedia format
- Explanation of physical principles using easily comprehensible animations
- Quiz and assessment tools for testing progress made during the course
- PC-supported evaluation of measurement data
- The following virtual instruments can be be started directly from the experiment instruction pages: Control Centre, DFIG Control, Synchroniser, Power Control, Status Control, Speed Control, FRT Monitor, Vector View, Oscilloscope and other measuring instruments

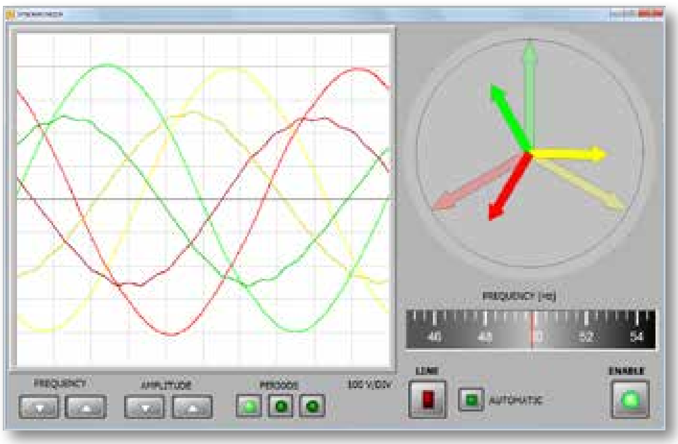


Wind emulator

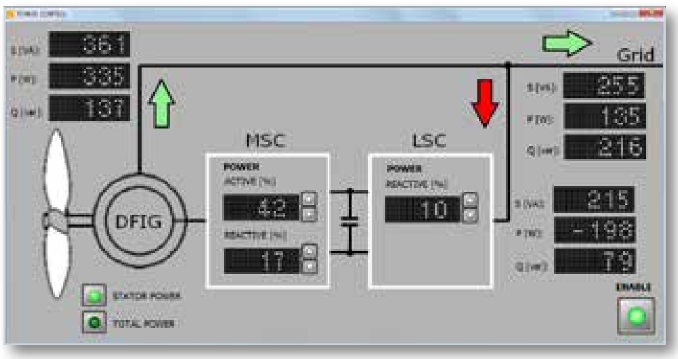
Wind and airfoil geometry serve to drive the generators at a real wind power plant. In the laboratory, this task is performed instead with the help of a servo machine test stand and WindSim software. This permits precise laboratory simulation of conditions prevailing at a real wind power plant.

- Realistic emulation of wind and airfoil geometry
- Speed and torque are matched automatically to wind strength and pitch
- Independently adjustable pitch and wind strength
- Wind profiles can be specified
- Mechanical and electrical variables can be recorded





Synchronisation of a wind power plant to the electricity grid



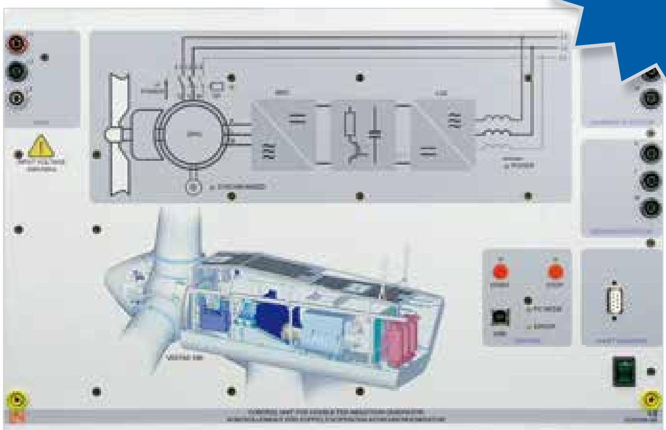
Power distribution and control of reactive power

Double-fed induction generator with control unit

- Control unit with two controlled inverters
- Generator control in sub-synchronous and super-synchronous modes
- Integrated power switch for connecting the generator to the network
- Automatic control of active and apparent power, frequency and voltage
- Manual and automatic synchronisation
- Measurement and display of all system variables
- Experiments on fault ride-through

"Double-fed induction generator"

"Fault ride-through"



