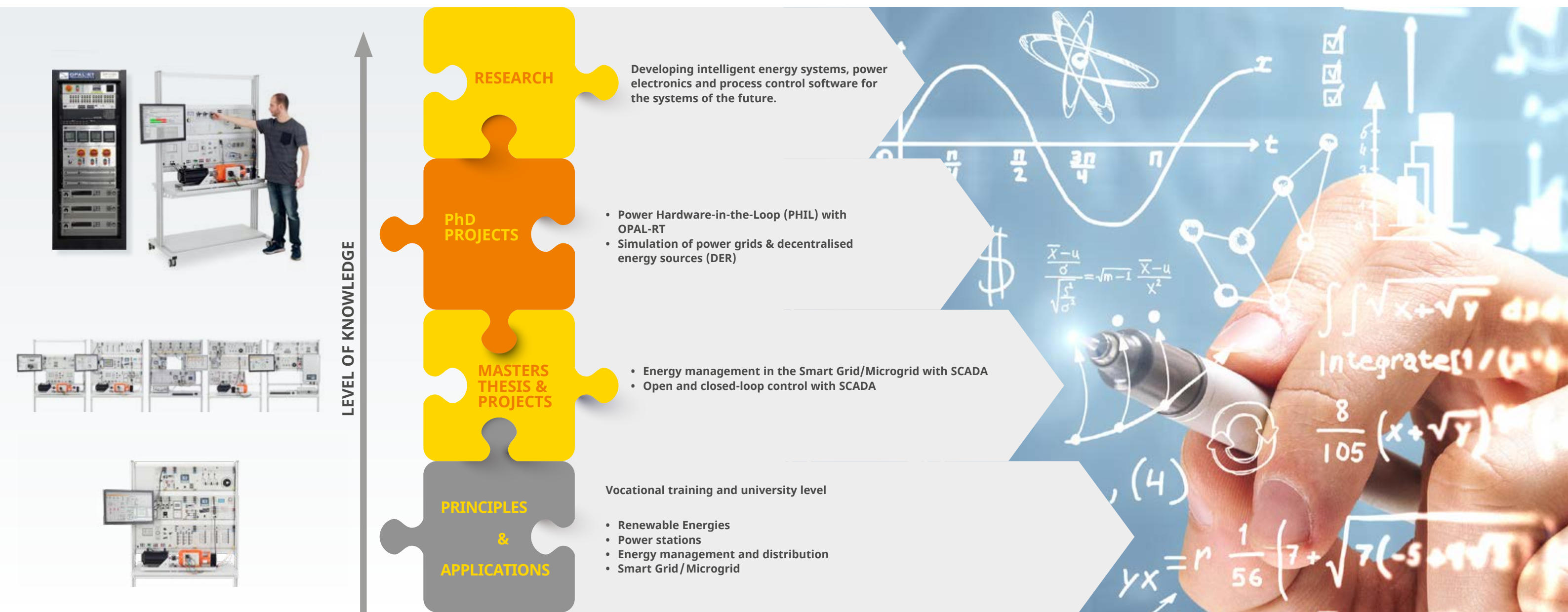




# HARDWARE-IN-THE-LOOP

**A Training System for Renewable Energies  
in Smart Grids, Microgrids and PHIL**

# FROM BASIC TRAINING TO RESEARCH



The training systems from Lucas-Nuelle are used to cover everything from basic principles up to research and development. That way, acquired know-how and applications developed with the training systems can also be seamlessly integrated into research projects. This means you can do research without having to bother with the cost-intensive and time-consuming business of learning new systems.

## Your benefits:

- Fundamentals and applications with digital multimedia course
- Modular systems
- Rapid prototyping systems
- Hardware-in-the-Loop (HIL)
- Power Hardware-in-the-Loop (PHIL)

