ELECTRICAL POWER ENGINEERING

Smart Grid | Microgrid | Renewable Energies

7th edition

CONTENTS

QUALIFICATIONS TO MEET NEW CHALLENGES

Training Systems for Power Engineering

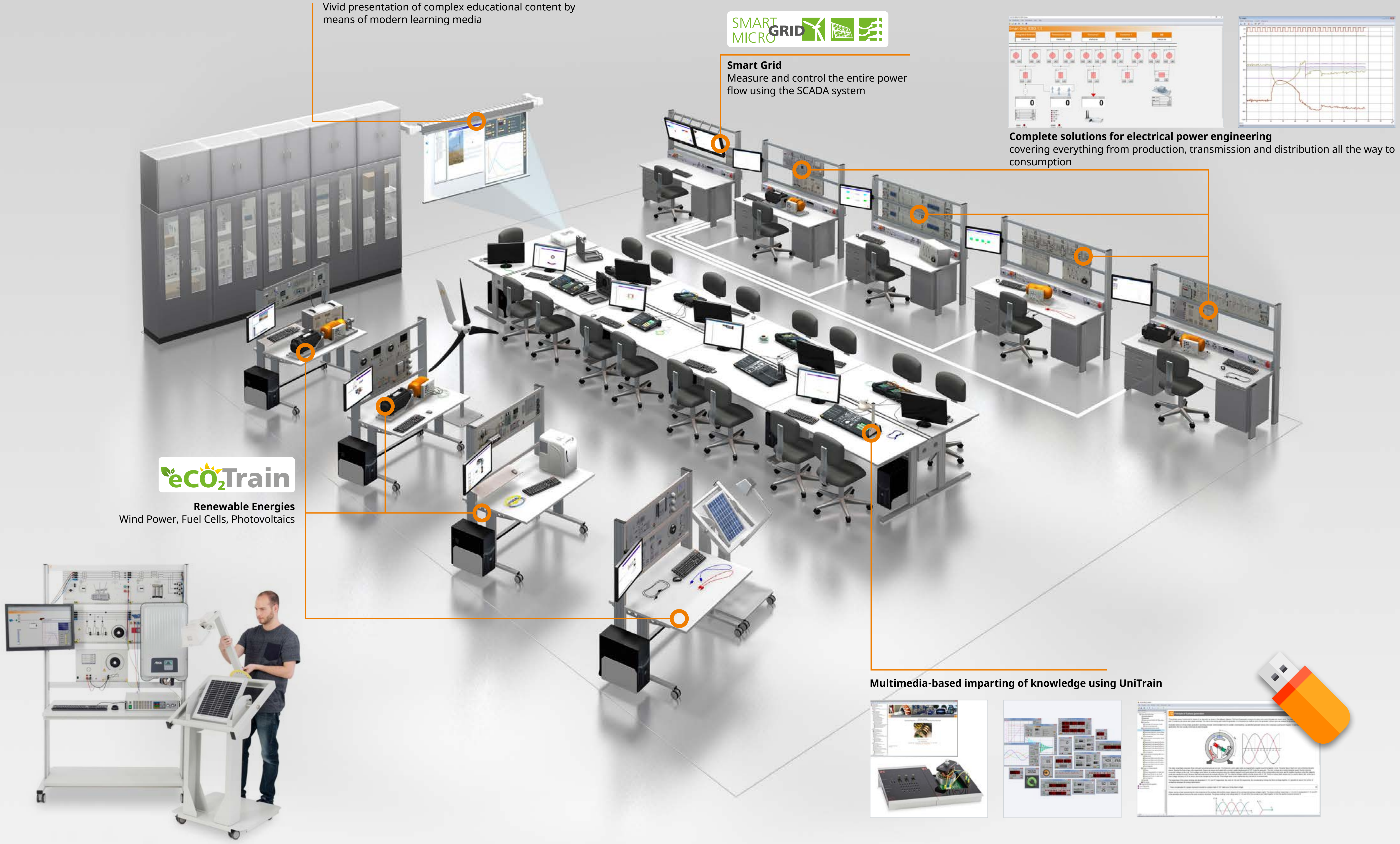
The transformations affecting electrical power supply…
The amount of renewable energies in use compared to fossil fuels such as coal, oil and gas continues to grow more and more globally. Thanks to innovative technologies and concepts, engineering opportunities are constantly gaining ground. Solar energy, wind power, hydrogen and biomass are well established and in use as environmentally friendly energy sources. Fluctuations in power generation are compensated for using energy management, energy storage technologies and sector coupling. In order for this trend to keep its momentum going and make the energy revolution a success, well-trained and qualified experts are needed worldwide.

… are having a major impact on education and training
Changing demands call for new, modern, practice-oriented training systems. These systems instruct trainees on the most up-to-date technology and provide them with the requisite skills.

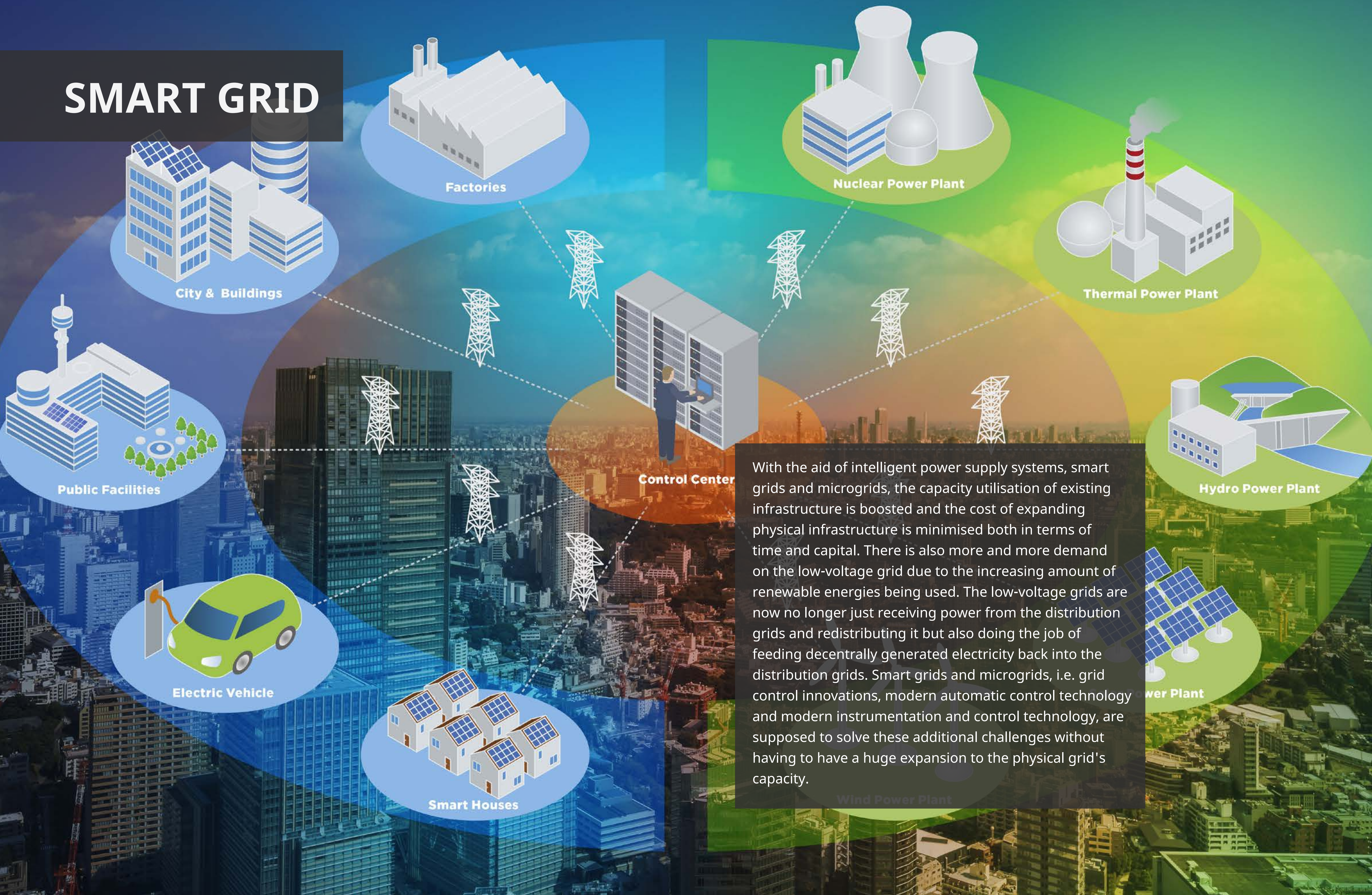
Learning with Lucas-Nülle
The vocational training systems are both modular and scalable, making them the innovative and future-proof foundation for excellent training and education in the area of power engineering.

Benefits
- Linking theory with practice
- Teaching and learning at your own pace
- Total DO-IT-YOURSELF learning
- Combines software and hardware
- Labsoft contains graphic animations and virtual instruments
- Software can be edited (language, teaching material, exams)

MORE THAN A TRAINING SYSTEM



SMART GRID



With the aid of intelligent power supply systems, smart grids and microgrids, the capacity utilisation of existing infrastructure is boosted and the cost of expanding physical infrastructure is minimised both in terms of time and capital. There is also more and more demand on the low-voltage grid due to the increasing amount of renewable energies being used. The low-voltage grids are now no longer just receiving power from the distribution grids and redistributing it but also doing the job of feeding decentrally generated electricity back into the distribution grids. Smart grids and microgrids, i.e. grid control innovations, modern automatic control technology and modern instrumentation and control technology, are supposed to solve these additional challenges without having to have a huge expansion to the physical grid's capacity.

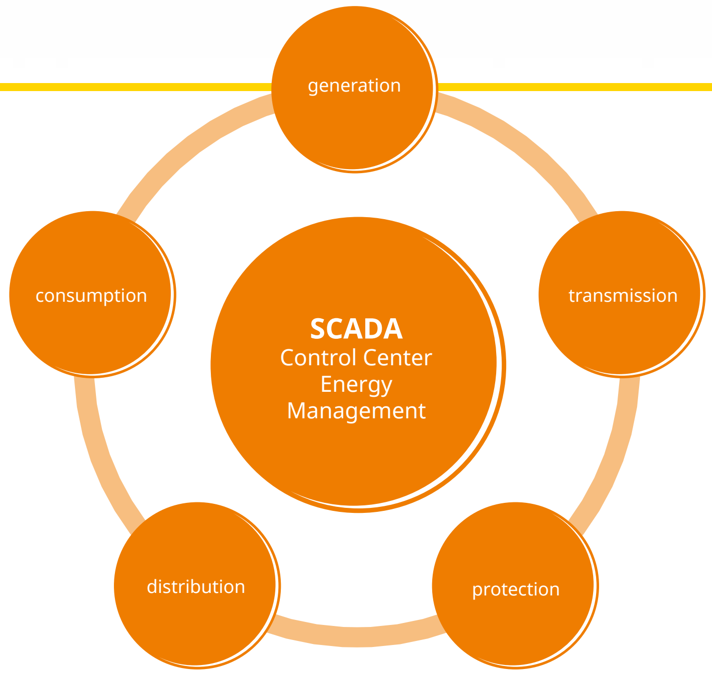
"SMART GRID" – INTELLIGENT POWER SUPPLY SYSTEMS

Video: Discover your smart grid solution!

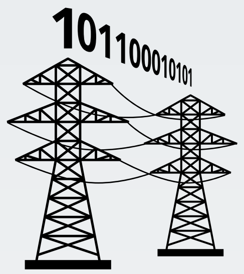
Totally equipped for the future:
Smart Grids inside the Power Engineering Laboratory
The Smart Grid is comprised of the power generation equipment sets with the aid of conventional and renewable energies, transmission, distribution, protection and energy management. Because the training system features a high degree of modularity, these equipment sets can be modified and expanded to fit any requirements.

The Networked Power Engineering Laboratory
The equipment sets make it possible for training systems to be combined electrically and in terms of their IT infrastructure for power generation, transmission, distribution, protection and energy management. This means the impact of renewable energy sources on power generation can be studied in the laboratory. The energy management system can demonstrate, among other things, the needs-oriented control of power loads. Any number of other scenarios can also be simulated and studied.

Benefits
- Huge selection of topics covering power generation, transmission, protection and energy management
- Modularly designed hardware for the simulation of a host of scenarios
- Educationally designed SCADA for carrying out practice-oriented experiments and exploring scenarios
- Digital multimedia courses with guided experiments
- Can be expanded by adding machine and drive technology experiment systems to explore energy-efficient drives and power electronics (using Matlab® Simulink®) as additional dynamic loads inside the smart grid

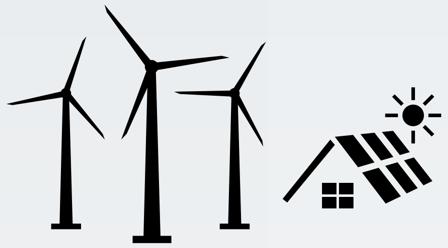


SCADA



Smart Grid

Cyber Security



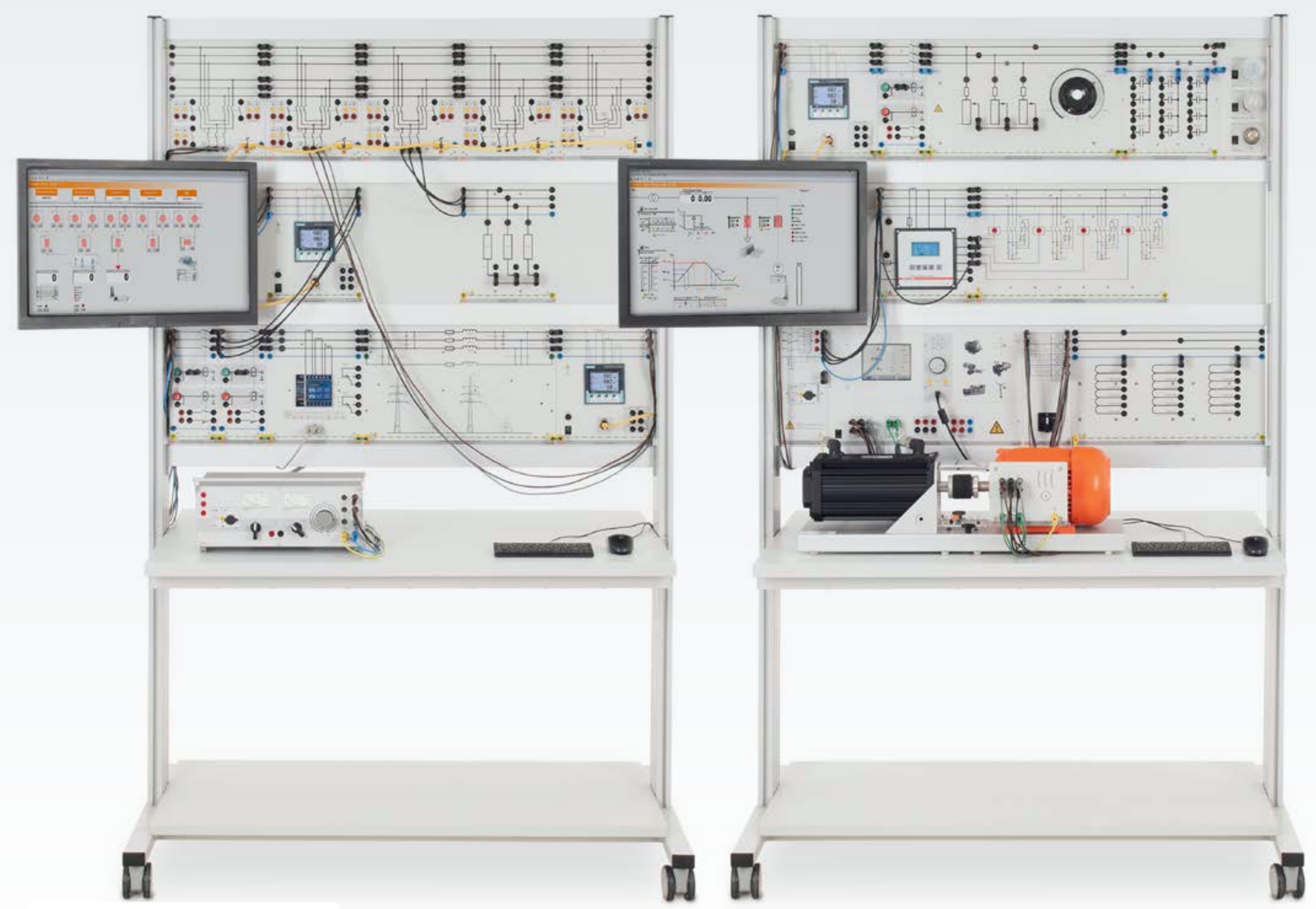
Renewable Energies

Fault ride-through

Flexible Configuration
Thanks to the system's modularity, the equipment can be configured very flexibly. In just a few minutes, complex applications can be set up on experiment trolleys and modified for flexible instruction. The combination of systems permits any number of scenarios to be set up all the way to the microgrid and smart grid.

Configurable for any budget
Procurement can be carried out step-by-step. Start with a minimal equipment set and build your system up at any time into a sophisticated power engineering laboratory.

BASIC SMART GRID EQUIPMENT SET



SMART MICRO GRID

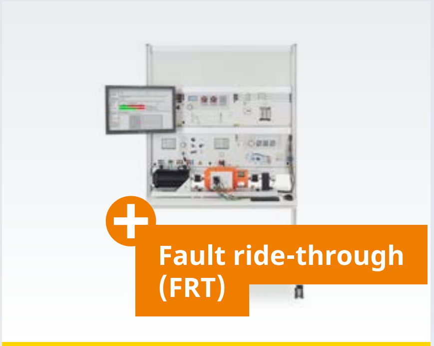
Smart Grid – Control Centre - Energy Management
This equipment set is the heart of the smart grid inside the power engineering laboratory. In addition to power generation, transmission and distribution, the SCADA software is used to collect all the values and trigger corresponding switching operations. This can be done manually and also automatically via Soft PLC. The smart grid control centre detects and monitors the feed-in of generated energy and any load variations and also carries out corresponding countermeasures to keep the power grid stable.