"Control unit for double-fed induction generator"

Your benefits

- Theoretical knowledge and practical know-how are conveyed using the Interactive Lab Assistant
- Wind power and mechanical design of wind power plants can be emulated accurately and in detail using the servo machine test stand
- The microcontroller-operated control unit for the double-fed induction generator permits user-friendly operation and visualisation during experimentation
- State-of-the-art technology incorporating "Fault ride-through"
- Integration into energy technology systems

Small Wind Power Plants

Decentralised Electricity Supply

Small wind power plants with outputs ranging up to 5 kW are deployed today for decentralised electricity supply. These plants generate direct voltages. The energy can be stored in batteries via charge controllers. Inverters produce alternating voltages to supply electrical consumers in the grid.
The effects of wind power and the mechanical design of wind power plants can be emulated down to the last detail using the servo machine test stand and the WindSim software.

Sample experiment "Small wind power plant" EWG 2

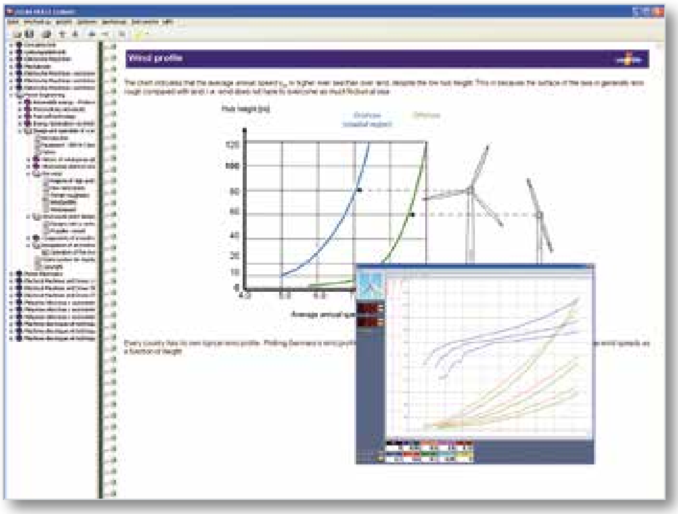
Training contents

- Understanding the design and operation of small, modern wind power plants
- Exploring physical fundamentals from "wind to shaft"
- Learning about different wind power plant concepts
- Setting up and operating a small wind power generator
- Operation at varying wind forces in storage mode
- Energy storage
- System optimisation
- Setting up an off-grid system for generating 230-V alternating voltage
- Investigating hybrid systems for autonomous power supply using wind power and photovoltaic systems

Convincing Product Characteristics

Interactive Lab Assistant

- Step-by-step instructions in multimedia format
- Explanation of physical principles using easily comprehensible animations
- Quiz and assessment tools for testing progress made during the course
- PC-supported evaluation of measurement data
- Virtual measuring instruments can be started directly from the experiment manual



Synchronous generator

- Wind power and mechanical design of wind power plants can be emulated accurately and in detail using the servo machine test stand
- The laboratory generator's response is identical to that of one forming part of a real system
- The small wind power plant is suitable for outdoor operation

Your benefits

- Theoretical knowledge and practical know-how are conveyed using the Interactive Lab Assistant
- Wind power and mechanical design of wind power plants can be emulated accurately and in detail using the servo machine test stand
- The laboratory generator's response is identical to that of one forming part of a real system
- The realistic, small wind power plant is suitable for outdoor operation and includes an integrable mast set