## Challenges facing power engineering

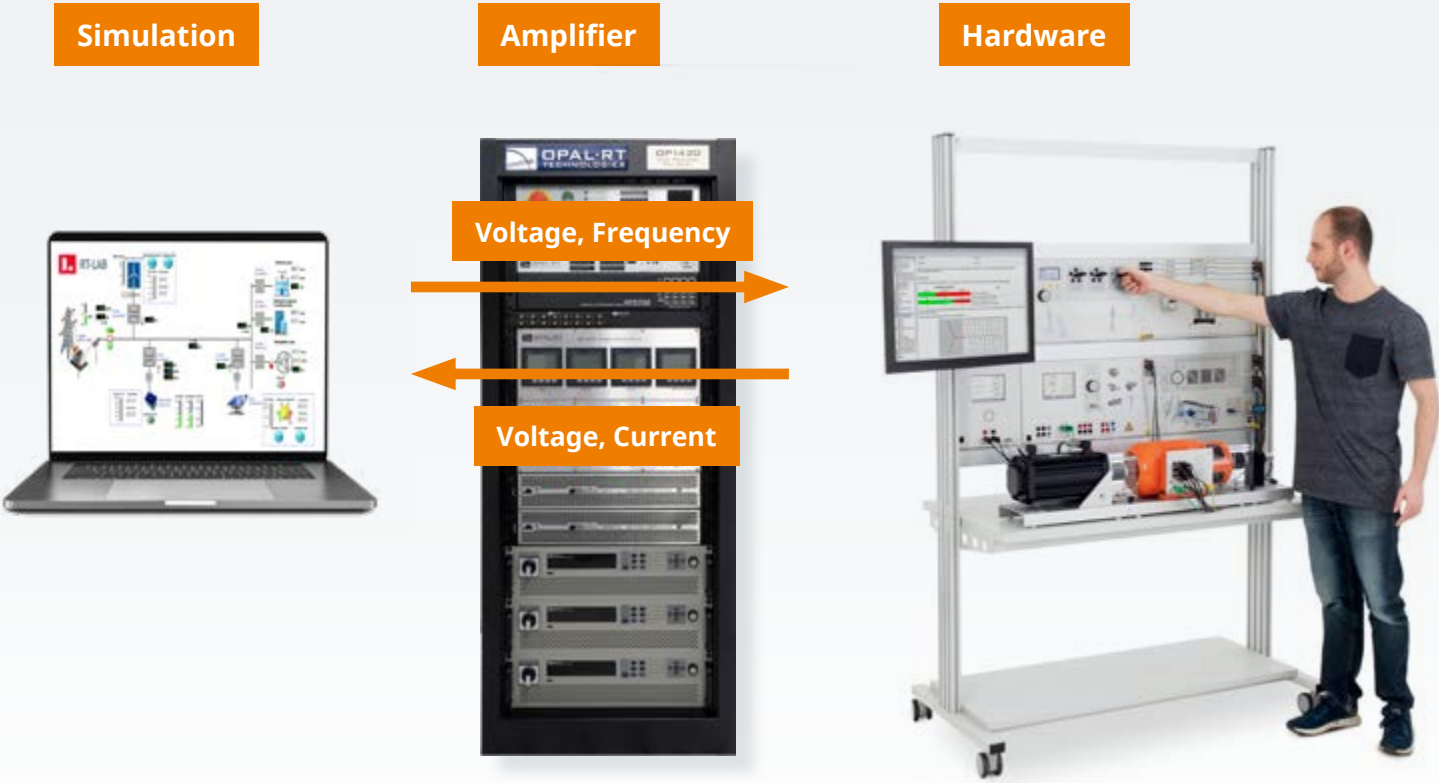
New and innovative concepts are needed for system-stabilizing automatic controls and improved strategies for operating power systems.