Training contents
- Three-phase double busbar system
- Investigations on three-phase power lines
- Overcurrent time protection for power lines
- Complex loads, energy consumption metering and peak load monitoring
- Manually activated and automatic reactive power compensation
- Load management – demand-side management
- Intelligent control of power generators and consumers

Order no. ESG1

EXTENSIONS: SMART GRID

EPH3 – Professional Photovoltaics



EWG1 – Wind power plants (turbines)

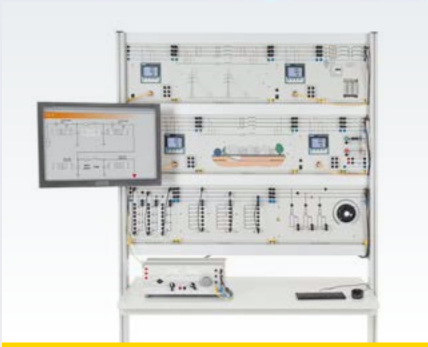
EDC – High-Voltage DC Power Transmission

EUG – Synchronisation Circuits

ECS1 – Industrial Cyber Security

EUK – Pumped Storage and Conventional Power Plants

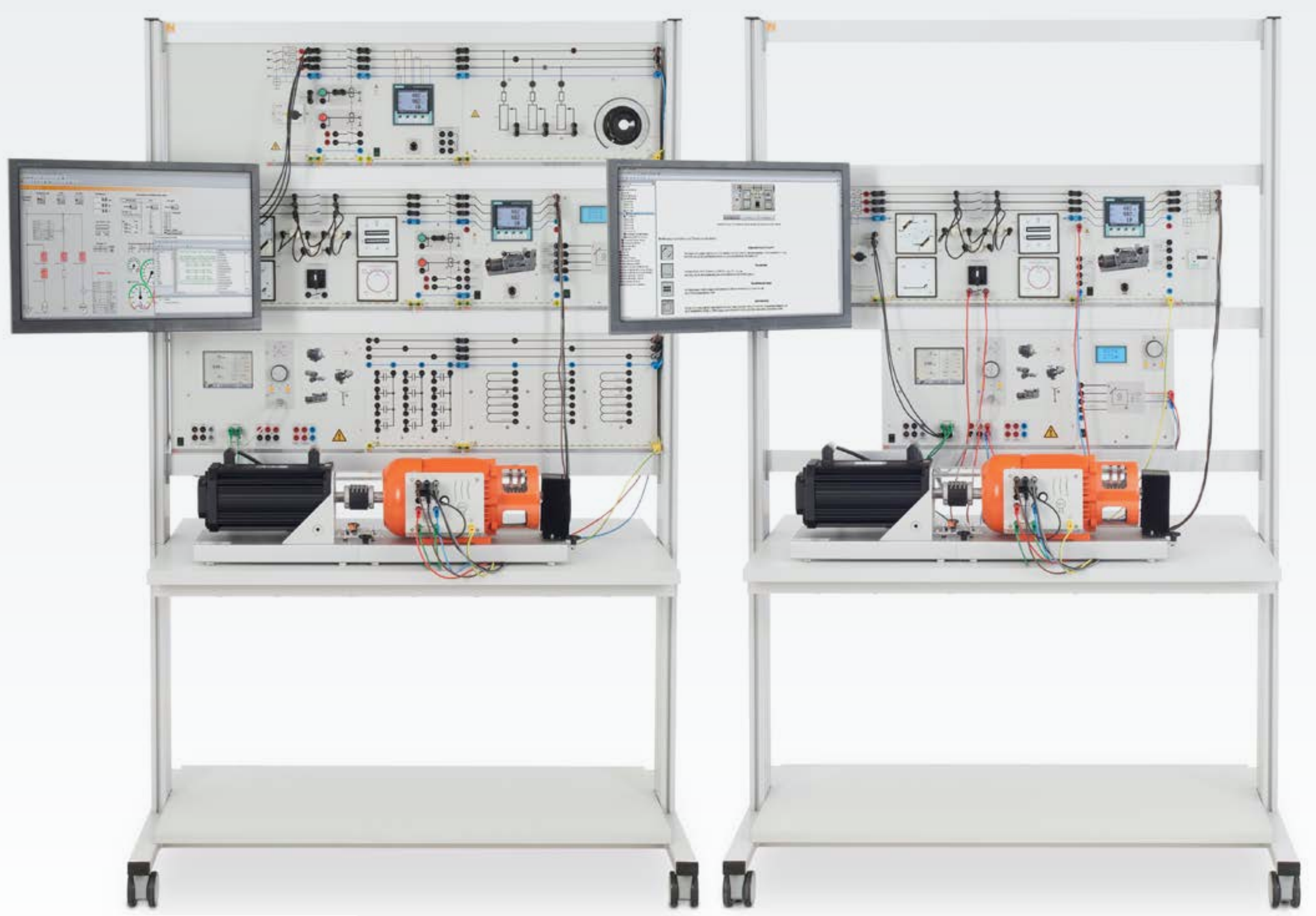
EUT – Investigating Transformers



EUL – Power Transmission Lines

ELP – Line Protection

BASIC EQUIPMENT SET: MICROGRID



Off-grid parallel mode / Microgrid
When this standalone system is coupled to the smart grid, then it is referred to as the microgrid. It has three operating modes: on-grid, off-grid and dual-mode. Microgrids will play a central role in the smart grids of the future.

Benefits

- Reduction of power transmission and transformer losses
- Independence from large power utilities
- Smart grid as a back-up system
- Intelligent power supply control and load control using SCADA
- Power generation with renewable energies
- Optimum current quality, reliability and sustainability

Order no. EMG

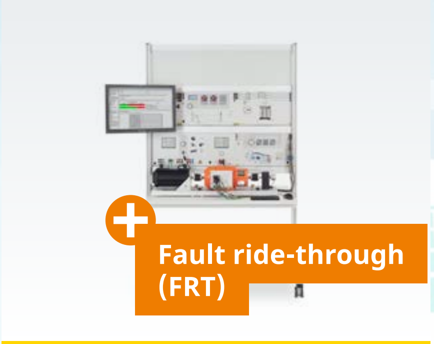
Training contents

- Automatic control of several generators in off-grid operation
- Automatic control of several generators in grid-parallel operation
- Coordination of energy demand and generation in off-grid mode
- Deployment of modern IT technology such as networked sensors/actuators, PLC control and SCADA user interface
- "Smart Metering" of a balance node to make a subnetwork autonomous.
- Manual control
- Automatic voltage control
- Automatic frequency control
- Automatic torque control
- Automatic cos-phi control
- Droop control

EXPANSIONS: MICROGRID

EMG 2 – Additional secondary system (up to three supplements)

EPH 3 – Professional Photovoltaics



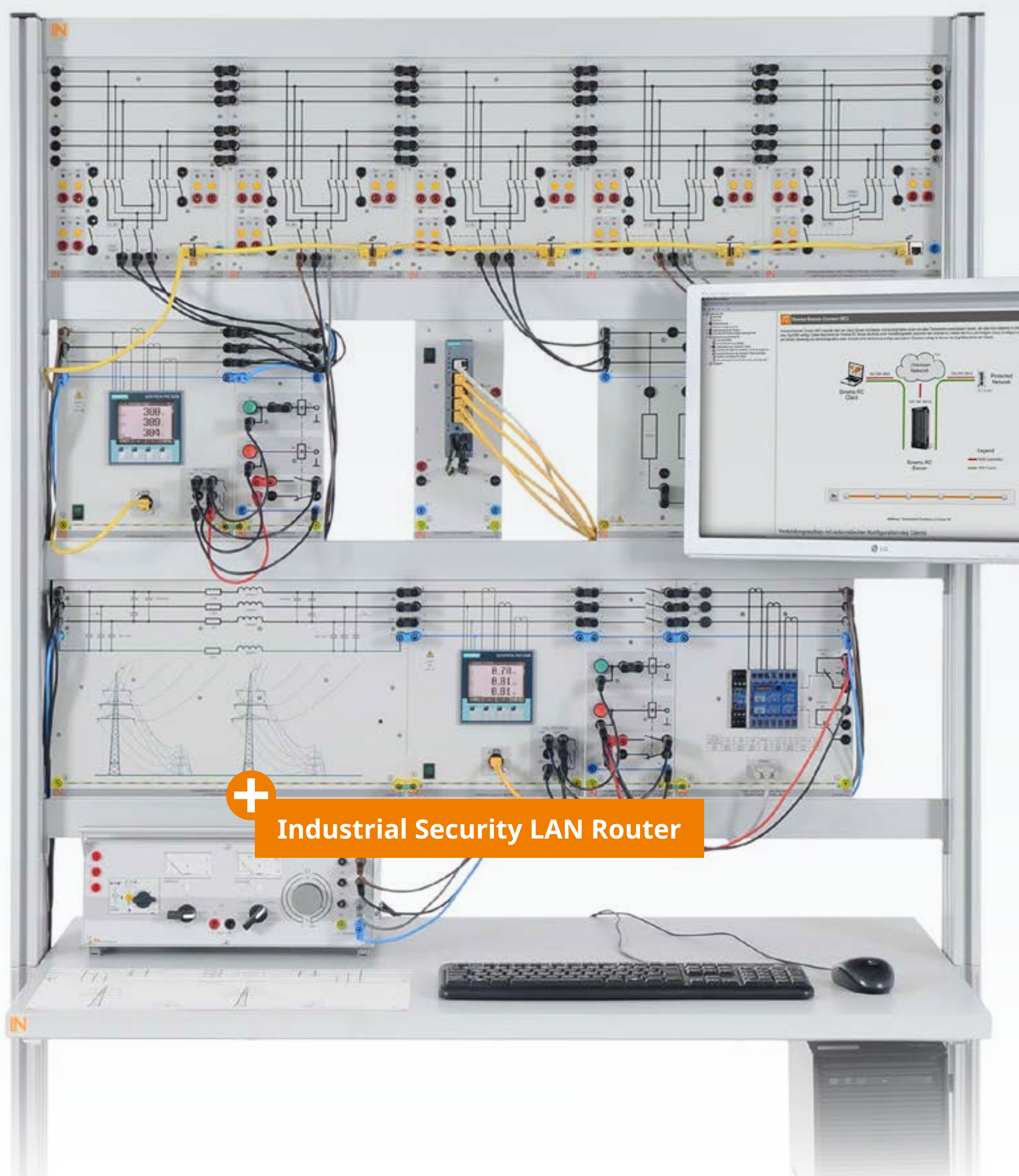
EWG 1 – Wind power plants (turbines)

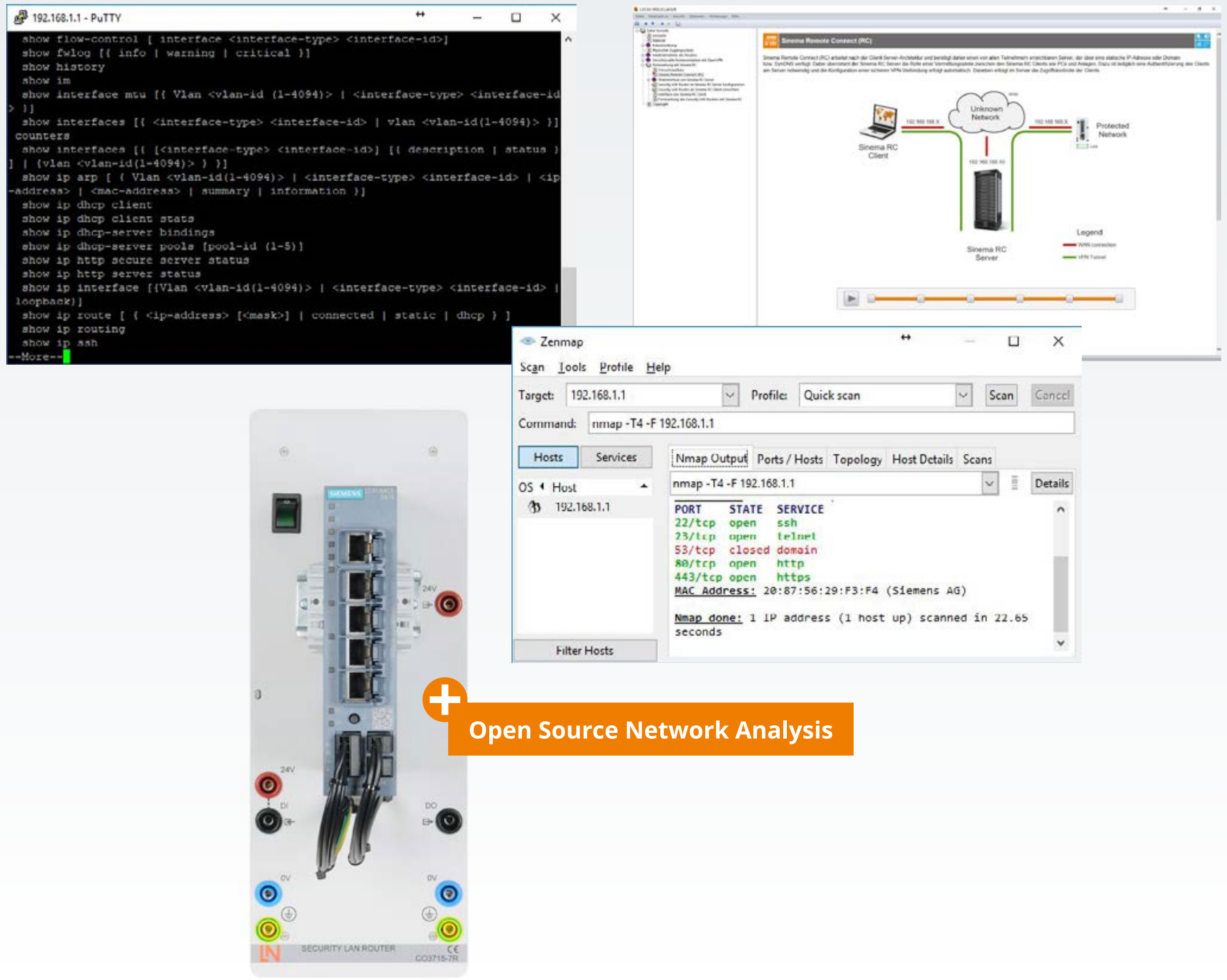
EUG 3 – Pumped Storage Power Plant

EUC 2 – Dynamic loads

ECS 1 – Industrial Cyber Security

INDUSTRIAL CYBER SECURITY





In modern power grids, the subject of cyber security is absolutely imperative. Using a host of exercises, we train all of the conventional safety measures used to combat cyber attacks on power engineering systems.

Training contents

- Code of conduct for operating such systems
- Physical measures
- Configuration of a security LAN router
- DHCP Server
- Firewall
- Open VPN
- Analysis of network protocols
- Secure Shell (SSH)
- HTTP(S)
- Remote monitoring with Sinema
- Access control / access restriction
- Authentication / clearance
- Encryption
- Certificates

Order no. ECS 1

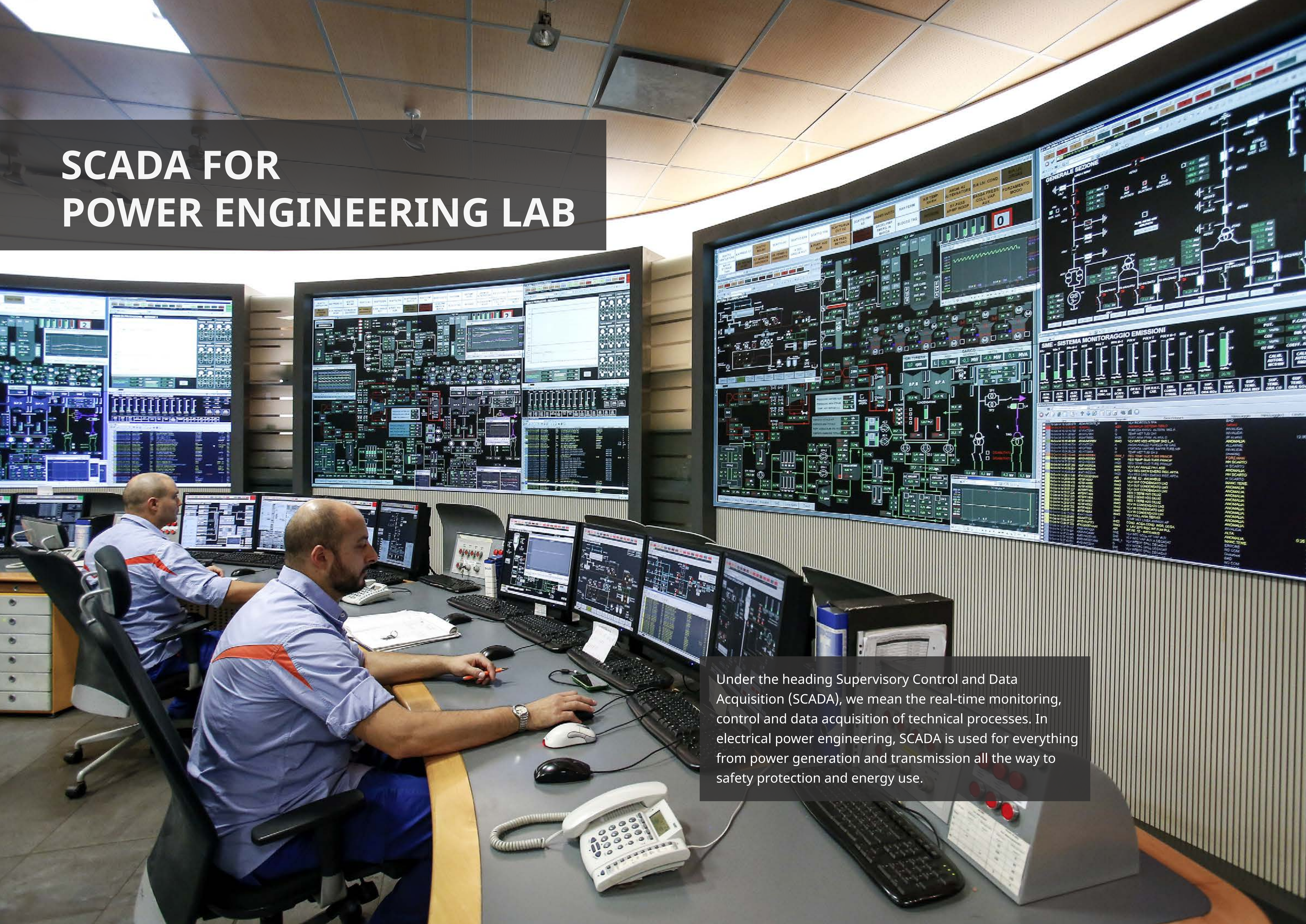
Industrial Security LAN Router

The SCALANCE S615 LAN router is used to protect equipment/networks in automation operations and to provide security for industrial communications via VPN and firewalls. Simple project planning is possible using web-based management.

Security functions

- Set up firewall: stateful inspection
- Product function / for VPN connection: IPsec, OpenVPN (as client for SINEMA RC)
- Type of encryption algorithms (VPN connection): AES-256, AES-192, AES-128, 3DES-168, DES-56
- Type of authentication procedures (VPN connection): Preshared Key (PSK), X.509v3 certificate
- Type of hashing algorithms (VPN connection): MD5, SHA-1, SHA-256, SHA-384, SHA-512
- Number of possible connections (VPN connection): 20
- Password protection
- Address conversion: NAT/NAPT
- Connection to SINEMA RC

SCADA FOR POWER ENGINEERING LAB



Under the heading Supervisory Control and Data Acquisition (SCADA), we mean the real-time monitoring, control and data acquisition of technical processes. In electrical power engineering, SCADA is used for everything from power generation and transmission all the way to safety protection and energy use.

SCADA FOR POWER LAB IN THE SMART GRID

Under the heading Supervisory Control and Data Acquisition (SCADA), we mean the real-time monitoring, control and data acquisition of technical processes. In electrical power engineering, SCADA is used for everything from power generation and transmission all the way to safety protection and energy use.

SCADA permits process data to be visualised and modified. Measured values are displayed on the screen in real time. Control signals can be adjusted during the process. The SCADA system can also automatically control the process. The recording of measurement values permits future process planning and economic optimisation. The system can be remotely controlled in local access networks (LAN) as well as via the internet.

SCADA for the Power Engineering Lab is a software designed for the control and monitoring of power engineering systems. Inside the software, all measurement values and operating states can be displayed on measuring devices within the system in real time. Critical parameters and signals can be controlled by the software.

The measured values and operating states of the devices can be selected, recorded and plotted over time. Signal evaluation and export are also possible.