Fuel Cell Technology

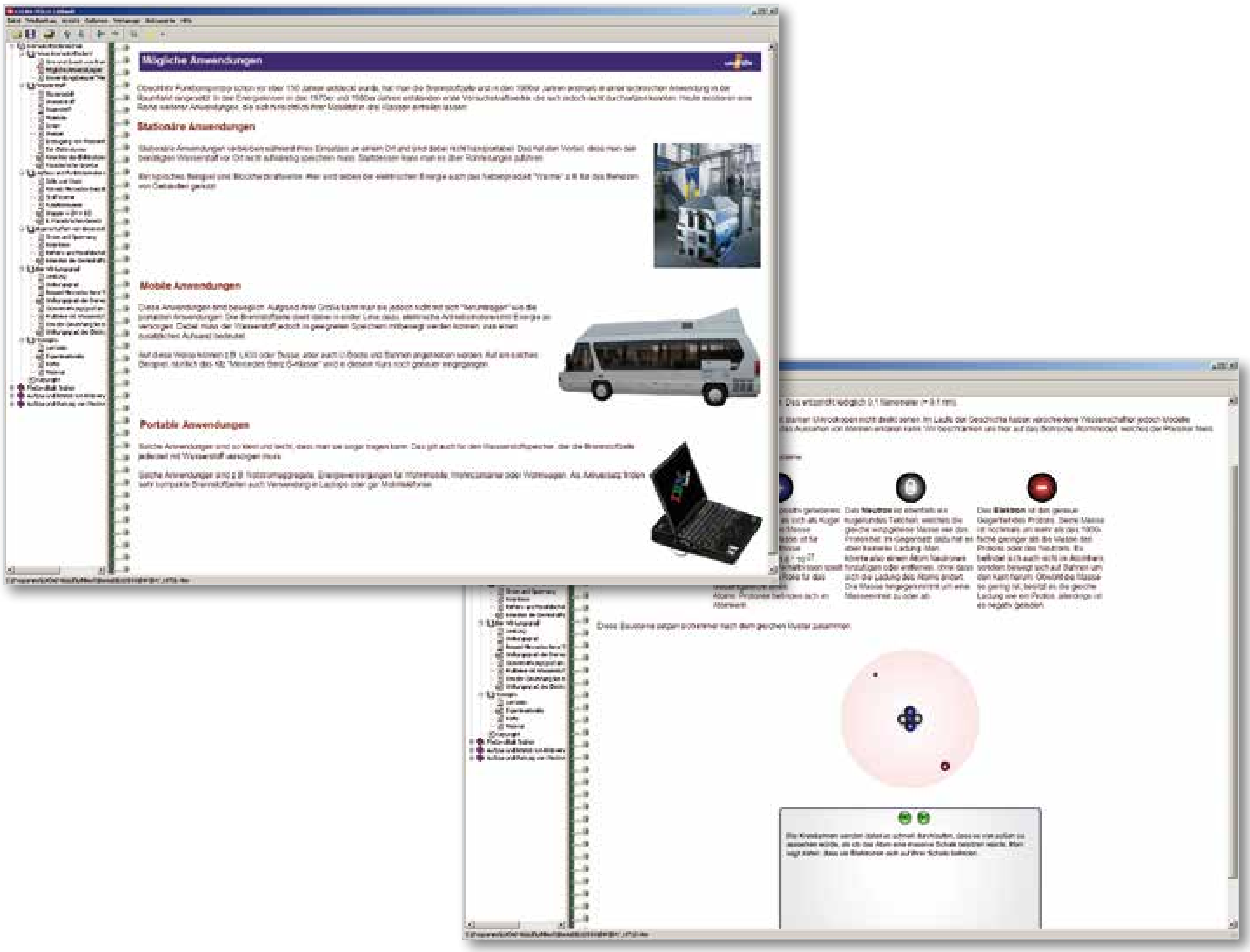
Design and Operation of Fuel Cells

Renewable energies are already considered a solution for dealing with expected energy shortages in the 21st century. The hydrogen-based fuel cell is part of this solution. As a complementary technology, it will be used in future energy systems to generate clean energy from renewable hydrogen.

Training contents

- Functions and operating principles of fuel cells
- Recording the characteristics of a fuel cell
- Understanding the electrochemical processes of electrolysis (Faraday's first and second laws)
- Determining a fuel cell's Faraday and energy efficiencies
- Series and parallel connections of fuel cells
- Power aspects of fuel cells
- Functions and operating principles of electrolysers
- Recording an electrolyser's UI characteristic
- Determining an electrolyser's Faraday and energy efficiencies

Multimedia Course Consolidates the Experiment



Your benefits

- Theoretical knowledge and practical know-how are conveyed using the Interactive Lab Assistant
- Compact device with PEM double fuel cell and PEM electrolyser including a gas storage element
- Safe handling of hydrogen
- 2 V / 2.5 A for supplying power to the integrated electrolyser
- Diverse loads (lamps, fans)
- Variable load for recording characteristics
- Course duration: 4.5h approx.