## Power grid in transformation

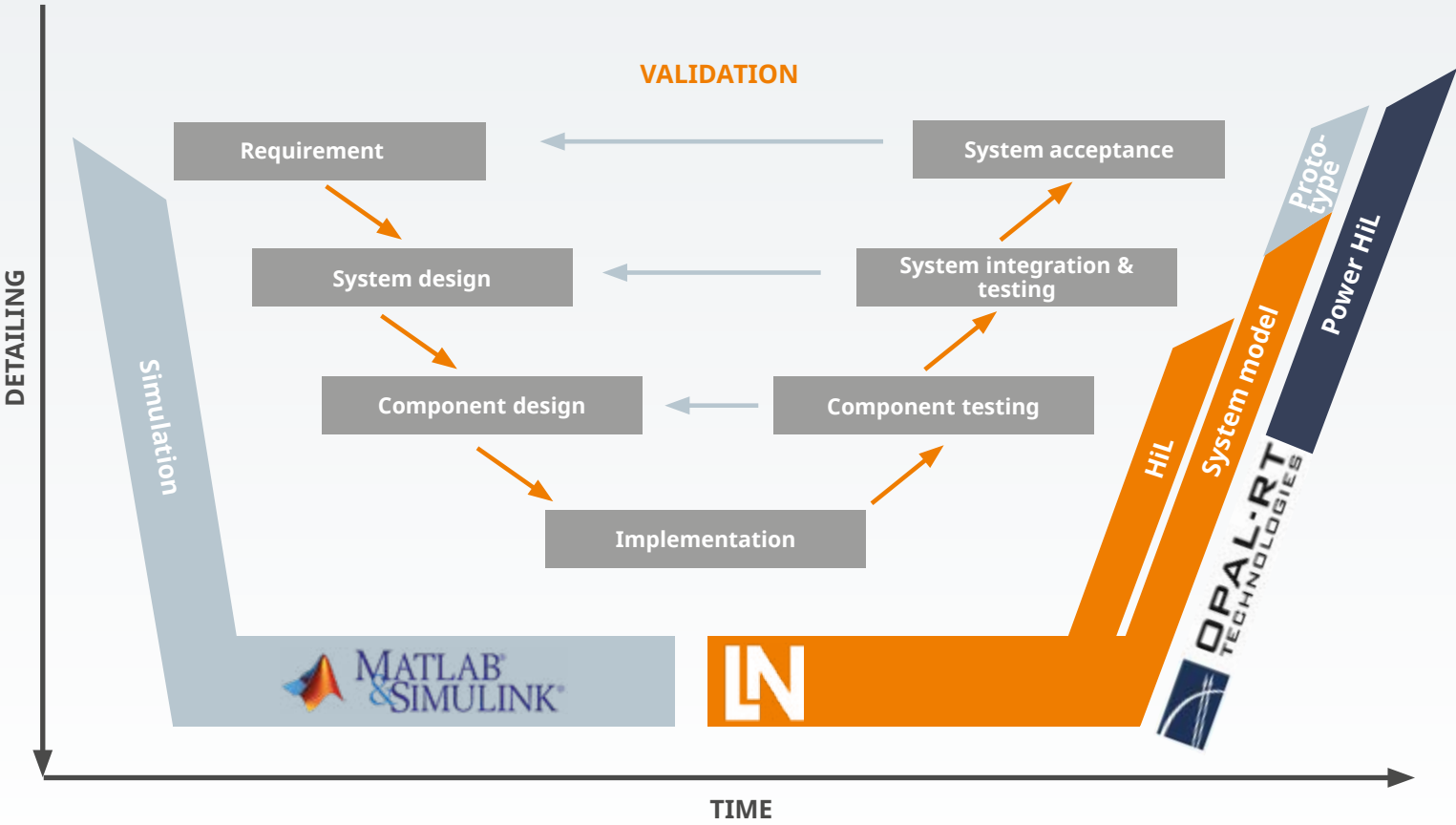
Renewable energies like wind power and photovoltaic systems are frequently based on inverter technology. With more and more renewable energy, the number of fossil-fuelled (large-scale) power stations with synchronous generators will decline. Thus the properties promoting system stabilization in synchronous machines that reduce mechanical inertia also permit reactive power to be made immediately available in large amounts during transient processes brought about by potential short-term overloading.



# POWER-HARDWARE-IN-THE-LOOP (PHIL)



Note: This image has been significantly simplified



## Power-Hardware-in-the-Loop (PHIL)

PHIL is an expansion of the Hardware-in-the-Loop (HIL) tests, in which the real-time simulation environment is able to exchange power with the DUT (device under test). The DUTs are connected to the simulator via a power amplifier which is controlled by the simulation.



- Fast simulation of power grids, energy sources and distributed energy sources (DER)
- Development of energy systems, power electronics and process control software
- System validation prior to installation into productive systems

## Using training systems in the research and development process

Using simulations, many design choices can be made at the very beginning of the development phase. During implementation, these decisions have to be validated for quality assurance purposes.