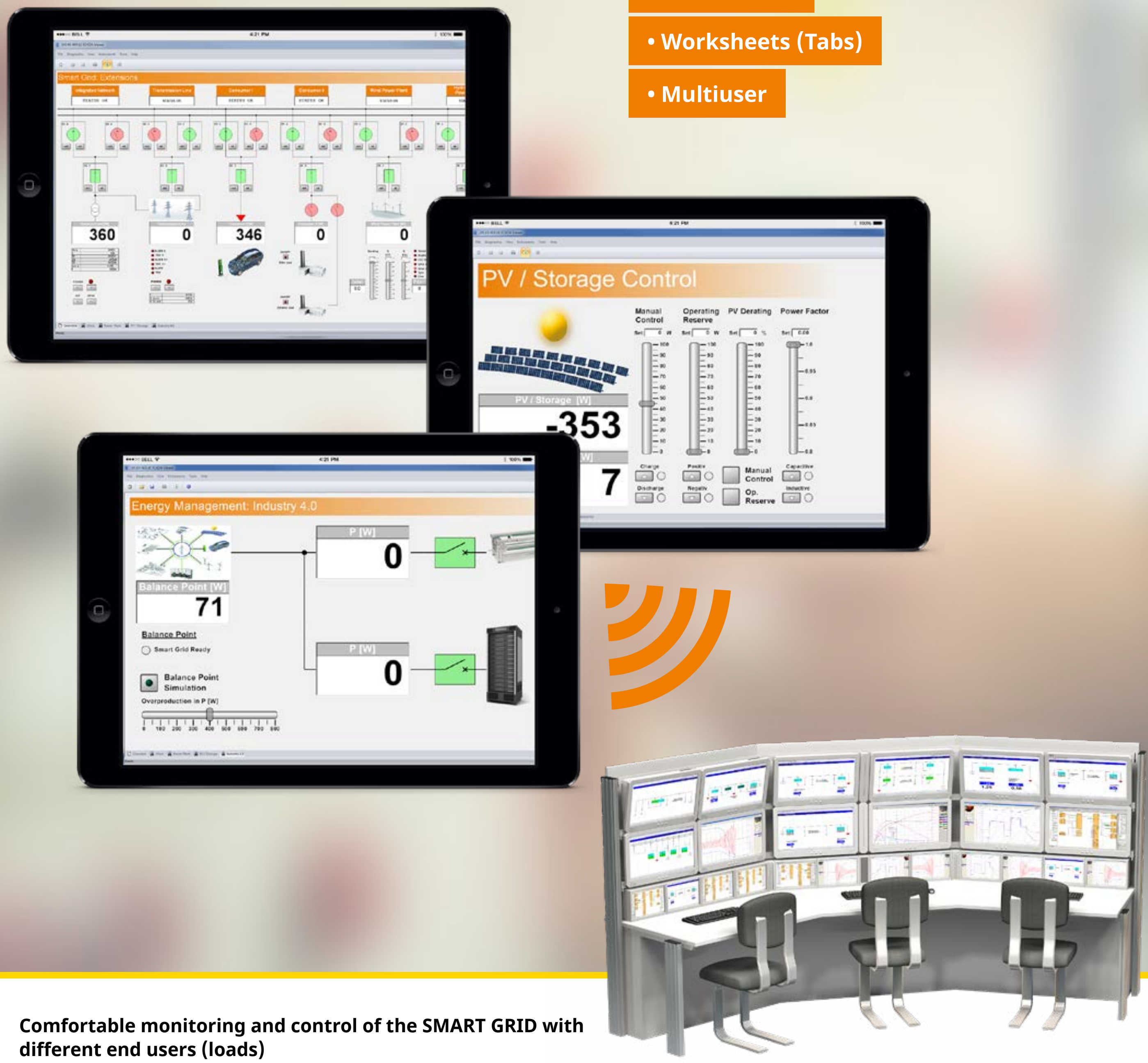
The SCADA Designer is used to create user interfaces. The viewer is the SCADA system for operating and monitoring the individual systems.

Features of the software

- **SCADA Designer**
  - Freely configurable user interfaces
  - Symbolic arrangement of all of the Lucas-Nuelle power engineering equipment
  - Standardised electronic circuit symbols for circuit visualisation
  - Individually configurable list of values to display any number of measurement values
  - Display of measurement values and operating states in real time
  - Implementation and analysis of smart grids
  - Design of multiple worksheets per system
- **SCADA Viewer**
  - Total control of the systems
  - Analysis of smart grids
  - Display of measurement values and operating states in real time
  - Configure files using SCADA Designer
  - Templates, i.e. sample files for all experiments
  - Multiuser capable

SCADA REMOTE CONTROL

- Tablet Mode
- Worksheets (Tabs)
- Multiuser

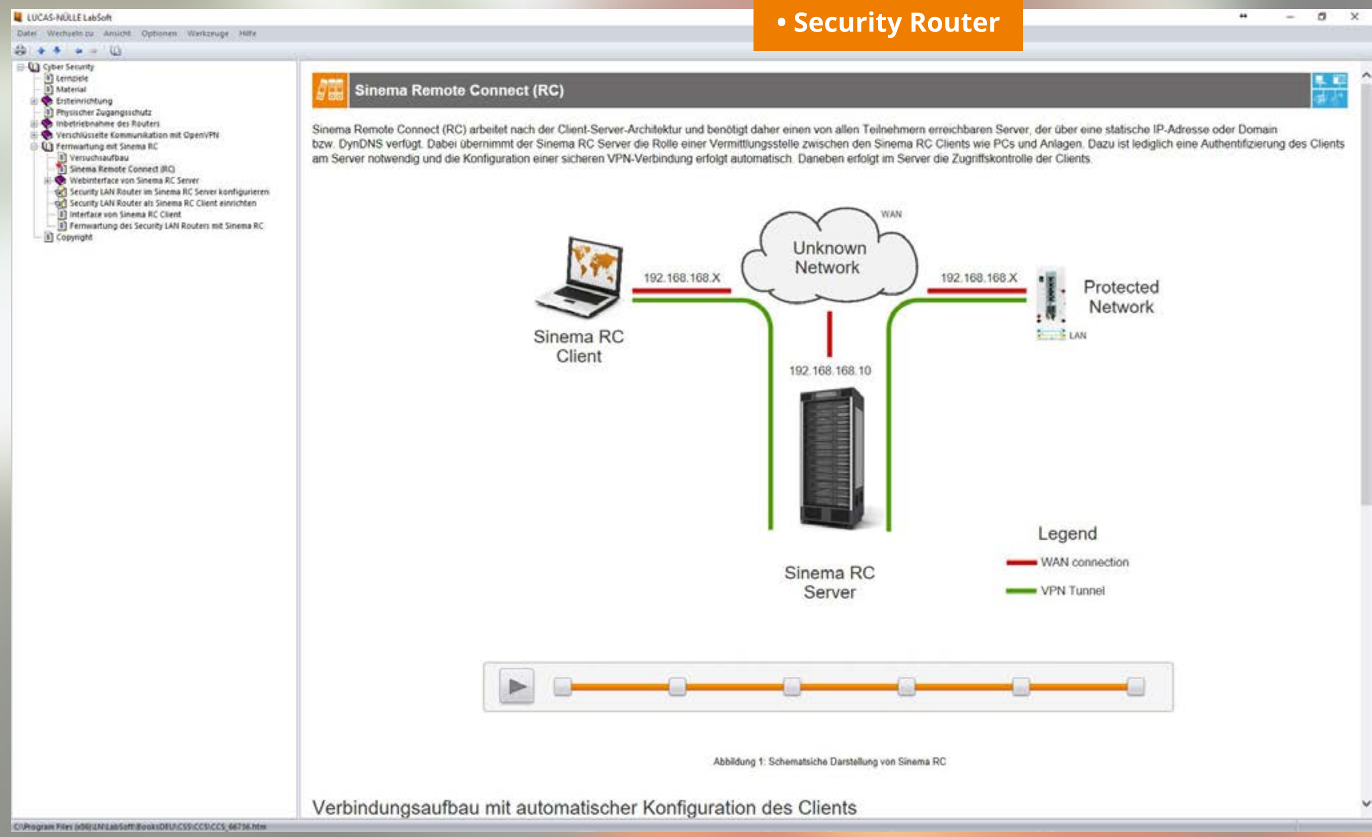


Comfortable monitoring and control of the SMART GRID with different end users (loads)

- Tablet mode
- Structured operation thanks to suitable worksheets:
  - Overview of the whole system
  - Operating the individual system
- Connection via WiFi
- Connection via Internet
- Simultaneous access from all computers

CYBER SECURITY

- Encryption
- Firewall
- Security Router



SO2805-4B: Course "Cyber Security in automation and power engineering technology“

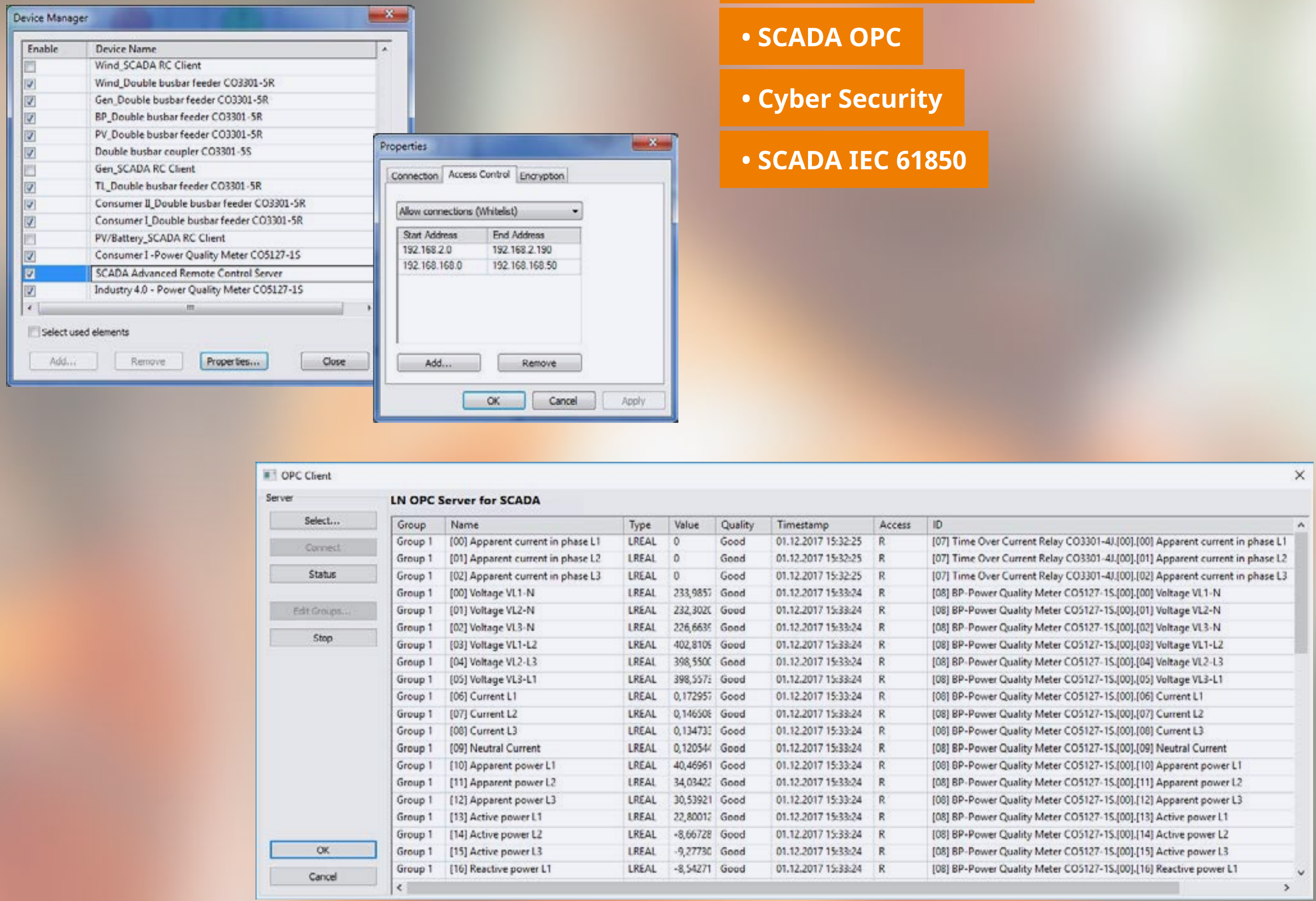
In modern power grids, the subject of cyber security is indispensable. All of the standard security measures used to combat cyberattacks on power engineering systems are covered with a host of exercises.

Training contents

- Code of conduct for operating systems
- Physical measures
- Configure a Security LAN Router
- DHCP Server
- Firewall
- Open VPN
- Analyse network protocols
- Secure Shell (SSH)
- HTTP(S)
- Remote control with Sinema
- Access control / restriction
- Authentication / enable
- Encryption
- Certification

SCADA NET

- SCADA Client Server
- SCADA OPC
- Cyber Security
- SCADA IEC 61850

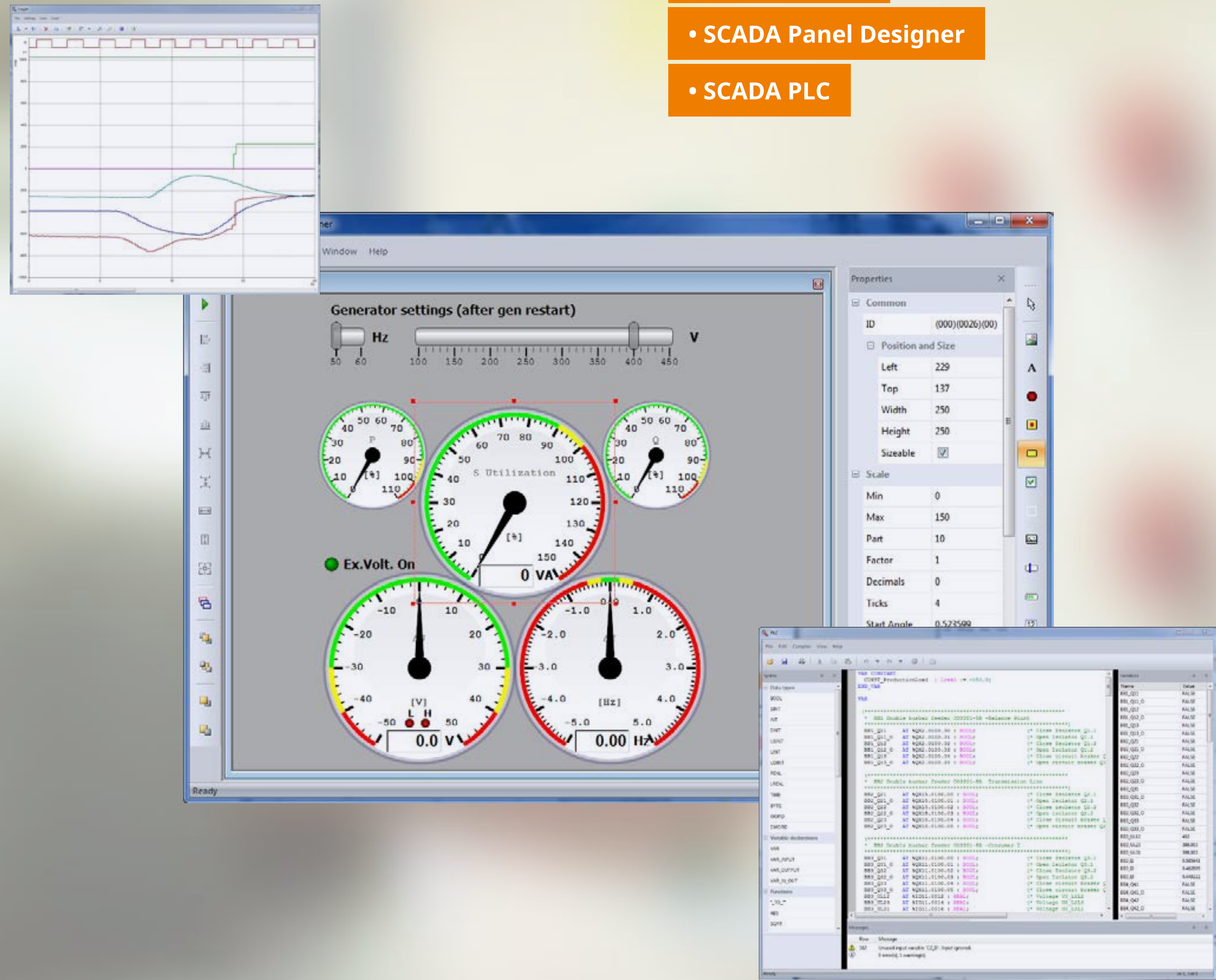


- **SCADA Remote Client / Server**
  - Monitoring and operating all systems on every PC inside the laboratory
  - The power engineering laboratory in the cloud
- **SCADA OPC Client**
  - Connection of external equipment, e.g. PLC
- **SCADA OPC NET Server**
  - Real-time connection to e.g. MATLAB®/Simulink® and LabVIEW via the OPC server

- **Cyber Security**
  - Restricting connections
    Access Control (Black / White List)
  - Encryption
- **Additionally supported protocols:**
  - SCADA IEC 61850 Client
    (connection of external equipment, e.g. PMU)
  - TCP/IP Client/ Server
  - MODBUS
  - SML (Smart Message Language)
  - HTTP

SCADA TOOLS

- SCADA Logger
- SCADA Panel Designer
- SCADA PLC



- **SCADA Logger**
  - Plotting graphs of measurement values and signals over time
  - Processing, analysing and exporting graphs
  - Scaling values

- **SCADA Panel Designer**
  - Design and configure one's own user interfaces

- **SCADA PLC**
  - Integrated Soft PLC
    (IEC61131 compliant)
  - Access to all values and signals in the smart grid
  - Automatic generation of variable lists
  - Monitor variables

POWER GENERATION WITH RENEWABLE ENERGY

The amount of renewable energy compared to fossil fuels like coal, oil, and gas is increasing more and more worldwide. The technical possibilities to utilise them are also on the rise, thanks to innovative concepts and engineering. Solar energy, wind power, hydrogen and biomass are well established and utilisable as environmentally friendly energy sources. Fluctuations in power generation are offset thanks to energy management, energy storage technologies and grid sector coupling. To be able to continue this trend and achieve the energy revolution, well-trained engineers and technicians will be needed all over the world.

PROFESSIONAL PHOTOVOLTAIC SYSTEMS – MODERN PV SYSTEMS OPERATING IN GRID-PARALLEL OPERATION

The set-up of PV systems is explored realistically in grid-parallel operation mode. For electricity grid stabilisation, techniques are taught involving derating the inverter and applying the regulatable local grid transformer. Theoretical knowledge, engineering know-how and PC-based evaluation of the measurement data are covered in detail by the photovoltaics professional multimedia course in conjunction with SCADA power lab software.

Training contents

Investigating solar modules

- Recording daily and annual solar irradiance
- Explore optimum alignment of solar modules (boosting energy yield)
- Recording solar module characteristics

Setting up PC systems in off-grid operating mode

- Measurement of energy generated by a PV system
- Derating the power of the PV inverter
- Determine the efficiency of the grid inverter
- Control operating response of the grid inverter, MPP tracking
- Recording the yield data using the solar emulator
- Investigating the response of the PV system to a power failure
- Economic efficiency of photovoltaic systems

Voltage regulation in the distribution substation

- Substation distribution transformer
- Derating the power of the PV inverter
- Automatic voltage regulation in the distribution substation
- Integration of modern PV systems within the SMART grid

Order no. EPH 3

INVESTIGATING BATTERY STORAGE UNITS WITH PV SYSTEMS

Take a look at the video on the subject!