Smart Grid

Ideally Equipped for the Future:
A Smart Grid in a Power Engineering Laboratory

In future, new technologies will better equip the power supply grid for the demands of a new era. More flexible network management should make the increasing contribution from renewable energies more compatible with the conventional power station infrastructure. The variety in the nature and number of such decentralised power generation systems requires a new way of running the power grid, a so-called intelligent network or "smart grid":

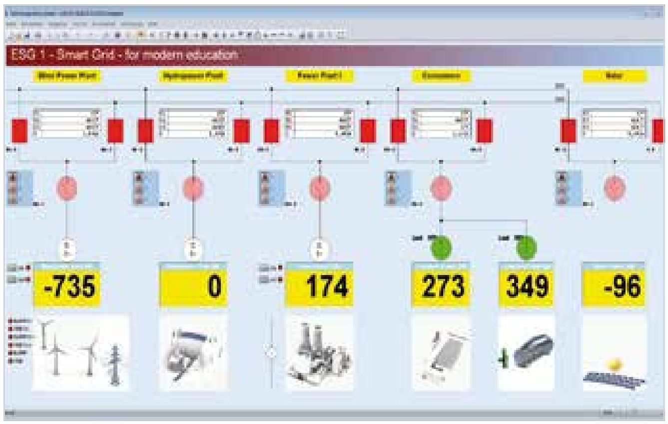
- Improved coordination between energy consumption and generation
- Use of modern information technology, such as the Internet, sensors, control systems and wireless communications equipment
- "Smart metering" – digital electricity meters measure power consumption by end users of the power grid
- Shifting of household consumption away from peak-load periods
- Automatic starting of flexible applications, such as washing laundry, by energy suppliers themselves outside of peak times

Modular integration of regenerative power generation into a smart grid:

- Photovoltaics
- Wind power
- Storage of electrical energy by means of pumped-storage hydroelectricity
- Conventional power generation
- Transmission and distribution
- Energy management (coordination of dynamic power generation and consumption)

SCADA software in a smart grid

- Implementation, control and analysis of complex, intelligent grids (smart grids)
- SCADA software adapted for education
- **SCADA PLC:** Integrated software PLC (IEC 61131)
- **SCADA Logger:** Recording, display, evaluation and export of all values recorded in a given period
- **SCADA Designer:** Symbolic layout of all equipment from Lucas-Nülle's energy supply range on a user interface
- **SCADA Viewer:** Display and control of measurements and status from all computers on the network
- **SCADA Net:** The client/server concept makes it possible to remotely access systems on the smart grid from multiple (student) PCs at the same time.
- **SCADA Panel Designer:** Design your own control panels



Smart measuring instruments:

- Smart measuring instruments with a variety of controls and ability to communicate via various interfaces (e.g. LAN, RS485, USB)
- Measurement and control of all relevant variables by means of smart meters and high-powered switches
- **SCADA Net-compatible:** Display and control of measurements and status from any PC on the network