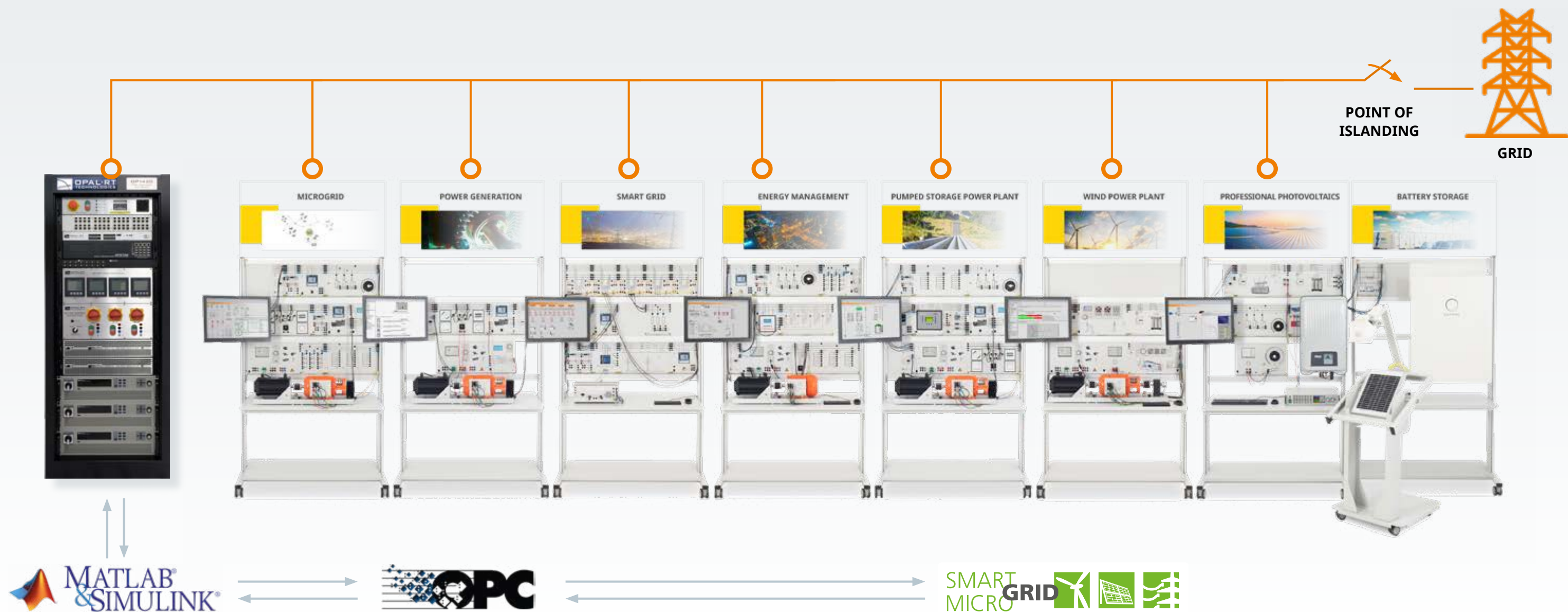
## Benefits with Lucas-Nülle training systems

- Modular system
- Simple configuration
- Rapid prototyping systems / Hardware-in-the-Loop (HIL) with Matlab Simulink
- Smart Grid/ Microgrid system models

## In conjunction with OPAL-RT

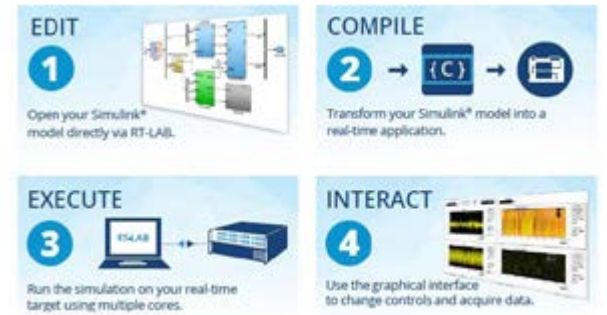
- Power Hardware-in-the-Loop (PHIL)

# SMART GRID AND PHIL WITH OPAL-RT



## OPAL-RT RT-LAB

Easy to commission and configure parameters in 4 steps



## OPAL-RTOP1420 – Power amplifier

- 4Q Power amplifier up to 15 kW
- Innovative soft-switching cell based on SiC transistor technology
- 100% energy recovery, no power losses
- Very high efficiency >96%
- Voltage and current mode
- Up to 10 kHz (-3dB), THD
- Microgrid Simulink Model
- FPGA real-time simulation possible
- Microgrid-grid emulator with busbar and measuring devices
- Safety measurement connections
- Protection against overloading, short-circuit and with temperature monitoring

## Lucas-Nuelle Smart Grid – Networked Systems in the Power Engineering Laboratory

Simulation of an entire power supply grid from energy generation all the way to end consumer