Investigating battery storage units with PV systems

An electrochemical energy storage unit with a photovoltaics system strives to achieve a shift of electricity generation into the periods of power consumption or to shift the power consumption into the periods of power generation. For this to happen, the available solar energy must be generated and then stored to make it available for use when power is needed. The most important features of an electrochemical energy storage unit are therefore:

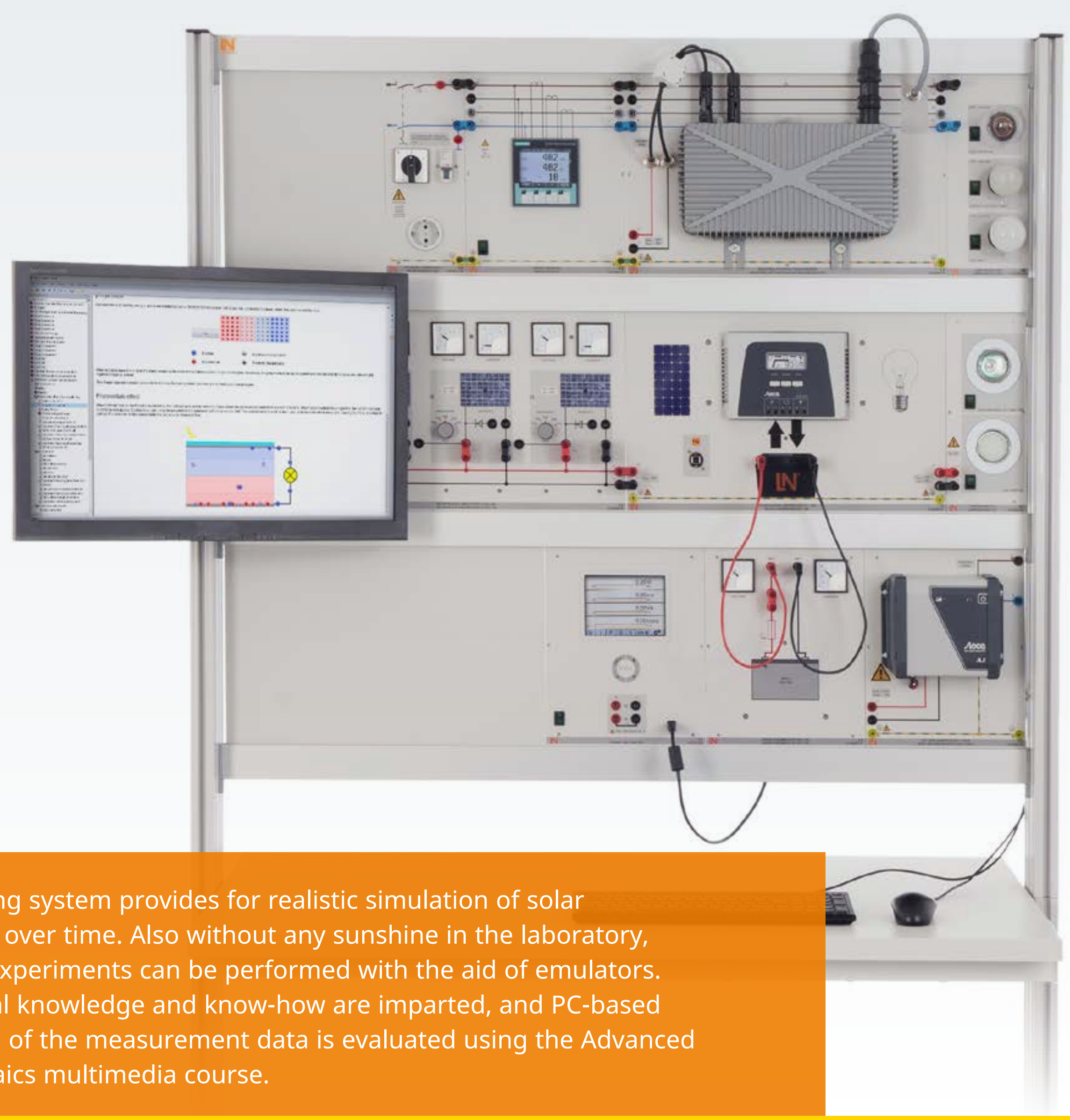
- Boosting intrinsic power consumption
- Power supply security thanks to emergency power

Training contents

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

Order no. EPH 3.4

ADVANCED PHOTOVOLTAICS – PROJECT WORK WITH INDUSTRIAL COMPONENTS



The training system provides for realistic simulation of solar irradiance over time. Also without any sunshine in the laboratory, practical experiments can be performed with the aid of emulators. Theoretical knowledge and know-how are imparted, and PC-based evaluation of the measurement data is evaluated using the Advanced Photovoltaics multimedia course.

Training contents

Investigation of solar modules

- Exploring optimal alignment of solar modules
- Recording solar module characteristics
- Investigating response during switch-off
- Investigating how the bypass diodes work
- Become familiar with different solar module connection types

Set-up of PV systems in off-grid operating mode

- Installation of PV systems
- Set-up and test of an off-grid (standalone) PV system in direct operation
- Set-up and test of an off-grid (standalone) PV system in storage mode
- Set-up and test of an off-grid (standalone) PV system for generating
- 230 V AC voltage

Set-up and test of a grid-parallel PV system

- Installation, set-up and testing of a PV system with grid feeding
- Measurement of a PV system's generated energy
- Determining the efficiency of the grid inverter
- Investigating the response of a PV system to a power failure

Order no. EPH2

SOLAR PUMPING SYSTEM

Solar pumps for an autonomous water supply

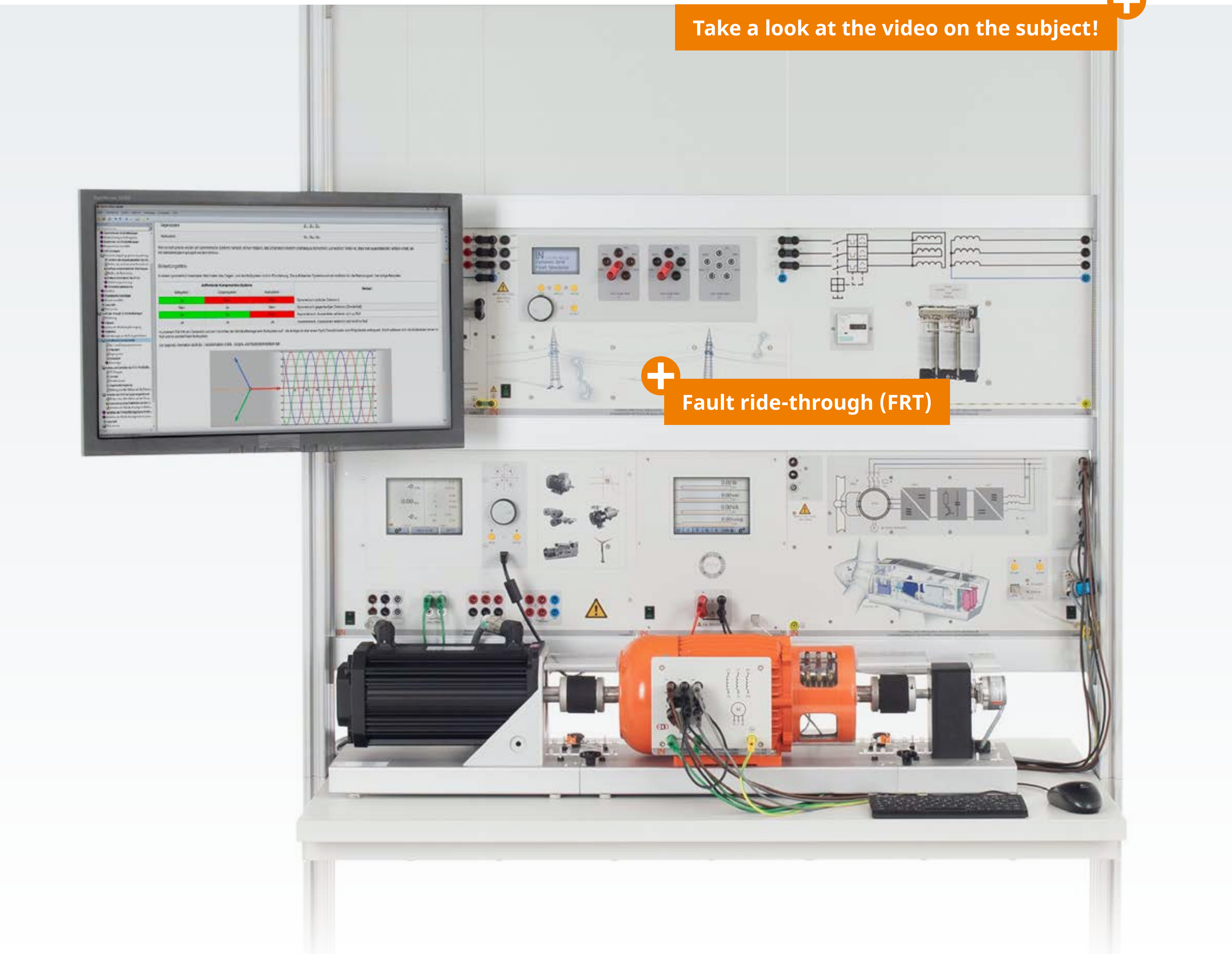
The combination of the solar pump system with the photovoltaic hybrid system permits the pumping of well water even without any sunshine because this hybrid system is also equipped with a battery storage unit. Besides pumping water, additional AC consumers can be supplied via the hybrid system. Here it is important that the components are trimmed to the corresponding requirements and to prioritise parameter configuration.

Training contents

- Distinguish between different solar pump systems
- Planning solar pump systems
- Measurement of flow rate
- Measurement of daily volume
- Investigating the operating response for different irradiance levels and shadings
- Investigating response with different irradiance durations per day
- Recording characteristics and calculating efficiency of the pump and the entire system

Order no. EPH 2.4

WIND POWER PLANTS (TURBINES)



Double-fed asynchronous generators (DFIG)
The equipment set permits the study of modern wind power turbines with "double-fed asynchronous generators". Wind can be realistically simulated using the servo machine test system and the "WindSim" software. Thanks to a PC connection, comfortable operation and visualisation are guaranteed while experimenting. The associated "Interactive Lab Assistant" multimedia course covers the theoretical background information and provides support in the experiment procedure and in the measurement data evaluation.

Training contents
- Understanding the design and function of modern wind power plants (turbines)
- Exploring the physical fundamentals going "from wind to shaft"
- Become familiar with different wind power plant concepts
- Setting up and putting into operation of a double-fed asynchronous generator
- Generator operation during fluctuating wind forces and regulation of output voltage and frequency
- Determining the optimum operating points under fluctuating wind conditions
- Investigating the operating response to grid faults
- "Fault ride-through"

Order no. EWG1

SMALL WIND TURBINES

Electricity for a decentralised power supply
Small wind turbines with power of up to 5 kW are used today for decentralised power supply. These turbines generate DC voltage. This power can be stored in batteries using charge controllers. AC voltages are generated using inverters for the operation of power system loads. The effect of wind force and the mechanical set-up of wind power turbines can be emulated realistically with the servo machine test system and the "WindSim" software.

Training contents
- Understanding the design and operation of small modern wind turbines
- Exploring the physical fundamentals going "from wind to shaft"
- Become familiar with different wind power system concepts
- Setting up and putting into operation a small wind power generator
- Operation with fluctuating wind forces in storage mode
- Energy storage
- Power system optimisation
- Set-up of an off-grid power plant for the generation of a 230V AC voltage
- Hybrid systems for self-sufficient power supply

Order no. EWG 2

THE EXPANDABLE HYBRID PHOTOVOLTAIC SYSTEM

The Expandable Hybrid Photovoltaic System
The training system permits a realistic set-up of a hybrid photovoltaic system using industrial components. The fault-protected terminals and safety connections help provide a safe environment for operating the system. Complicated energy flows within the hybrid system are visualised graphically and evaluated with the aid of SCADA. Off-grid, grid-connected and uninterruptible power supply (UPS) operating modes can be simulated using the compact training system. The experiments are performed in the lab using a solar field emulation. That means reproducible experiment results are obtained even without any sunlight.

Training contents

- Configuration of the charging characteristic for the accumulator
- Efficiencies of the system components
- Operating principles of an inverter
- Dimensioning the system components
- Set-up and configuration of the components
- Consideration of different operating modes: Off-grid, grid-connected and UPS operation
- Analysis of complex energy flows with SCADA
- Expandable with the small wind turbine to create a microgrid
- Hybrid systems for self-sufficient power supply

Order no. EPH4

Real components as expansion
The training system can be combined with the small wind turbine and solar pump training systems to make a microgrid. Optionally the system can be expanded by adding a real PV and wind power turbine system to deploy the training system outside of the laboratory.

Sensible expansion for the hybrid photovoltaic system

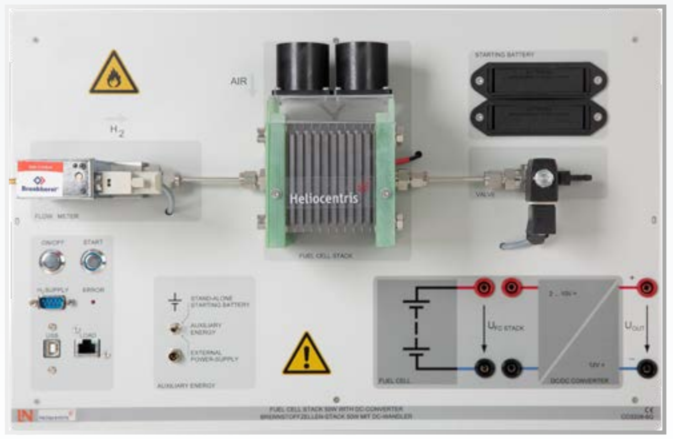
- Small wind turbine system (EWG2)
- Solar pump (EPH2.4)
- Solar module CO3208-1X

Order no. EPH 2.4 Order no. Solar module CO3208-1X
Order no. EWG 2

ADVANCED FUEL CELL TECHNOLOGY

"Interactive Lab Assistant"

- Step-by-step multimedia instructions
- Demonstrating physical fundamentals using easy-to-understand animations
- Test learning progress using the questions from the evaluation tool
- PC-based evaluation of measurement data
- Start virtual measuring instruments directly from the experiment instructions



50 VA fuel cell stack

Fuel cell stack

- 50 VA stack
- Flow-rate meter for hydrogen feed line
- Fan with variable speed to ventilate fuel cells
- Measurements of all relevant variables

Self-sufficient power supply with fuel cells

The generation of electrical power with the aid of fuel cells is developing more and more into an essential area with a multitude of technical applications in electrical and automotive engineering. The experiment system makes it possible to safely explore a host of interesting subjects on how to work with hydrogen and fuel cells and is suitable for demonstrations and for hands-on practical experience. Animated theory, experiment instructions and results are realised with the aid of the "Interactive Lab Assistant".

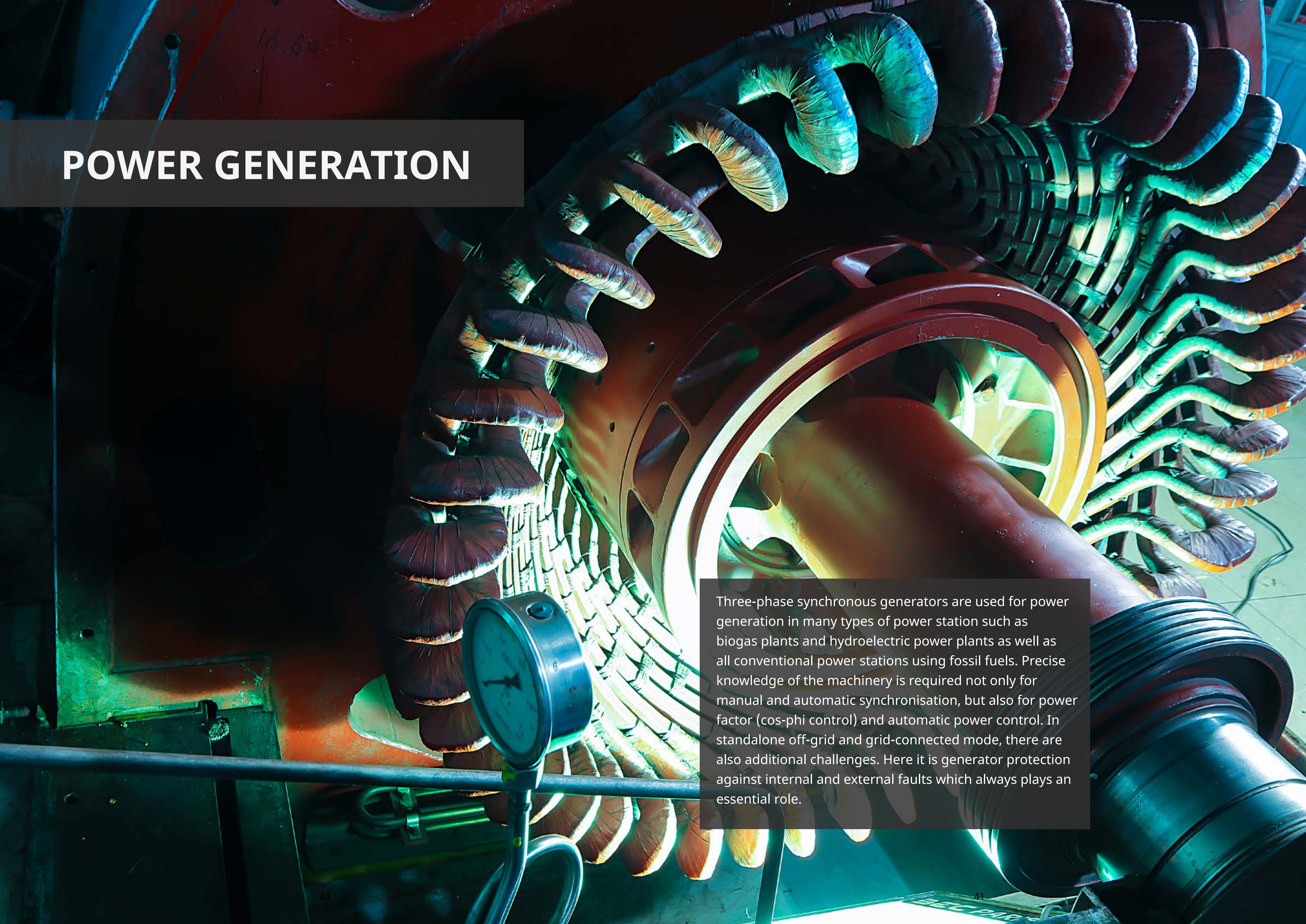
Training contents

- Design and operation of fuel cells
- Design and operation of an electrolyser
- Design and function of a metal hydride canister
- Thermodynamics of fuel cells
- Characteristics and power curves of fuel cells
- Efficiency
- Necessary components for a self-sufficient power supply
- Power electronics and voltage conversion

Benefits

- Conveying theoretical knowledge and practical know-how using the "Interactive Lab Assistant" multimedia course
- Easy introduction to the subject of fuel cells
- Safe experimenting with hydrogen
- 50 VA fuel cell stack
- Connection terminal for hydrogen pressure tank
- Powerful electrolyser
- A host of loads
- Variable load for recording characteristics

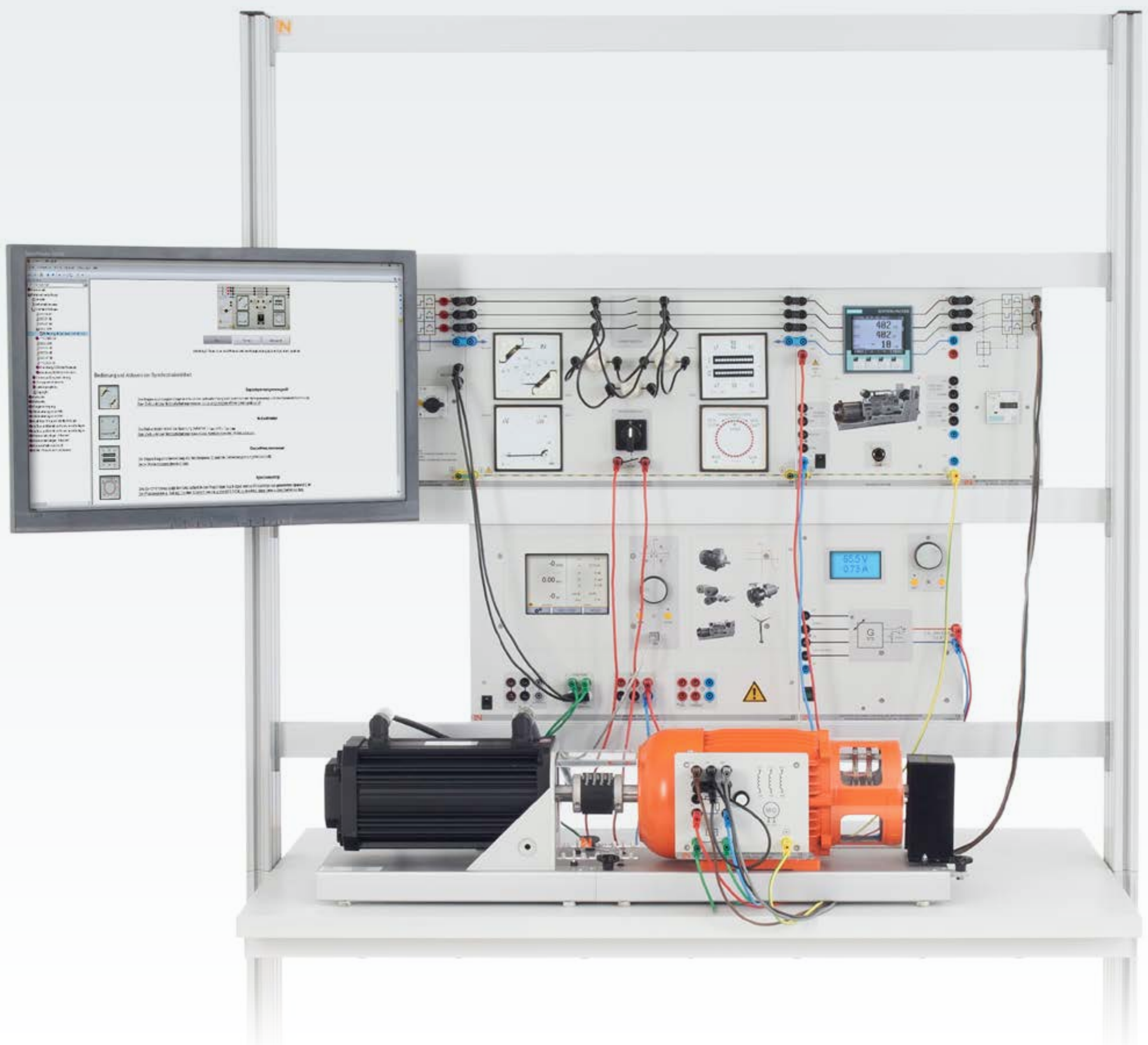
Order no. EHY 1



POWER GENERATION

Three-phase synchronous generators are used for power generation in many types of power station such as biogas plants and hydroelectric power plants as well as all conventional power stations using fossil fuels. Precise knowledge of the machinery is required not only for manual and automatic synchronisation, but also for power factor (cos-phi control) and automatic power control. In standalone off-grid and grid-connected mode, there are also additional challenges. Here it is generator protection against internal and external faults which always plays an essential role.