Smart Grids

The Networked Power Engineering Laboratory

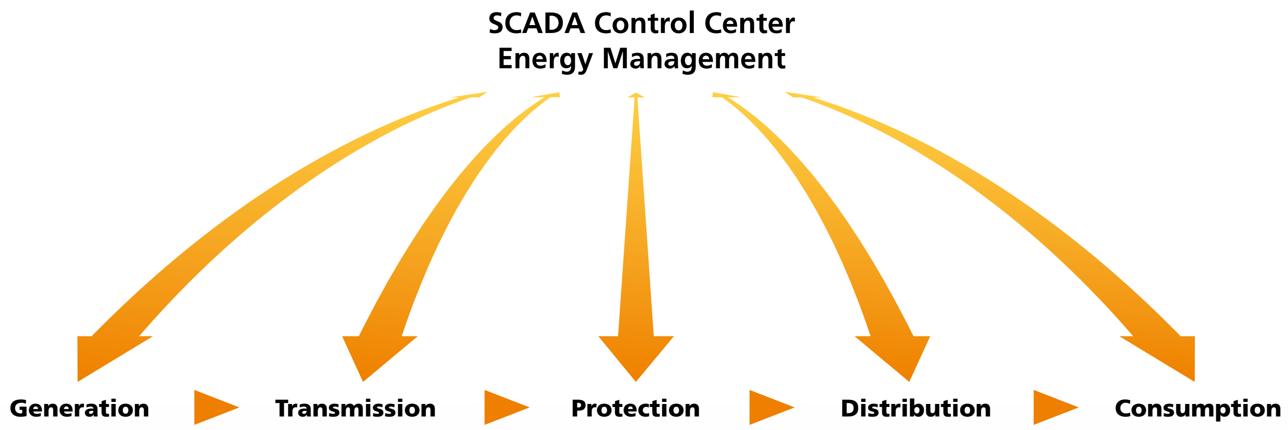
These equipment sets allow training systems covering the generation, transmission and management of electrical energy as well as the protective equipment required to be combined, both electrically and by means of computer networks. All relevant values can be measured via the smart grid control centre and the necessary switching operations undertaken. This makes it possible to study the influence of renewable energy generation in laboratories. A host of scenarios can be emulated, such as the following:

- Charging of electric cars when there is a surplus of wind energy
- Storage of excess energy in pumped-storage hydroelectric plants
- Disconnection of consumers to reduce peak load
- Compensating for energy deficits by means of pumped-storage hydroelectric power

The SCADA software allows the whole system to be observed or controlled from any work station

Photovoltaics | **Hydroelectric power plant** | **Wind power plant**

eCO2Train

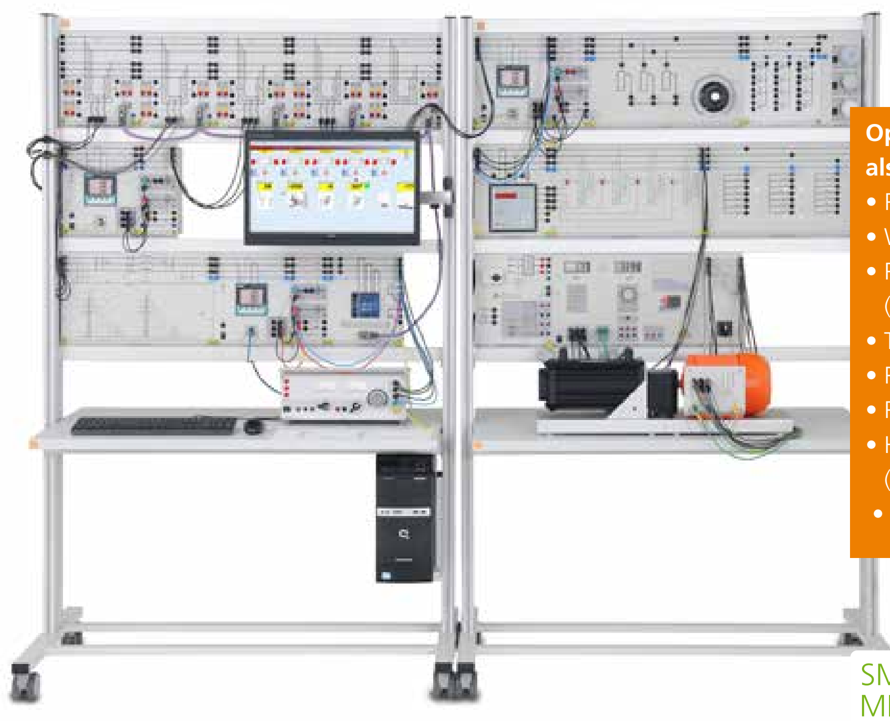


SMART MICRO GRID

Smart Grid

Smart Grid – Control Centre – Energy Management

This equipment set forms the core for a smart grid in a power generation lab. In addition to generation, transmission and distribution of energy, the SCADA software records all relevant values and handles the requisite switching operations. This can be done manually or automatically by means of SoftPLC software. Energy feeds from generating sources and changes in load are recorded by the smart grid control centre and the requisite actions taken to keep the power grid balanced.