- Renewable energies with fluctuating power generation
- Power distribution with transmission lines, transformers and double busbars
- Systems, measurement and protective devices integrated in SCADA
- Centralized evaluation and control using SCADA
- Unlimited potential for design and investigation of smart grids and power systems in the lab

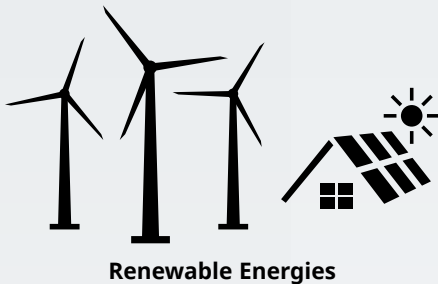
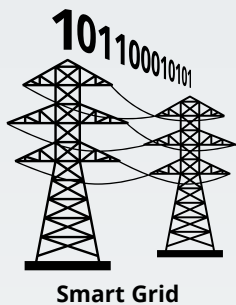
## Smart grid and power amplifier

### Benefits:

- Realistic training systems for training fundamental principles and applications
- Combination of simulation, real and industrial hardware
- Modular design means rapid configuration and adaptation
- Fast and easy PHIL implementation
- Fault-protected hardware
- Pre-assembled models for fast immersion into PHIL



# SCADA



**Flexible Configuration**

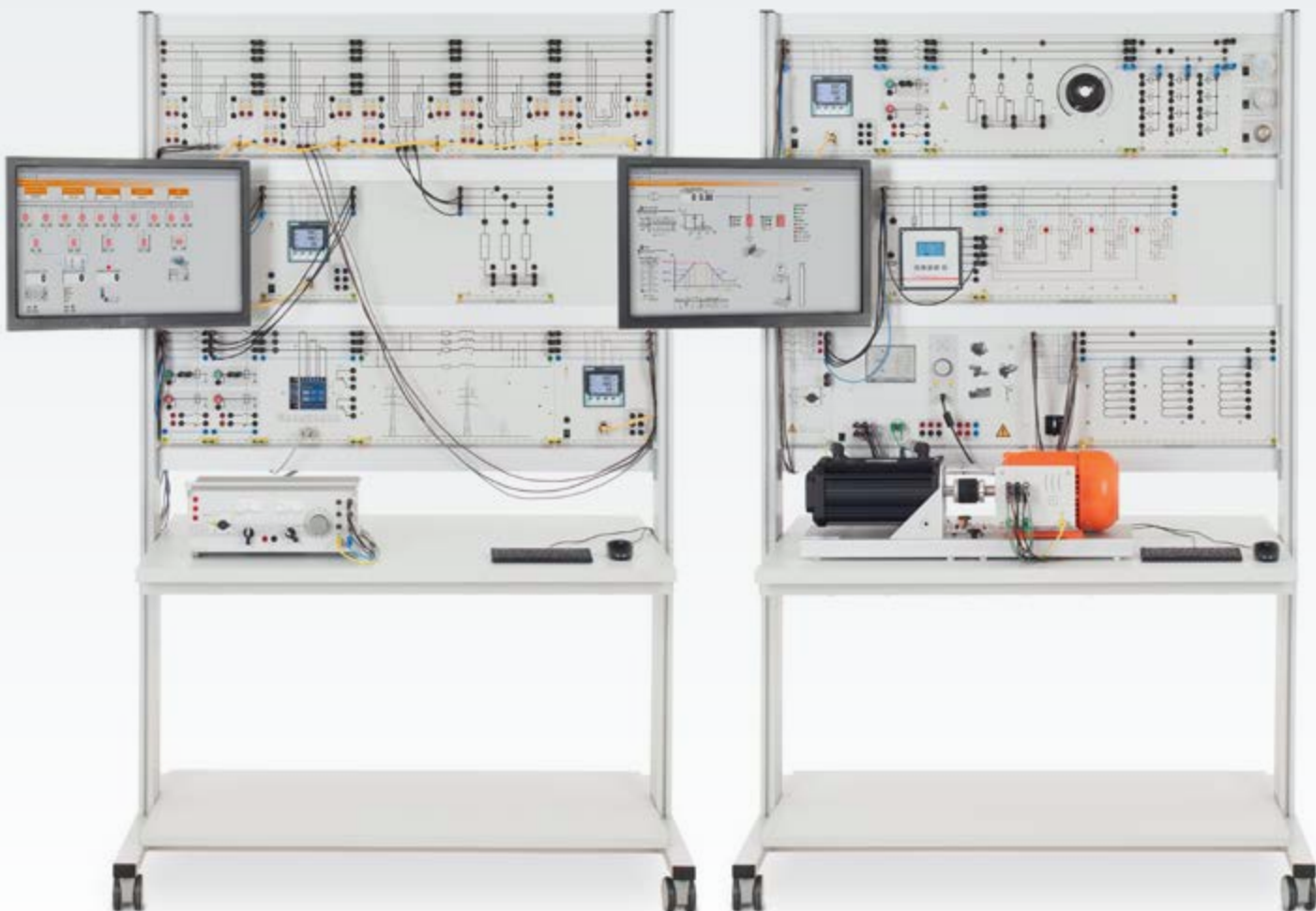
Thanks to the system's modularity, the equipment can be configured very flexibly. In just a few minutes, complex applications can be set up on experiment trolleys and modified for flexible instruction. The combination of systems permits any number of scenarios to be set up all the way to the microgrid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