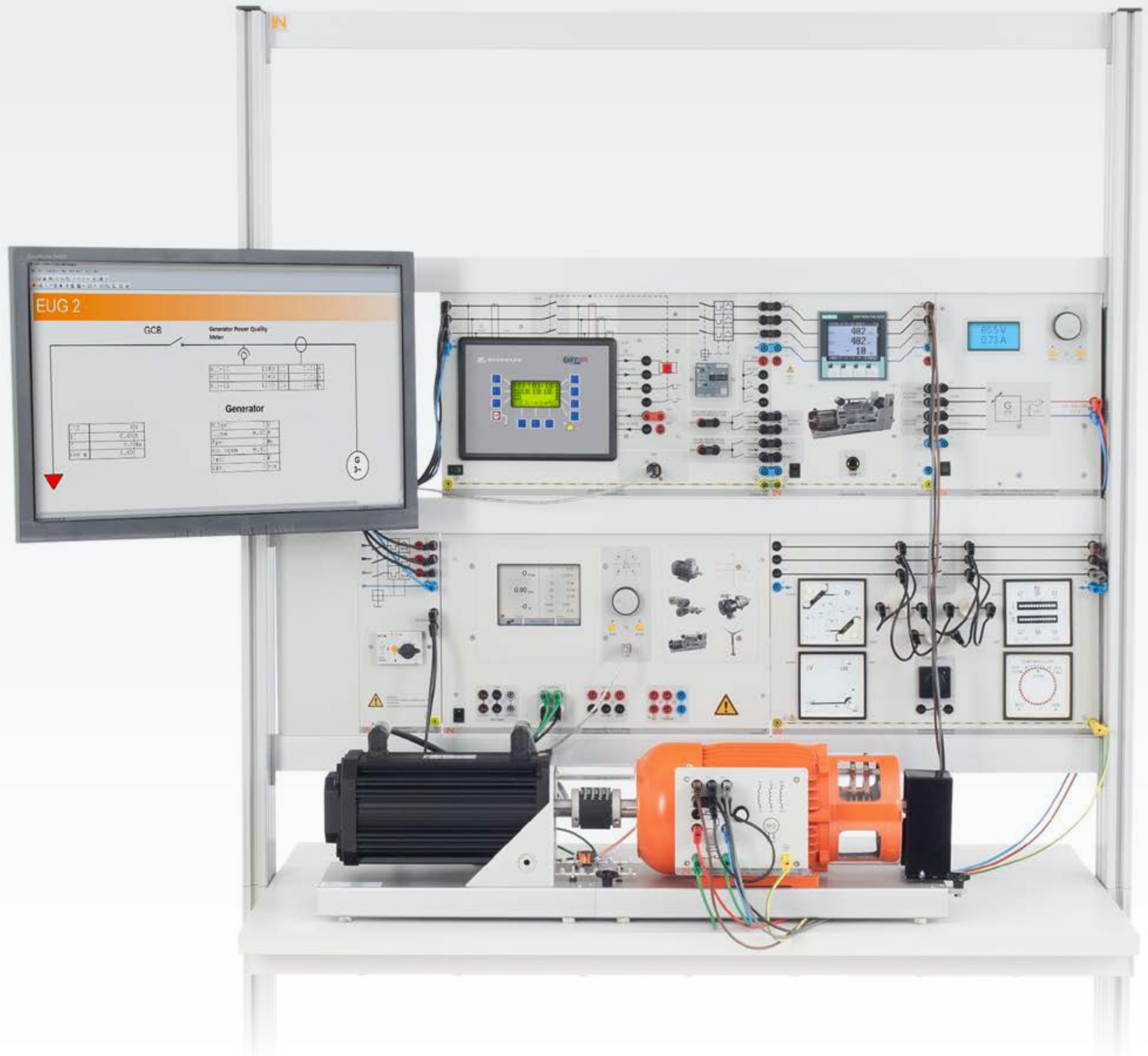
AUTOMATIC GENERATOR CONTROL AND SYNCHRONISATION



Manually activated synchroniser circuits
Electrical power is primarily generated by three-phase generators. This is true for conventional steam and hydroelectric power plants as well as for power generating sets and wind power generators. In addition to the basic experiments on three-phase synchronous generators, a variety of experiments are carried out on manually activated synchroniser circuits.

Training contents
- Dark lamp circuit
- Bright lamp circuit
- 2 bright 1 dark lamp circuit
- Active power generation
- Lagging reactive power
- Leading reactive power

Order no. EUG1

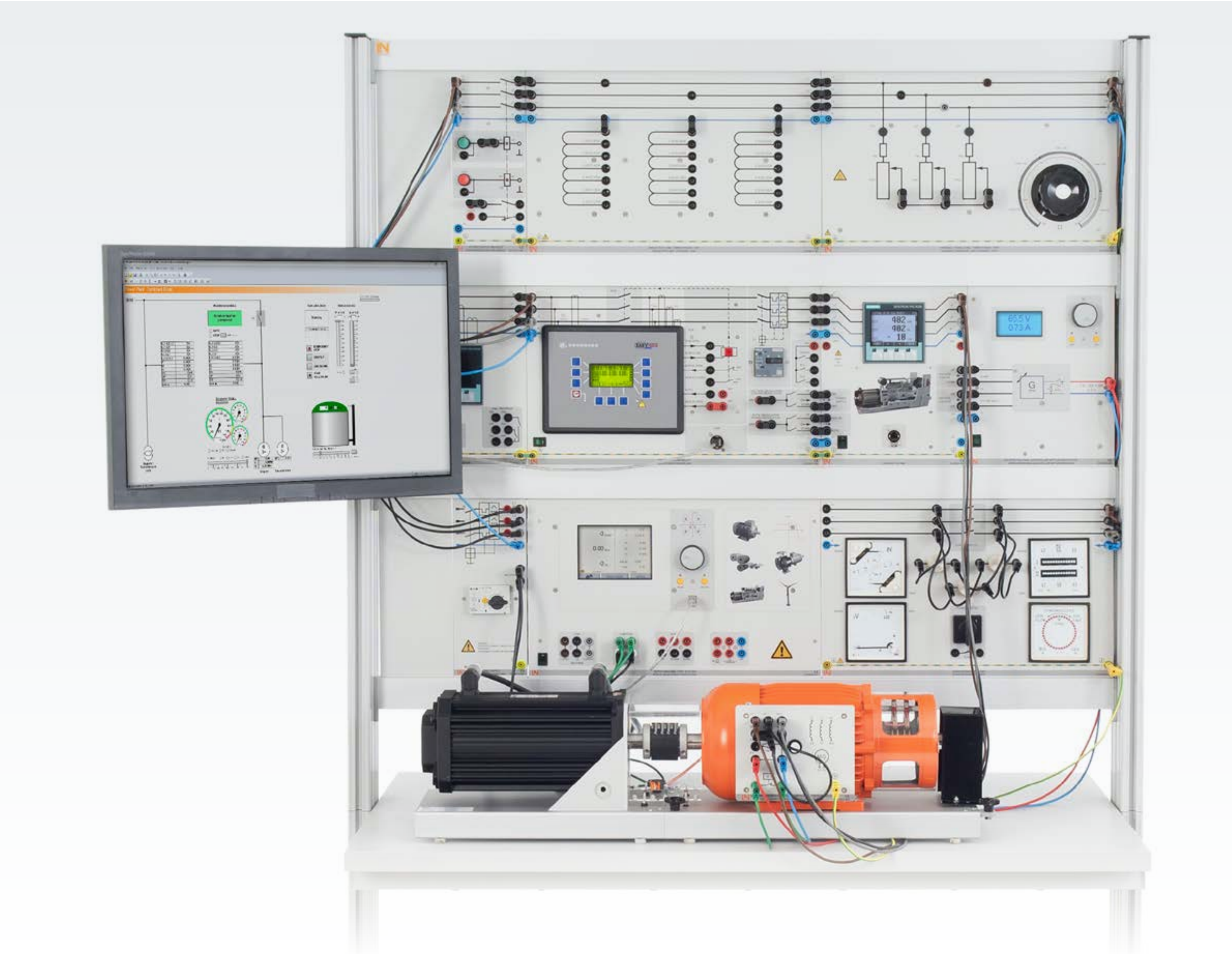


Automatic synchronisation circuits, automatic power and power factor control
In addition to the experiments on automatic synchroniser circuits, experiments are also conducted on automatic power factor (cos-phi) and power control. That means a power station can be simulated in off-grid standalone mode and grid-connected mode.

Order no. EUG2

Training contents
- Automatic synchroniser circuits
  - Putting into operation and configuring the automation device
  - Synchronisation in testing mode
  - Synchronisation on the real power system
  - Operating response of the automation device in the event of faulty programming
- Automatic power factor control
  - Parameter configuration of the automatic cos-phi controller
  - Synchronisation of the generator to the grid
  - Automatic cos-phi control of the synchronous generator
  - Automatic cos-phi control of the grid
- Automatic power control
  - Parameter configuration of the automatic power controller
  - Synchronisation of the generator to the grid
  - Response of power controller to setpoint changes and disturbances
  - Sensitivity and action direction of the power controller

POWER STATIONS



24 h Power Cycle - CO3301-5L01

Coal-Fired Power Plant - CO3301-5L02

Gas-Fired Power Plant - CO3301-5L03

Biogas CHP - CO3301-5L04

Nuclear Power Plant - CO3301-5L05

Hydroelectric Power Plant - CO3301-5L06

Emulation of different power stations

In the experiments, the following power station types are explored and compared to one another on the basis of their typical operating characteristics and parameters. Also the pump storage power station is examined in more detail as an energy storage unit in the smart grid.

- Lignite-fired power plant
- Hard coal-fired power plant
- Gas turbine power plant
- Gas and steam-turbine power plant
- Biogas combined heat and power plant
- Nuclear power station
- Hydroelectric power plant
- Pump-storage power plant

Order no. EUG 4

Training contents

- Synchronisation equipment
  - Putting a multifunction relay into operation
- Generator operation
- Grid synchronisation
  - Configuring the parameters of a multifunction relay
  - Automatic synchronisation
- Manual power control in generator and motor mode
- Automatic generator control using SCADA
- Power stations
  - Types of power stations
  - Typical characteristics and parameters
  - Commissioning and operating different power station types
  - Explore how power stations operate

GENERATOR PROTECTION

Multifunction relays
Effective generator protection against internal and external faults requires the use of a host of protective measures and devices. The time overcurrent protection forms the back-up protection for the generator and can also be used for the detection of external faults such as short-circuit and overloading. Faults to ground are detected with the stator earth fault protection. The "EGP" experiment series on generator protection is rounded off with an exploration of reverse power protection and unbalanced load protection as well as overvoltage/undervoltage protection.

Training contents
- Time overcurrent protection
- Unbalanced load protection
- Reverse power protection
- Over and undervoltage protection
- Stator earth fault protection

Order no. EGP 1

Generator differential protection
The generator differential protection which detects internal faults like short-circuit, winding and interwinding faults or double line-to-ground faults serves as the primary protection device.

Training contents
- Calculating the tripping values of the protection mechanisms
- Fault detection within the protection range
- Testing the tripping and the deexcitation in the event of faults inside and outside the protection range
- Disconnection and deexcitation of the generator
- Measurement of the tripping currents of the protection device for balanced and unbalanced faults
- Comparing the measurement values with the set parameters

Order no. EGP 2

Rotor earth fault protection
The rotor earth fault protection is used to determine earth faults inside the excitation circuit of synchronous machines.

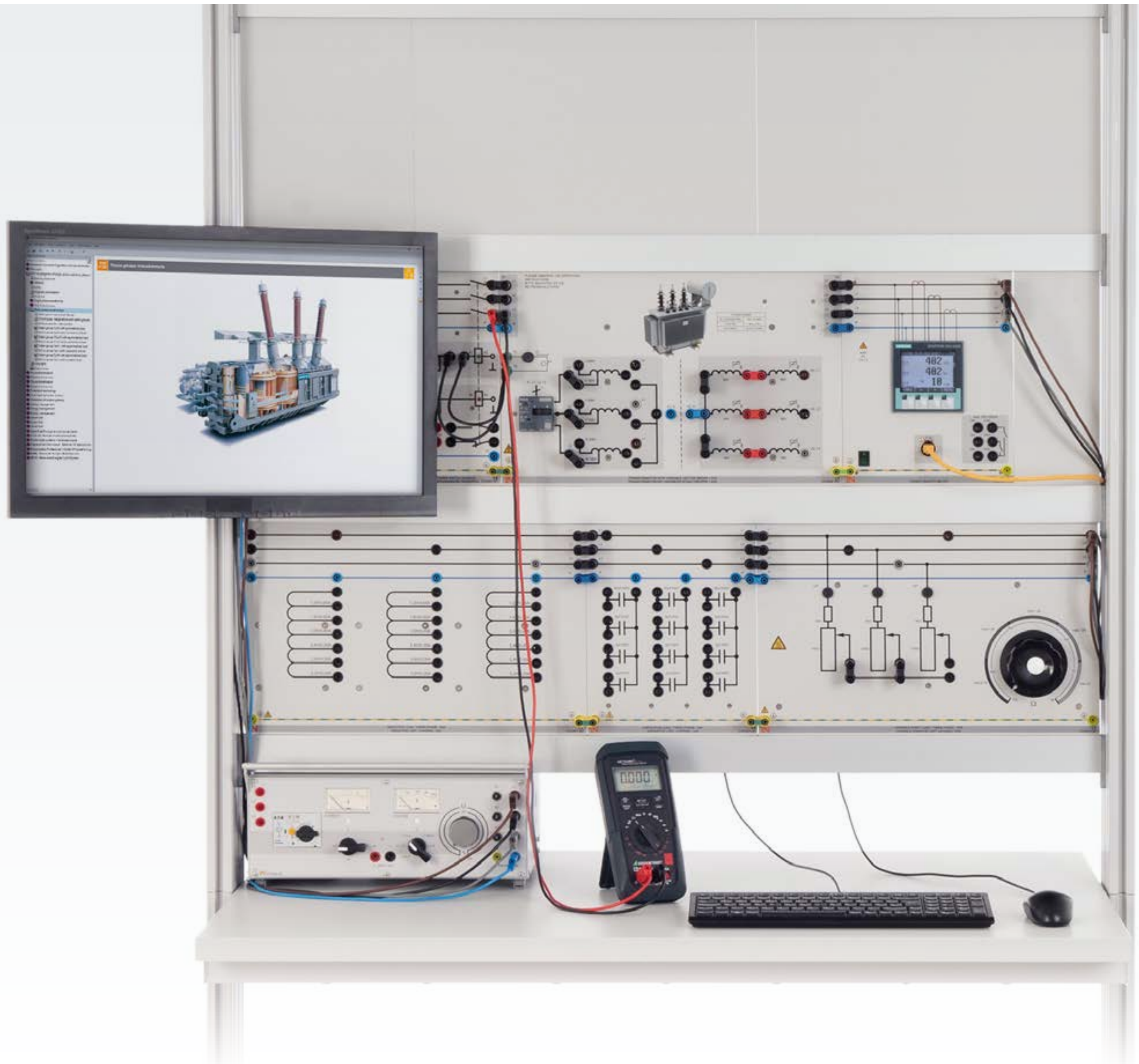
Training contents
- Putting the synchronous generator into operation
- Investigation of a rotor earth fault during normal operation
- Measurement of the rotor earth fault current
- Rotor earth fault relay during earth fault operation
  - Connection and testing the rotor earth fault relay
  - Presetting different rotor earth-fault short circuits
  - Testing the fault signalling and the disconnection process

Order no. EGP 3

TRANSFORMERS

Transformers are used in power engineering to connect different power grid voltage levels with each other.
In transformer stations, the electricity of the regional distribution system with the medium voltage of 10 to 36kV is transformed to the 400 or 230 V used in the local transforming substation for the purpose of supplying power to lower voltage end customers. The heart of a substation is the transformer, which needs protective equipment. By carrying out hands-on measurements and fault simulations on the training system, students gain an understanding of the complexity of such systems in the classroom.