Optional supplementary sets are also available for the Smart Grid:
- Professional photovoltaics (EPH3)
- Wind power plants (EWG1)
- Pumped-storage power plant (EUG3)
- Transformers (EUT)
- Power transmission (EUL)
- Power protection (ELP)
- HVDC direct current transmission (EDC1)
- Power generation (EUG)

Example experiment "Smart grid: Generation, distribution, transmission and management of electrical power, ESG1"

Training contents
- Three-phase busbar systems
- Investigation of three-phase transmission lines
- Overcurrent-time protection for transmission lines
- Complex consumers, measurement of power consumption and monitoring of peak load
- Manual and automatic reactive power compensation
- Load management – demand side management
- Intelligent control of generators and consumers

Microgrid

Parallel Operation of Stand-alone Networks/Microgrids

When an off-grid network is coupled to a smart grid it is referred to as a microgrid. Such a grid has three different operating modes: on-grid, off-grid and dual mode. A microgrid features the following benefits:

- Reduction of transmission and transformer losses
- Independence from large power suppliers (utilities)
- Smart grid as back-up system
- Intelligently controlled power supply and consumption thanks to SCADA
- Power generation with renewable energy sources
- Optimum electrical power quality, reliability and sustainability

Microgrids are playing an ever more prominent role in the smart grids of tomorrow.

Optional supplementary sets are also available for the stand-alone Microgrid:

- Professional photovoltaics (EPH3)
- Wind power plants (EWG1)
- Pumped-storage power plant (EUG3)
- Dynamic consumers (EUC2)

Example experiment "Parallel operation of stand-alone networks with two generators" EMG2

Training contents

- Control of multiple generators in a stand-alone network
- Control of multiple generators in parallel generation mode
- Coordination of energy needs and generating capacity in stand-alone networks.
- Use of modern information technology such as networked sensors/actuators, PLC control and the SCADA operating environment
- Smart metering of a "slack bus" to make a sub-network autonomous.
- Manual control
- Voltage control
- Frequency control
- Torque control
- Power factor (cos phi) control
- Droop control

Smart Grid – Microgrid

Energy Generators in Smart Grids and Microgrids

These supplementary sets can optionally be used, either individually or in conjunction with the "smart grid" equipment set ESG 1 or the "microgrid" set EMG. This allows for extensive investigation of a smart grid or a microgrid.

Example experiment "Smart grid supplement to ESG 1: Energy generators in a smart grid"

Training contents

Wind power plants, EWG 1
- Operating a generator under changing wind speed plus control of output voltage and frequency
- Determining optimum operating points under changing wind conditions

Photovoltaic systems operating parallel to the main grid, EPH 3
- Setup and testing of photovoltaic systems with feed to the grid
- Measurement of energy generated by a photovoltaic system
- Determining efficiency of grid-connected power inverters
- Voltage control in a local power grid

Synchronous generators, EUG
- Generator control and synchronisation
- Manually operated synchronisation circuits
- Automatic synchronisation circuits
- Automatic power correction
- Automatic power factor correction

Pumped storage power plant/Power plants

In the power plants course, the way the following types of power plant operate is covered: Lignite power plants, Coal-fired power plants, Gas turbine power plants, Gas and steam power plants, Biogas combined heat and power (cogeneration) plants, Nuclear power plants, Hydroelectric power plants. The pumped storage power plant course analyses how electrical energy can be stored by transforming it into potential energy of water and then transforming it back into electrical energy again for feeding to the grid. Pumped storage plants are becoming increasingly necessary due to the increase in renewable energy generation and also provide indispensable energy storage capacity in a high-quality smart grid.

Example experiment "Smart grid supplement to ESG 1: Pumped-storage hydroelectric plant EUG 3"

Training contents

- Setting up synchronisation
  - Putting a multi-function relay into operation
- Generator operation
- Grid synchronisation
  - Setting parameters for a multi-function relay
  - Automatic synchronisation
- Manual power regulation for generators and motors
- Generator control using SCADA
- Power plants
  - Types of power plant
  - Typical characteristic curves and parameters
  - Commissioning and operation of various types of power station
  - Finding out how power plants work
  - Automatic load following with externally measured active and reactive power
- Pumped storage power plants in a smart grid

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