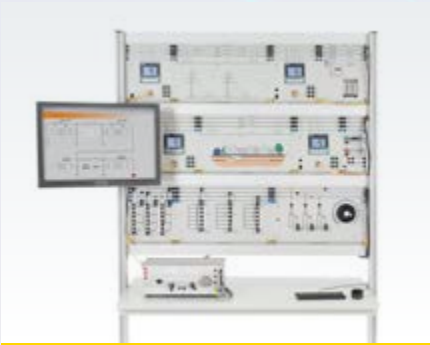
ECS1 – Industrial Cyber Security



EUC – Pumped Storage and Conventional Power Plants



EUT – Investigating Transformers



EUL – Power Transmission Lines



ELP – Line Protection



## BASIC EQUIPMENT SET: MICROGRID



SMART  
MICRO

### 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

### 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

Order no. EMG

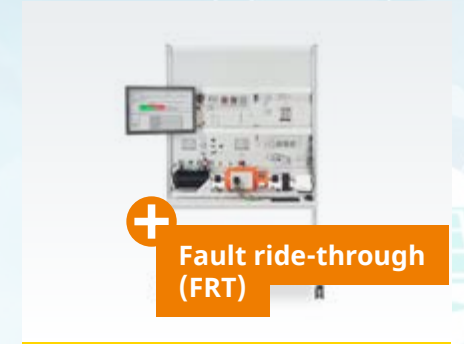
## EXPANSIONS: MICROGRID



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



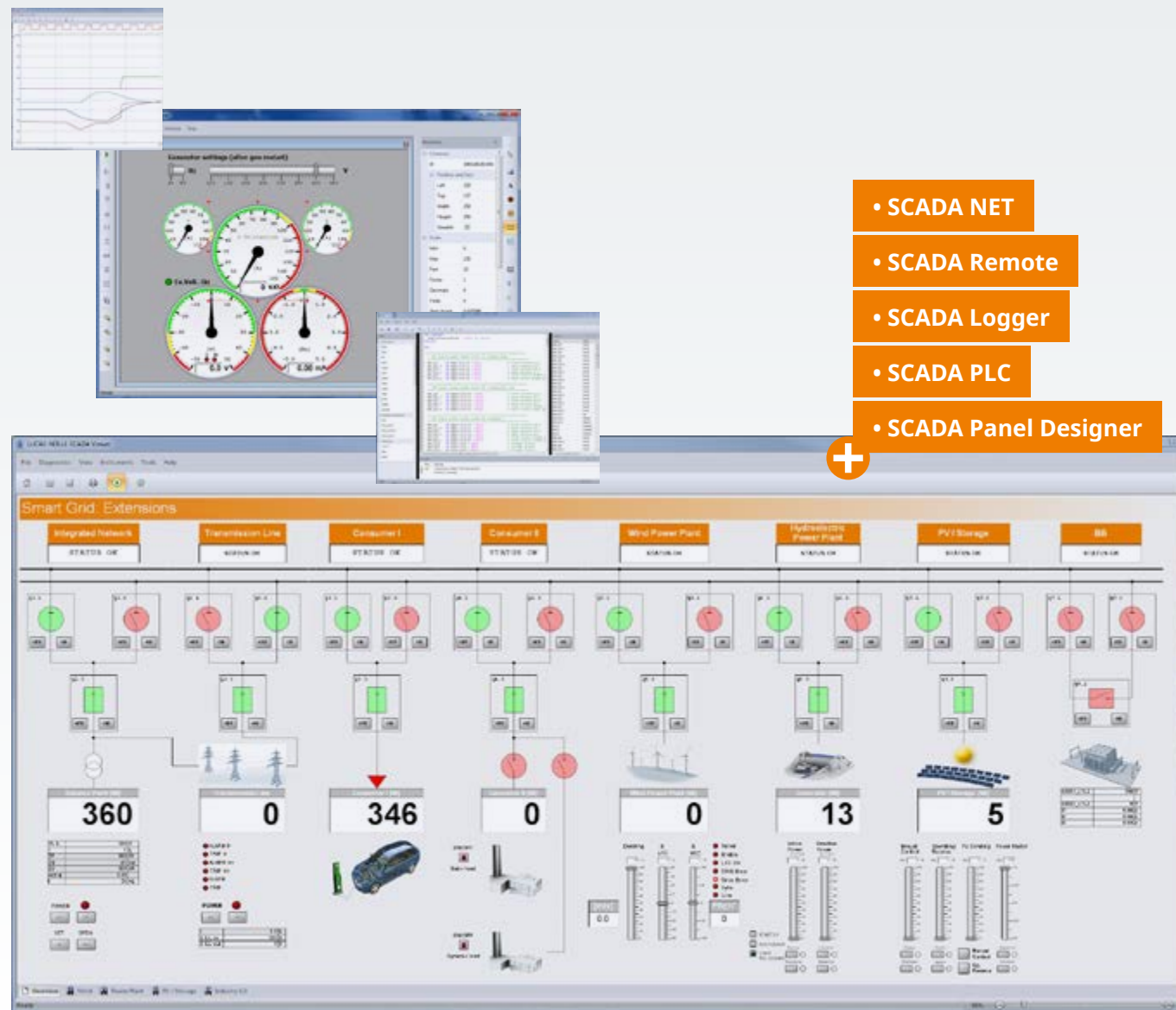
EUC 2 – Dynamic loads



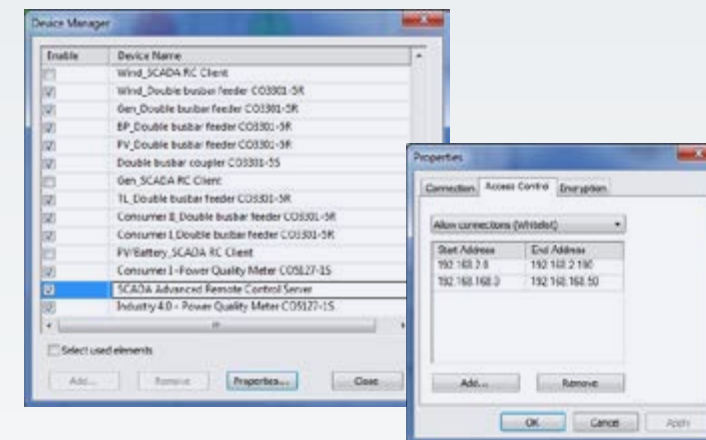
ECS 1 – Industrial Cyber Security



# SCADA FOR POWER LAB



- SCADA NET
- SCADA Remote
- SCADA Logger
- SCADA PLC
- SCADA Panel Designer



- SCADA Client Server
- SCADA OPC
- SCADA IEC 61850

Group	Name	Type	Value	Quality	Timestamp	Access	ID
Group 1	[X] Apparent current in phase L1	UREAL	0	Good	01.12.2017 15:32:25	R	[97] Time Over Current Relay CO3301-4L[33].001 Apparent current in phase L1
Group 1	[X] Apparent current in phase L2	UREAL	0	Good	01.12.2017 15:32:25	R	[97] Time Over Current Relay CO3301-4L[33].001 Apparent current in phase L2
Group 1	[X] Apparent current in phase L3	UREAL	0	Good	01.12.2017 15:32:25	R	[97] Time Over Current Relay CO3301-4L[33].001 Apparent current in phase L3
Group 1	[X] Voltage V1.1-N	UREAL	233.985	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Voltage V1.1-N
Group 1	[X] Voltage V1.2-N	UREAL	212.303	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Voltage V1.2-N
Group 1	[X] Voltage V1.3-N	UREAL	216.663	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Voltage V1.3-N
Group 1	[X] Voltage V1.1-L2	UREAL	432.8106	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Voltage V1.1-L2