INVESTIGATIONS ON TRANSFORMERS



Transformers

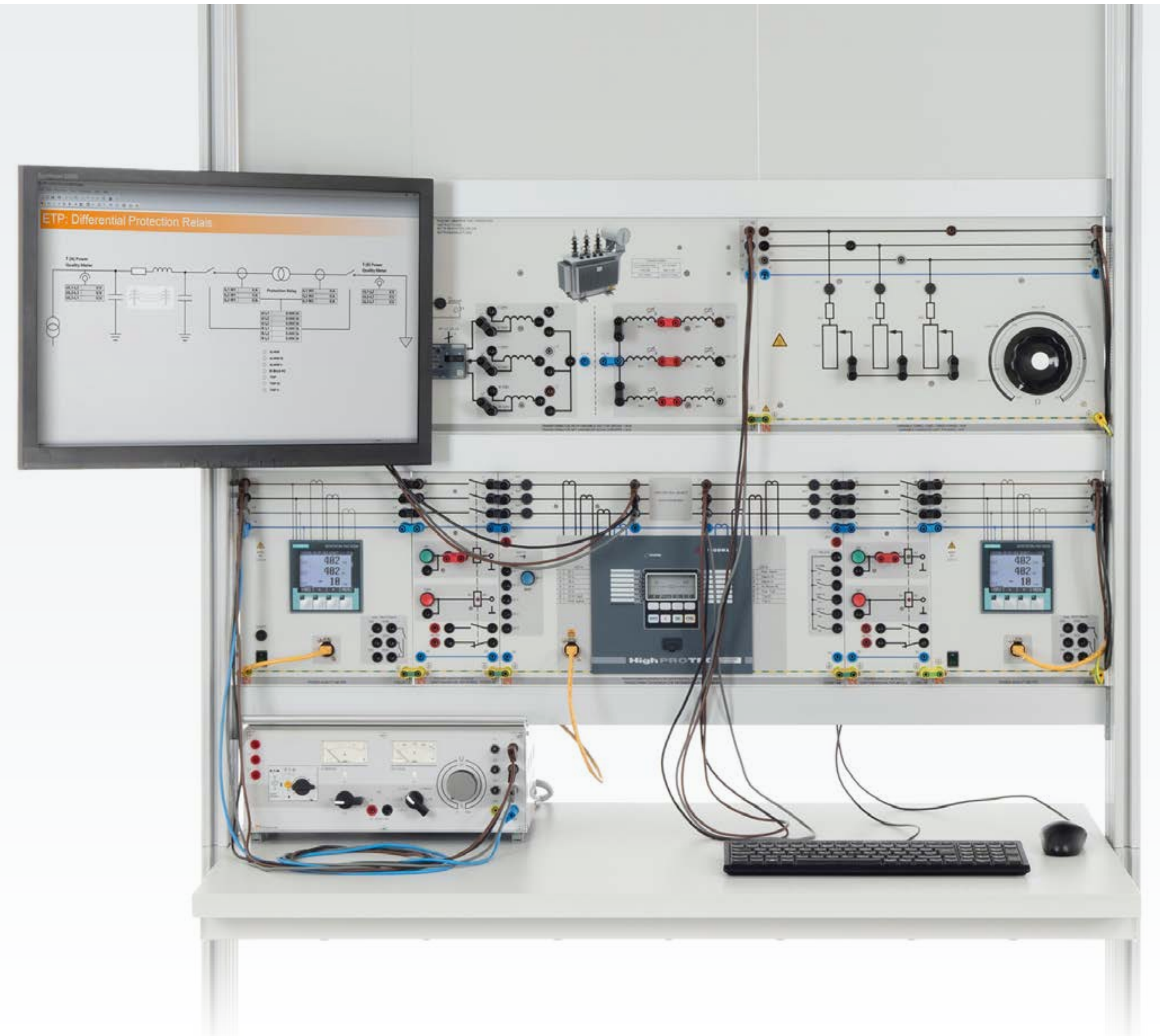
In power engineering, transformers are used to connect different power grid voltage levels to each other. In the experiments, we cover the transformer equivalent circuit diagram

Training contents

- Transformer equivalent circuit diagram
- Multiphase transformer operating in no-load and short-circuit operation
- Multiphase transformer with resistive, inductive and capacitive load
- Parallel operation of multiphase transformers
- Current distribution for different vector groups
- Determination of zero impedance
- Investigating the transmission ratio

Order no. EUT

TRANSFORMER PROTECTION



Transformer differential protection

Use measurement techniques to explore differential protection for transformers (as of approx. 1 MVA) for different winding configurations (star, delta) in various vector groups and, depending on the star point treatment (floating, direct earth connection or via earth fault coil), in normal operation and in the event of a variety of different fault scenarios.

Time overcurrent protection

The time overcurrent protection complements the protection measures of the transformer differential protection device. The time overcurrent protection safeguards the transformer from short-circuits outside the protection range and against overload.

Order no. ETP

Training contents

- Detection and disconnection of transformer in case of internal faults
- Detection of peak inrush currents (RUSH) without disconnection
- Faulty triggering due to incorrectly dimensioned transformer
- Selection of tripping characteristic with the differential currents taken into consideration
- Configuring time overcurrent relay with the current transformation ratio taken into consideration
- Detection of tripping values for balanced and unbalanced faults
- Faulty tripping of the protection device due to transformer's switch-on response
- Transformer switch-on response in terms of protection

CURRENT AND VOLTAGE TRANSFORMERS

Current transformer for protection devices

Current and voltage converters are used in a wide variety of different jobs in electrical power engineering. These experiments investigate the power transmission response, the overcurrent limit factor, magnitude and phase angle errors e.g. for different loads. Furthermore, system requirements can be explored for standard operation, short-circuit, and unbalanced faults.

Training contents

- Current transformer secondary current as a function of the primary current
- Impact of loads on current faults
- Testing the rated overcurrent factor (accuracy limit)
- Current transformer circuit in a three-wire power system
- Current transformer circuit in a four-wire power system
- Determination of residual current

Order no. EUB 1

Voltage transformer for protective devices and equipment

The protection of system installations and system components is not only dependent on the protective equipment selected, but also on the correct detection and measurement of the smallest fault currents and voltages. Various measurement circuits are used for different star point configurations in order to be able to detect and locate potential faults.

Training contents

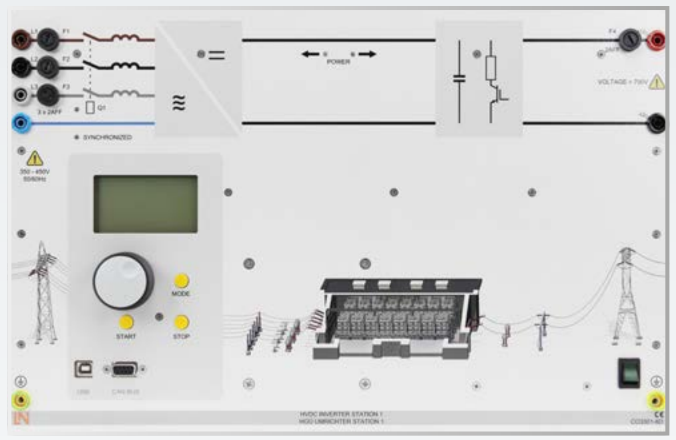
- Voltage converter characteristics
- Calculation of voltage faults and class accuracies
- Impact of loads on the transformation ratio
- Three-phase voltage transformer in a healthy power system
- Three-phase voltage transformer in a power system with an earth fault on the primary side.

Order no. EUB 2

POWER TRANSMISSION

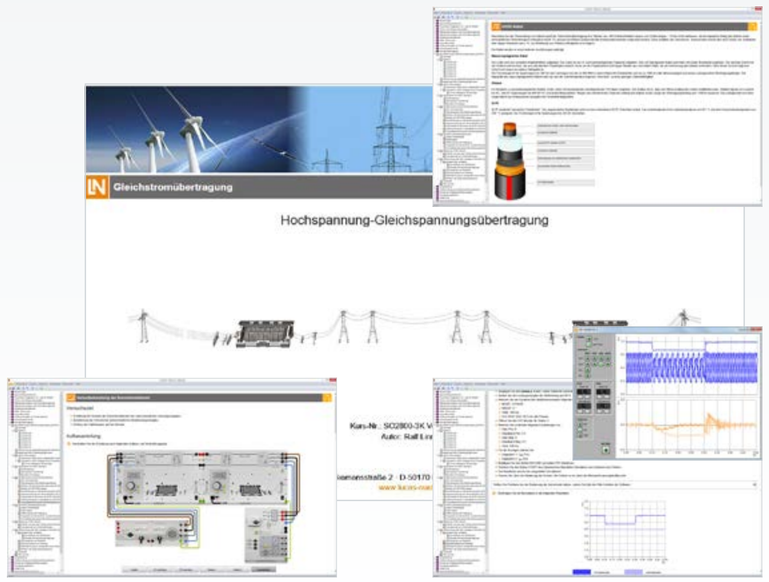
High voltage grids are generally operated with voltages of 110 kV up to 380 kV, while cities and large industrial plants are supplied with 110 kV and 380 kV is selected for long-distance power transmission. The transmission line model is designed such that the model voltages are at a level between 110 V and 380 V. Different line lengths can be selected using corresponding overlay masks. Investigations on the training system can be carried out in no-load, in normal operation, in short-circuit mode, and with unbalanced faults including earth fault with and without compensation. Over and beyond this, it is possible to set up complex structures by connecting the transmission line models in parallel or in series configuration. The voltage feed can be carried out using a stiff power system with constant voltage and frequency or via a synchronous generator.

HIGH VOLTAGE DC POWER TRANSMISSION



Inverter station

- Active power control in both directions
- STATCOM operating mode
- Connection of synchronous generators, wind turbines and loads
- Coupling between grids with different frequencies
- Self-sufficient automatic control of reactive and active power, frequency, voltage
- Measurement and display of all system variables
- Manual and automatic synchronisation with active power grids
- Power transmission of up to 1000 W



"Interactive Lab Assistant"

- Step-by-step multimedia instructions
- Demonstrating physical fundamentals using easy-to-understand animations
- Testing learning progress using questions with evaluation tool
- PC-based evaluation of measurement data
- Start virtual instruments directly from the experiment instructions
- Interactive demonstration of experiment set-ups
- Transfer measurement results to course via "Drag and Drop"

Sustainable power transmission for the efficient and reliable power grids of the future

High voltage DC transmission (HVDC) is one method of transmitting electrical power with high DC voltage. HVDC technology serves in transmitting power using DC current over long distances. This is because, as of a certain distance and despite additional converter losses, HVDC features lower transmission losses than transmission via three-phase voltages. The high voltage DC transmission is also frequently used to transmit power over comparatively short distances when the power transmission cable is designed with very high capacitance per unit length. This is typically the case for deep-sea cables or even underground cables.

Order no. EDC1

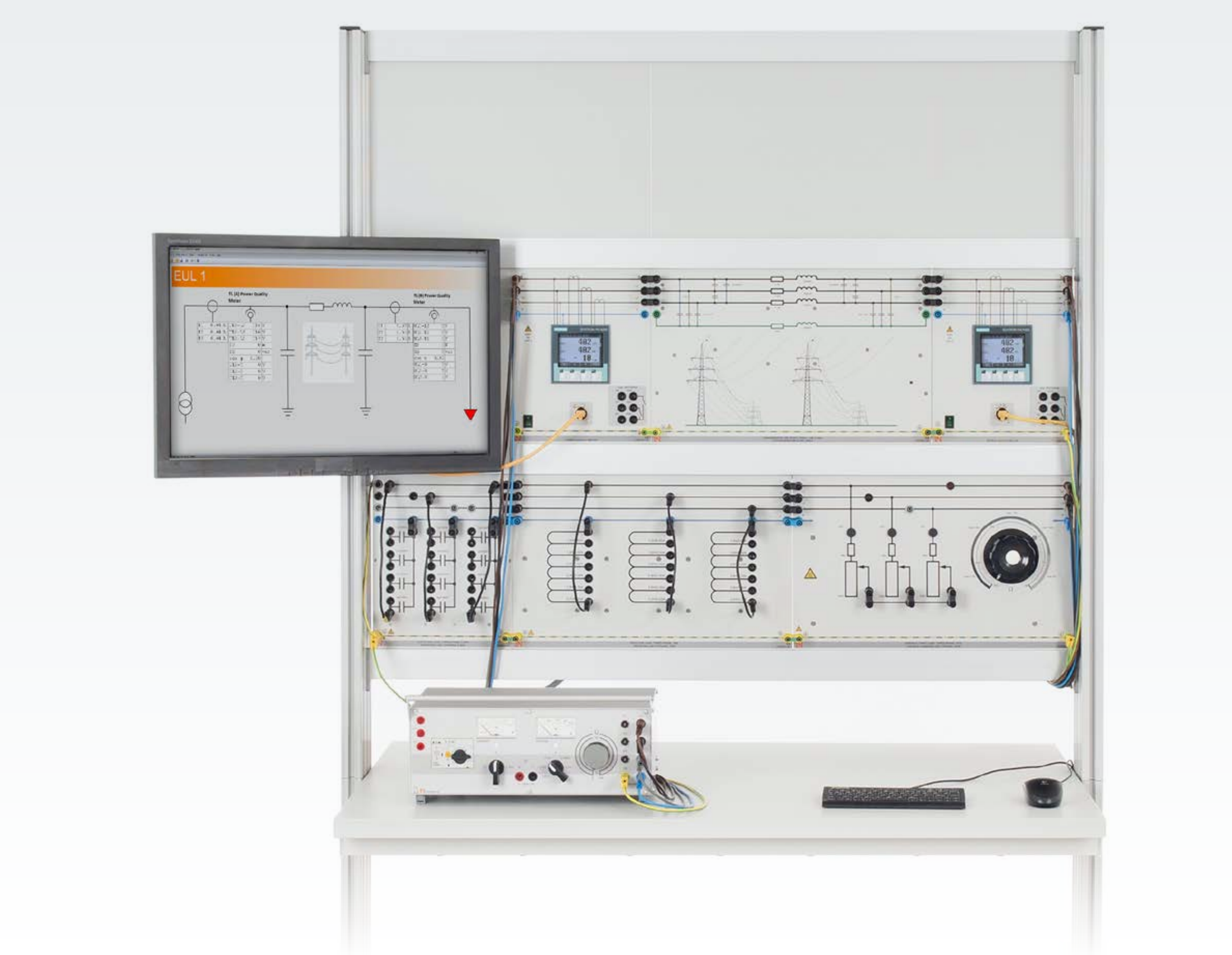
Training contents

- Automatic control of the DC link voltage
- Reactive power provision without active power flow (STATCOM)
- Manual and automatic synchronisation with the grid
- Automatic active power control of the DVDC with power flow change
- Individual automatic reactive power control for both inverter stations
- Considering power loss for varying HVDC cable lengths
- Power supply via HVDC (black start) to a grid with passive loads
- Coupling wind turbines
- Investigating FRT response of HVDC systems

Benefits

- Theoretical knowledge and know-how learned using the "Interactive Lab Assistant" multimedia course
- PC-based evaluation of measurement data
- Integration into the power engineering systems
- State-of-the-art technology with "fault ride-through"
- The microcontroller-operated control unit of the inverter station gives the system user-friendly operation and visualisation while doing the experiments
- Modern HVDC (Voltage Source Converter, VSC)
- SCADA control - monitor and control the inverter stations within the smart grid

TRANSMISSION LINES



Investigations of three-phase lines

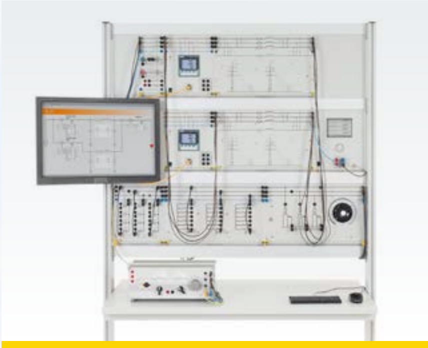
For your own safety, the investigation of 380 kV and 110 kV transmission lines and their interconnection takes place on the lower voltage level without losing the properties of real high voltage lines. These realistic transmission line models of a 3880kV cable and a 110 kV cable switch automatically back and forth between different transmission line lengths when the overlay masks are put in place. There is also the possibility of configuring complex networks thanks to the use of different transmission cable models.

On three-phase transmission line models in parallel configuration, the power transmission parameters with feed-in from a rigid grid with constant frequency and voltage or with generator feed-in are measured and the operational relationships are evaluated both quantitatively and qualitatively.

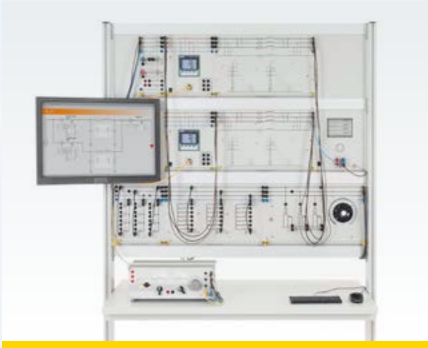
Order no. EUL

Training contents

- Capacitive and inductive power loss
- Phase shift, load distribution, power flow and voltage distribution
- Earth fault compensation
- Power and current distribution of a generator-fed wiring network
- Ferranti effect, charging power, critical length
- Resistive, inductive and mixed resistive-inductive load
- Determining the zero phase-sequence impedance
- Balanced and unbalanced short-circuits
- Star-point treatment and earth fault
- Overhead power line, transformer station and cable
- Difference between unregulated/regulated transformer
- Transformer with in-phase, quadrature and phase angle regulation
- Controllable substation transformer



EUL 1 – Investigations on three-phase transmission lines

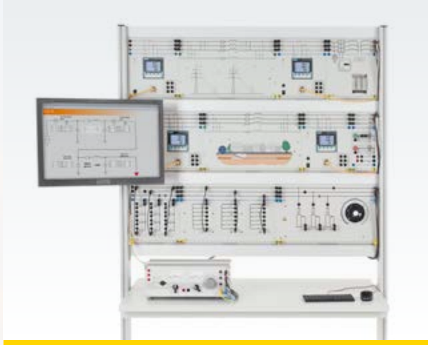


EUL 2 – Parallel and series connection of transmission lines

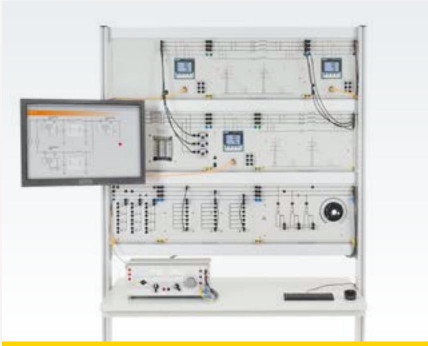
EUL 3 – Transmission line with earth fault compensation

EUL 4 – Power transmission systems with synchronous generator

EUL 5 – Investigations on three-phase cables



EUL6 – Combined network of cables and lines



EUL 7 – Controlling flow of power in meshed networks

EUL 8 – Load-dependent voltage regulation of a power transmission line

LINE PROTECTION

Line protection
Any failure affecting components in the power supply in lower, medium and high voltage power systems can have huge repercussions on the systems downstream and the power grid in general. Furthermore, these components are a valuable investment. The protective equipment is supposed to protect these components from the effects of electrical faults and help guarantee a reliable power supply to those consumers unaffected by this. It is essential that faults are detected immediately and reliably and selectively disabled.

Training contents
- Measurement and configuration of protection relays
- Determining pick-up and drop-out values
- Determining operating delay time (base time)
- Relay response
- Set and test various characteristics

Order no. ELP

ELP 1 – Overcurrent time protection for lines

ELP 2 - Directional overcurrent time protection

ELP 3 - Overvoltage and undervoltage protection

ELP 4 - Directional power protection

ELP 5 - Earth fault voltage protection

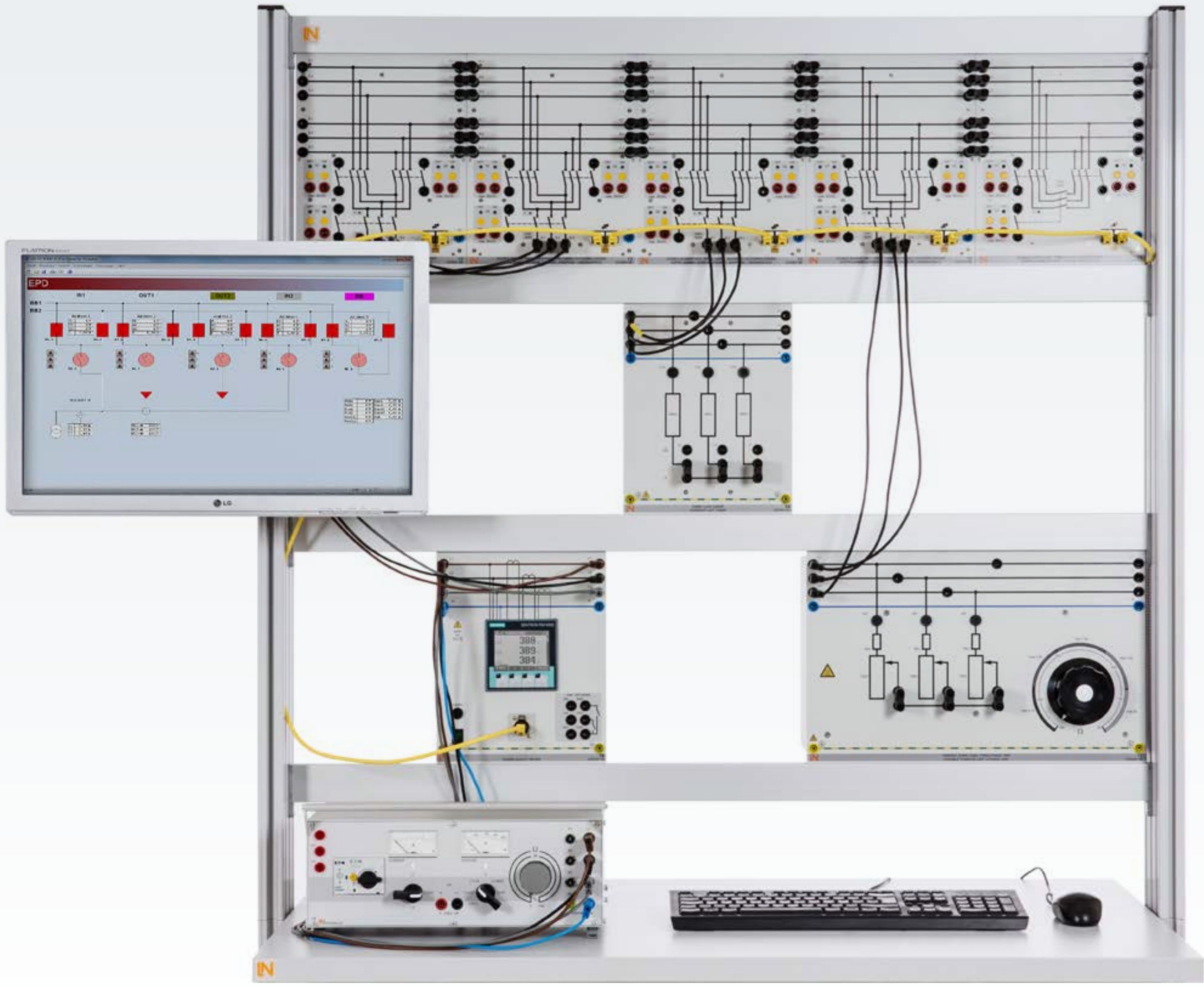
ELP 6 - Protection for lines connected in parallel

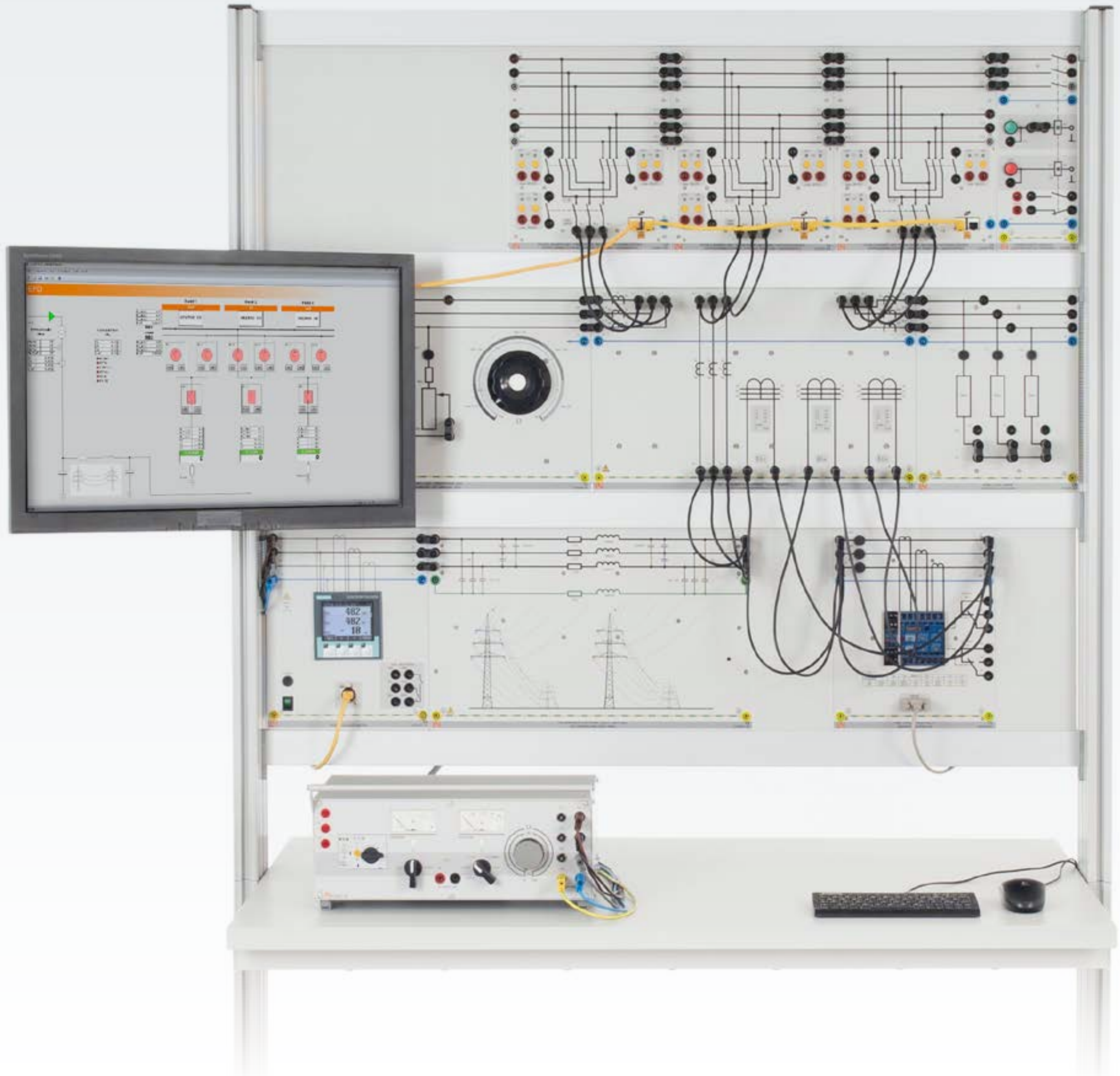
ELP 7 - High-speed distance protection

POWER DISTRIBUTION

The distribution of electrical power is performed in bigger switchgear systems almost exclusively using double busbar systems. These switching systems contain coupling fields for the connection of the two busbars, incoming feeders and outgoing feeders as well as measurement coupling fields. In the incoming, outgoing and coupling feeders there are power circuit breakers and one isolator in each busbar connection terminal. For safety reasons, the switching logic used here has to be strictly adhered to. The double busbar model contains all functions which are relevant for actual work on the job. Integrated measurement equipment for currents and voltages makes it possible to immediately assess and analyse switching operations.

THREE-PHASE DOUBLE BUSBAR SYSTEM





Centrally distributed and controlled
Double busbars serve as centralised trunks of electrical power because all of the incoming and outgoing lines are connected to the busbars. Busbars are comprised of in-feeders, out-feeders, coupling and converter panels. In the Lucas-Nuelle equipment set, these functions are combined into switchgear panels which contain circuit breakers, isolators and measuring devices.

Training contents

- Basic circuitry of a three-pole double busbar system
- Three-phase double busbar system with load
- Busbar switching without branch interruption
- Explore switching algorithms for different switching operations
- Busbar coupling

Order no. EPD

Overcurrent protection for busbars
Thanks to busbar differential protection, the incoming and outgoing current undergo summation using a current transformer. In the case of residual currents, the tripping criteria are determined on the basis of the characteristic sensitivity.

Training contents

- Detecting currents in normal operation
- Detecting currents in 1-pole, 2-pole or 3-pole short-circuit
- Faults outside the protection range
- Protection response to faults inside and outside of the switchgear system

Order no. EDP

ENERGY MANAGEMENT

A rational utilisation of energy is becoming ever more important due to economic and environmental needs. The experiments on manual and automatic reactive power compensation, as well as experiments on reducing the peak load by measurements with an active current and maximum counter, demonstrate how the grid load can be reduced or evenly distributed over 24 hours. For the measurement technology to be used effectively, the grid and the connected consumers must be analysed. Therefore, static, dynamic, symmetrical and asymmetrical loads can be examined in depth in the individual experiments. Furthermore, the protection of electrical consumers is an important part of the training.

ENERGY MANAGEMENT

Complex loads, energy consumption measurement and peak load monitoring
The experiments on reducing peak load through measurements using active current meters and maximum meters show how the power grid load can be reduced or distributed evenly over 24 hours. The prerequisite for the effective use of measurement technology is an analysis of the grid and all connected loads. For that reason, static, balanced and unbalanced loads are studied in detail in the individual experiments.

Training contents

- Three-phase consumer in star and delta circuit configuration (R, L, C, RL, RC or RLC load)
- Measurement with active kWh and reactive power demand kVArh meters
  - for balanced and unbalanced RL load
  - for phase failure
  - for overcompensation (RC load)
  - for active load
  - for energy-flow reversal
- Determination of the first and second power maxima
- Determination of a power maximum for unbalanced load
- Recording of load response characteristics

Order no. EUC 1

Dynamic loads
A three-phase asynchronous (induction) motor coupled with the servo machine test system is used as a dynamic load. The active and reactive power (cos-phi of the motor) depend on the motor's load and for that reason fluctuate. The servo machine test system can also operate the asynchronous motor so that active power is delivered to the three-phase power system.

Training contents

- Dynamic three-phase load (asynchronous motor)
- Power measurement for power-flow reversal

Order no. EUC2

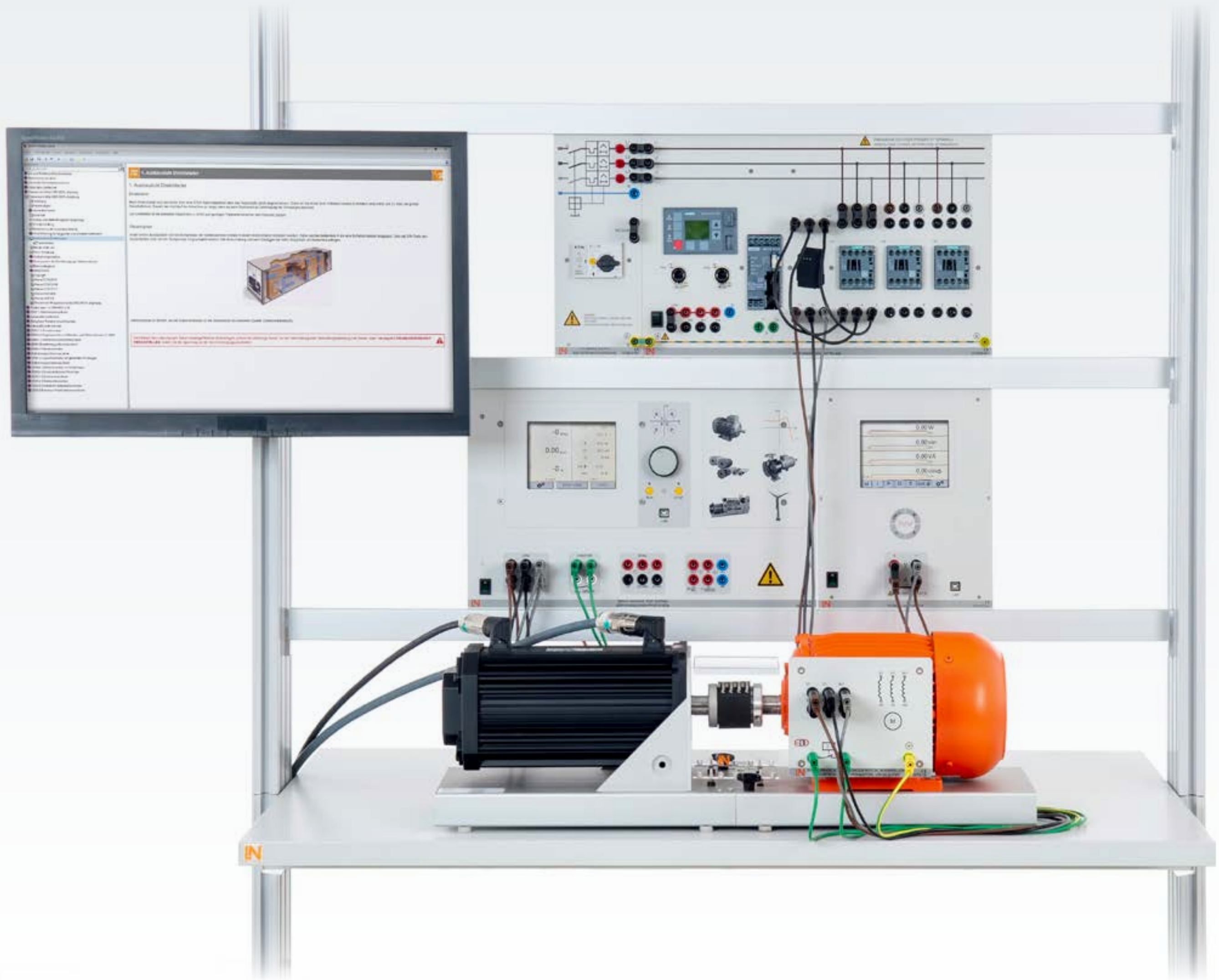
Manually activated and automatic reactive power compensation
In reactive power compensation of three-phase systems, the unwanted reactive power including the associated higher current is reduced. This entails adding capacitive loads at the central feeding point to all inductive loads. The leading reactive power counteracting this is as close to the same magnitude as possible as the installed lagging reactive power. This means unwanted reactive power is reduced and all the systems and components needed for the provision and transmission of reactive current do not have to be unnecessarily large.

Training contents

- Putting the asynchronous machine into operation and recording the characteristic values
- Calculation of compensation capacitors
- Compensation with different capacitors
- Determining the stage power
- Manually activated reactive power compensation
- Automatic connection detection of the reactive power controller
- Automatic reactive power compensation

Order no. EUC3

PROTECTION OF ELECTRICAL LOADS



Effective motor protection - precautionary maintenance
Motor management systems are used in modern automation systems and offer the possibility of providing optimum protection, control and monitoring of drive systems and installations. They can detect, for example, motor temperature, voltage or current. By including connection of a primary process automation using field bus systems (e.g. PROFIBUS), motor operation is more transparent. Thus the motor's capacity utilisation and energy consumption can be determined remotely without having to be on site.

Training contents
- PC-based commissioning of the motor management system
- Programming the functions direct start, star-delta start-up, start-up of pole changing multispeed motors, motor protection
- Configuring the parameters of overload variables and the disconnect response to different loads
- Measurement of dynamic processes during starting
- Precautionary maintenance

Order no. EDT 51

Three-phase asynchronous (induction) machines
Squirrel-cage motors are designed for steady-state load operations. Changes in the load but also excessive starting currents lead to impermissible motor heating. Sensors monitor the temperature and the current consumption of the motor. They activate the protection devices such as the motor circuit breaker, motor protection relays or thermistor relays.

Training contents
- Selection, installation and configuration of various motor protection systems
- Motor circuit-breaker
- Motor protection relay
- Thermistor protection
- Effect of different operating modes on motor heating
- Protection systems' tripping characteristics
- Protection against impermissible load states

Order no. EEM 4.6

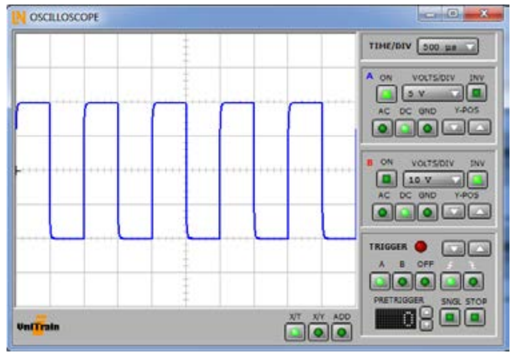
FUNDAMENTALS OF POWER ENGINEERING

Using the training systems from Lucas-Nülle, you can teach all the necessary skills and expertise in practical exercises and projects. In digital learning units, the systems convey the fundamentals and demonstrate how electrical machines work, allowing you to explore typical machine operating characteristics.

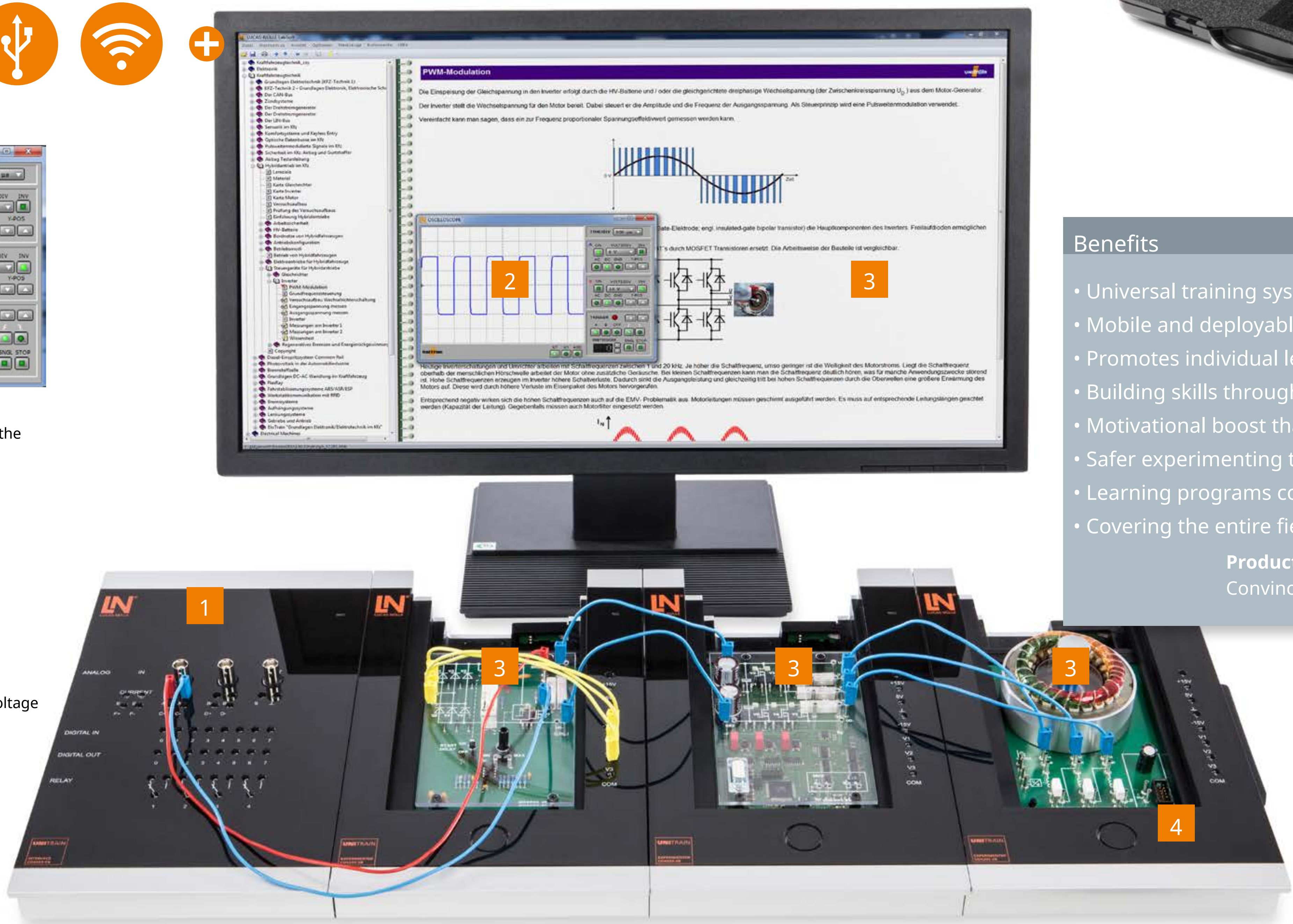
UNITRAIN – DESIGNED FOR MOTIVATIONAL LEARNING

One system covers all technical vocational training

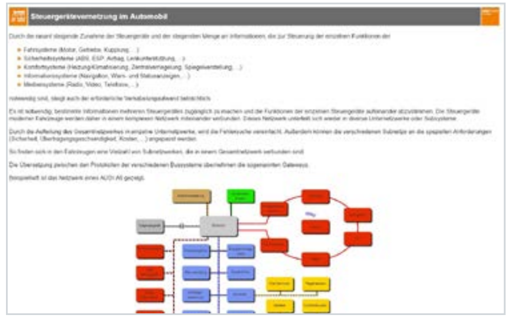
Knowledge and the know-how to operate technical systems continue to make quantum leaps in complexity in ever shorter time frames. This is the daunting challenge facing the vocational training of today and tomorrow. To meet this challenge, the UniTrain system helps with its computer-assisted, multimedia experiment and training system for vocational training in electrical engineering and electronics. The linking of learning programs with a fully fledged electrical laboratory in a single mobile interface permits theory and practice to be taught anywhere and at any time.