Group 1	[X] Voltage V1.2-L2	UREAL	396.5506	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Voltage V1.2-L2
Group 1	[X] Voltage V1.3-L1	UREAL	396.5575	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Voltage V1.3-L1
Group 1	[X] Current L1	UREAL	0.172951	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Current L1
Group 1	[X] Current L2	UREAL	0.149508	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Current L2
Group 1	[X] Current L3	UREAL	0.134731	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Current L3
Group 1	[X] Neutral Current	UREAL	0.12584	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Neutral Current
Group 1	[X] Apparent power L1	UREAL	40.46961	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Apparent power L1
Group 1	[X] Apparent power L2	UREAL	34.05422	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Apparent power L2
Group 1	[X] Apparent power L3	UREAL	32.39821	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Apparent power L3
Group 1	[X] Active power L1	UREAL	22.80012	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Active power L1
Group 1	[X] Active power L2	UREAL	-1.86728	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Active power L2
Group 1	[X] Active power L3	UREAL	-9.27730	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Active power L3
Group 1	[X] Reactive power L1	UREAL	-3.54271	Good	01.12.2017 15:32:24	R	[98] BP-Power Quality Meter CO3127-15[31].001 Reactive power L1



## • SCADA Viewer | Designer

- Custom configurable user interface
- All Lucas-Nuelle power engineering equipment symbolically represented and arrayed
- Standardized electronic circuit symbols for clear visualization of the circuitry
- Individually configurable value lists to display any relevant measurement value
- Display of measured values and operating states in real time