2 Virtual instruments
120 virtual instruments available to control the interface



1 UniTrain interface
Measurement and control interface:
Analog / digital measurement inputs and voltage sources for the experiments



3 LabSoft course
Over 130 learning programs with experiment hardware from all areas of electrical engineering

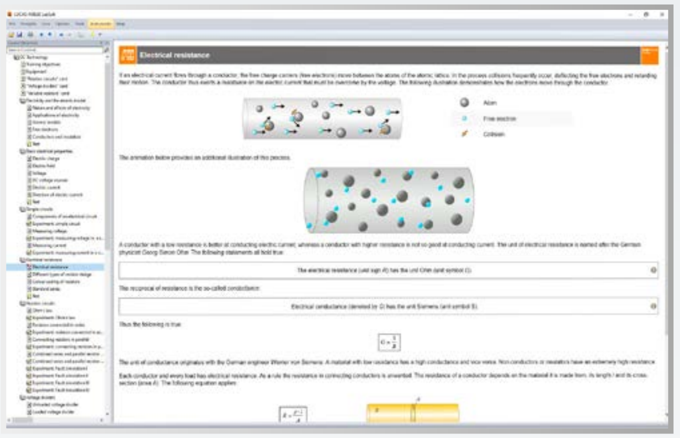
Benefits

- Universal training system
- Mobile and deployable anywhere
- Promotes individual learning
- Building skills through hands-on experiments
- Motivational boost thanks to a variety of challenges
- Safer experimenting thanks to extra-low voltage
- Learning programs combine theory and practice
- Covering the entire field of electrical engineering

Product video
Convince yourself of the benefits

4 Experimenter
Accommodates experiment cards and additional voltage outputs (three-phase current)

DC TECHNOLOGY



UNITRAIN
SYSTEM

Current, voltage and resistor circuits

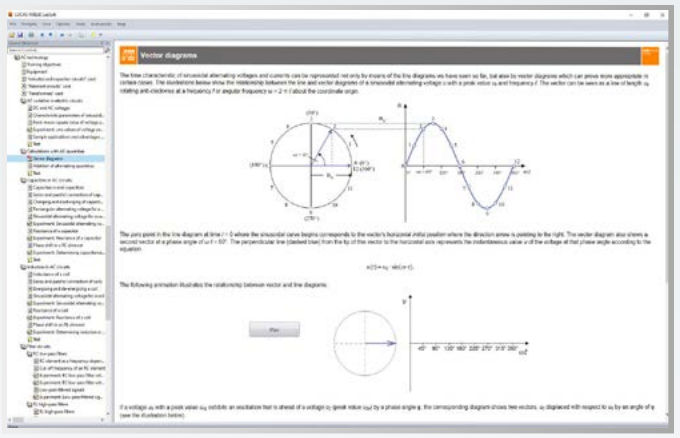
Current, voltage, resistance – learn the basics of electrical engineering hands-on by doing practical work. In the course, the basic laws of electrical engineering are explored in numerous, easy-to-understand experiments supported by animations and text material.

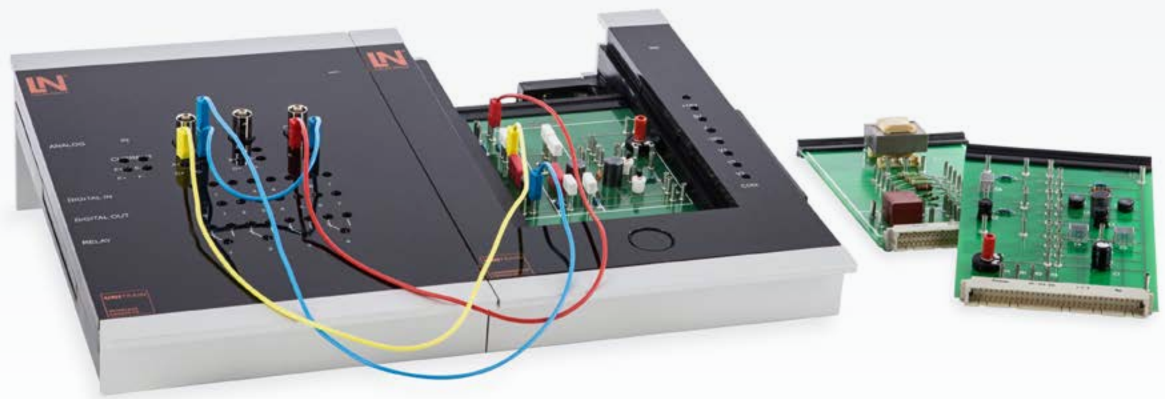
Training contents

- Basic terminology: electrical charge, electrical field, current, voltage, resistance and power
- How to operate power sources and measuring equipment
- Experimental verification of Ohm's law and Kirchhoff's laws
- Measurements on series circuit, on parallel circuit and voltage dividers
- Recording the characteristics of variable resistors (LDR, NTC, PTC, VDR)
- Investigating coils and capacitors in a DC circuit
- Fault finding
- Course duration: approx. 8 h (of which 1.5 h fault finding)

Order no. CO4204-4D

AC TECHNOLOGY





UNITRAIN
SYSTEM

Inductance, capacitance, oscillating circuit/transformer

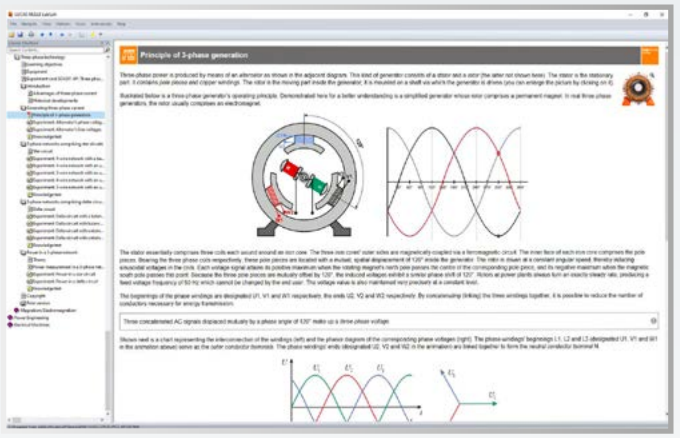
How do coils and capacitors respond when connected to AC current? What is an oscillating circuit and how does a transformer work?

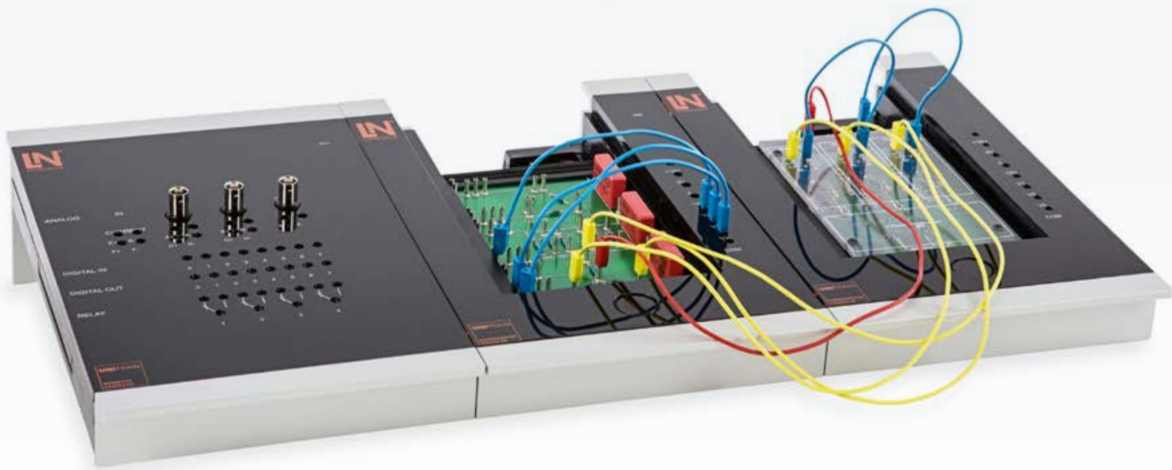
Training contents

- Parameters of periodic and sinusoidal signals
- Working with vector diagrams
- Experiment determination of coil and capacitor reactance
- Explaining active, reactive and apparent power
- Determining the frequency response of simple filter circuits
- Electrical oscillating circuit: resonance, quality, bandwidth and cut-off frequency
- Measurement of frequency response of series and parallel oscillating circuits
- Load, no-load and short-circuit measurements
- Frequency response of transformers
- Fault finding
- Course duration: approx. 8 h (1 h of which fault finding)

Order no. CO4204-4F

THREE-PHASE TECHNOLOGY





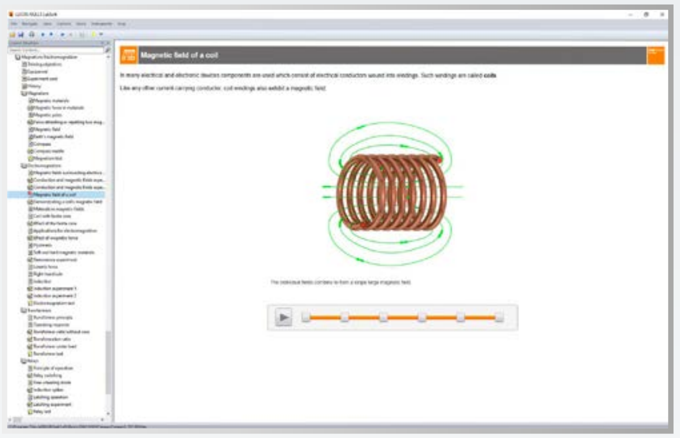
UNITRAIN SYSTEM

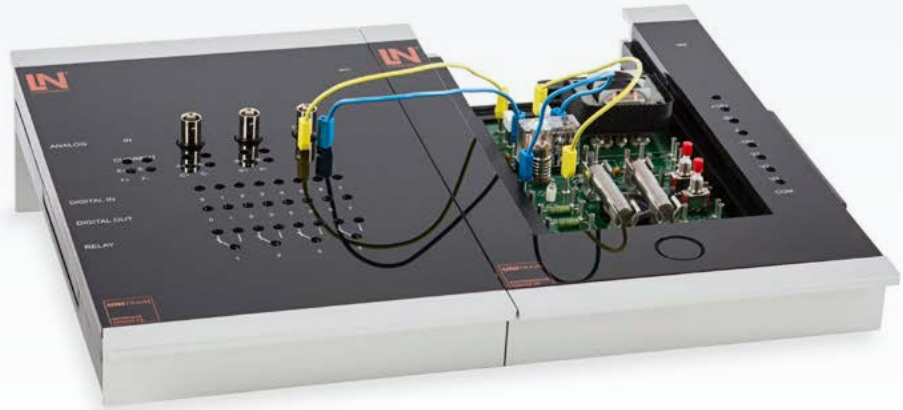
Star and delta configuration, three-phase generator
Three-phase current has a dominant role in power transmission and drive technology, in generating electrical energy and transporting it, and also in the operation of powerful industrial machinery.

Training contents
- Measurements of phase and line quantities in three-phase systems
- Determine experimentally the relationships between line and phase voltages (phase-to-phase)
- Resistive and capacitive loads in star and delta configuration
- Phase displacement between line and phase voltages
- Measurement of the compensation currents in the neutral conductor
- Effects of neutral conductor interruptions
- Current and voltage measurements in the event of balanced and unbalanced loads
- Power measurement of a three-phase load
- Course duration: approx. 4 h

Order no. CO4204-4H

MAGNETISM/ELECTROMAGNETISM





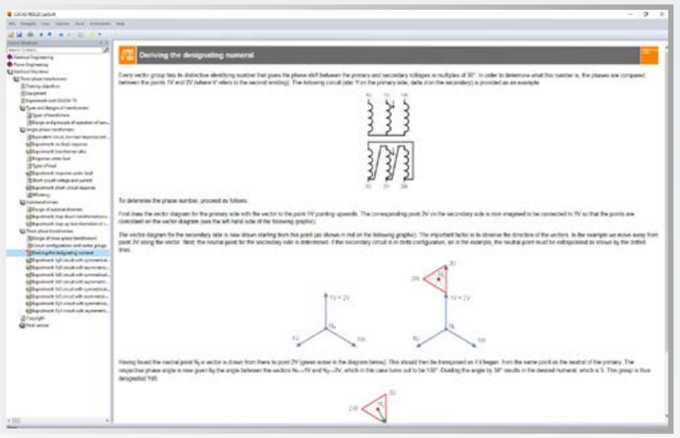
UNITRAIN SYSTEM

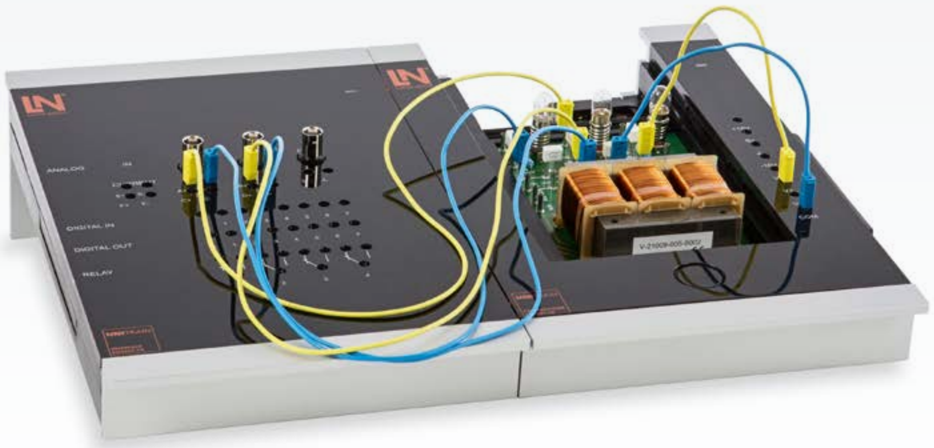
Magnetic field, induction, components
Magnetism and electricity are closely intertwined. Many components in electrical engineering use electromagnetic effects.

Training contents
- Magnetism: magnetic poles, magnetic fields, field lines and field strength
- Hard and soft magnetic materials, hysteresis
- Investigating the magnetic field of a current-carrying conductor
- Investigating the magnetic field of a coil (air-filled coil, coil with core)
- Electromagnetic induction and Lorentz (electrodynamic) force
- Transformer design and function
- Investigating a transformer operating at various loads
- Design and function of electromagnetic components: relays, reed switches, Hall switches
- Investigation of application circuits
- Course duration: approx. 4 h

Order no. CO4204-4A

THREE-PHASE TRANSFORMER





UNITRAIN
SYSTEM

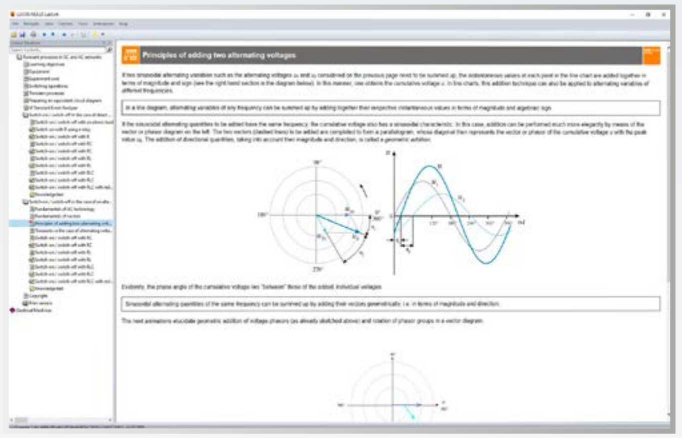
Design types, connection types, load response
Transformers are electrical machines that serve to transform AC or three-phase currents to higher or lower voltages. Three-phase transformers play a particularly significant role in the transmission of electrical power.

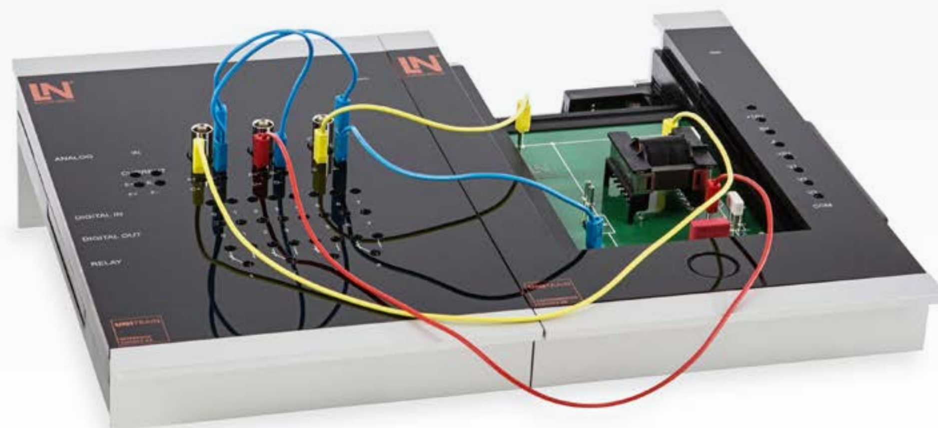
Training contents

- Become familiar with the transformer principle and the equivalent circuit diagram
- Investigate load response of single-phase transformers in single and four-quadrant operation
- Recording current and voltage with and without load
- Investigating the transmission ratio
- Become familiar with three-phase transformers
- Investigating load cases for various vector groups
- Investigation of unbalanced loads in connection with different vector groups
- Determining the short-circuit voltage
- Course duration: approx. 3 h

Order no. CO4204-7Y

POWER SYSTEMS AND SYSTEM MODELS





UNITRAIN
SYSTEM

Transient processes in DC and AC power systems
In existing low, medium and high-voltage power grids, there are two different processes that arise: steady-state (constant loads) and transient responses. These typical transient responses which arise during the generation and distribution of electrical power require special attention and are simulated in experiments using safe extra-low voltage.

Training contents

- Become familiar with the significance of switching processes in power systems and grids
- Assess the effects (hazards) of switching processes in power grids
- Experiment-based investigation of current and voltage characteristics during DC voltage switch-on
- Investigate the effect of various loads (R, L, C) on the signal characteristic
- Experiment-based investigation of the current and voltage response during AC voltage switch-on
- Investigation of the effects of switch-on and switch-off time point
- Signal response measurements at different switch-off times
- Determine the optimum switching time
- Analyse switching complex loads (R, L, C) on and off at different times
- Course duration: approx. 3.5 h

Order no. CO4204-3B

PHOTOVOLTAICS

UNITRAIN
SYSTEM

Sunny prospects with the photovoltaic course
In times when energy costs are skyrocketing and environmental awareness is high, photovoltaics constitute an extremely interesting alternative to conventional energy generation. With the photovoltaic course, not only do you become familiar with and study the basics of solar cells but a photovoltaic system is also simulated in direct or in storage operating mode.

Training contents

- Become familiar with how solar cells operate
- Record the characteristics of a solar module
- Explain the dependencies of the solar module's current and voltage on the temperature, irradiance and angle of incidence
- Become familiar with series, parallel and other circuit configuration types used for solar cells
- Become familiar with how solar cells are manufactured
- Explain various types of solar cells
- Become familiar with the design of a solar battery
- Become familiar with various types of solar power plants
- Design of a microgrid with solar batteries

Order no. CO4204-3A

FUEL CELL TECHNOLOGY

UNITRAIN
SYSTEM

Design and operation of fuel cells
Renewable energies are already being considered as a solution for the anticipated energy scarcity to come in the 21st century. The fuel cell based on hydrogen is part of this solution. As a complementary technology, it will be used in future energy systems for the generation of clean energy from regenerative hydrogen.

Training contents

- Become familiar with the operating principle and function of fuel cells
- Record characteristics of a fuel cell
- Explain electrochemical processes involved in electrolysis (Faraday's 1st and 2nd laws)
- Determine the Faraday efficiency and energy efficiency of a fuel cell
- Series and parallel connection of fuel cells
- Consideration of fuel cell power
- Become familiar with the principle and operation of the electrolyser
- Recording the UI characteristic of the electrolyser
- Determine the Faraday efficiency and the energy efficiency of an electrolyser

Order no. CO4204-3C

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