- Implementation and analysis of intelligent power networks (Smart Grid)
- Design of several worksheets per system

## • SCADA Logger

- Recording diagrams of the measured values and signals over time
- Editing, analysing and exporting the diagrams
- Measuring the values

## • SCADA Panel Designer

- Design and configuration of user interfaces

## • SCADA Remote Client / Server

- Monitoring and operating all systems at every PC in the laboratory
- The power engineering lab in the cloud

## • SCADA OPC Client

- Connection to external devices, e.g. PLC
- OPC DA V2.02

## • SCADA OPC NET Server

- Real-time connection, e.g. to the MATLAB®/Simulink® and LabVIEW via the OPC-Server

## • SCADA PLC

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

## • Other supported protocols include:

- SCADA IEC 61850 Client (Links up external devices, e.g. PMU)
- TCP/IP Client/ Server
- MODBUS
- SML (Smart Message Language)
- HTTP

Ready-made sample files (templates) are available for all experiments of the multimedia courses.



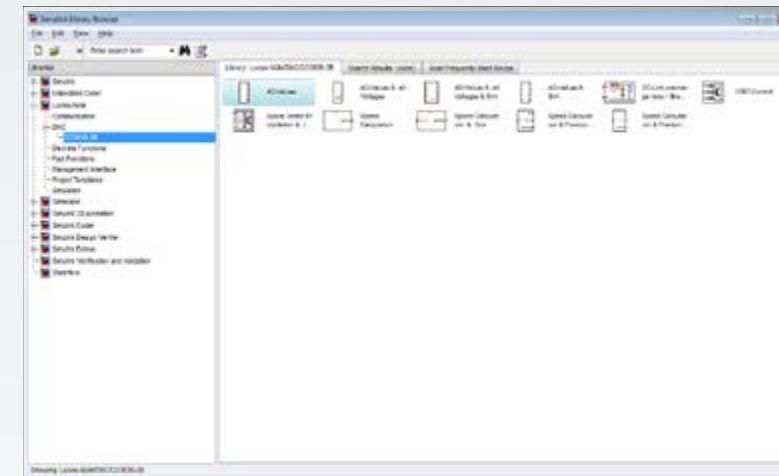


## Expand the Training System to a Programmable, Rapid Prototyping System for Drive Technology

Nearly all electrical drives such as those used in industrial plants and electric vehicles incorporate three-phase technology. The automatic control of such drives, for instance, to ensure smooth start-up or measured acceleration, entails mathematically complex and elaborate programming. Implementation is therefore often characterized by very long development times. A newly created toolbox will in future make it possible to simulate complex controller structures for three-phase drives with Matlab®/Simulink® in advance, and subsequently test them on a real converter with a motor and load by means of automatically generated code.

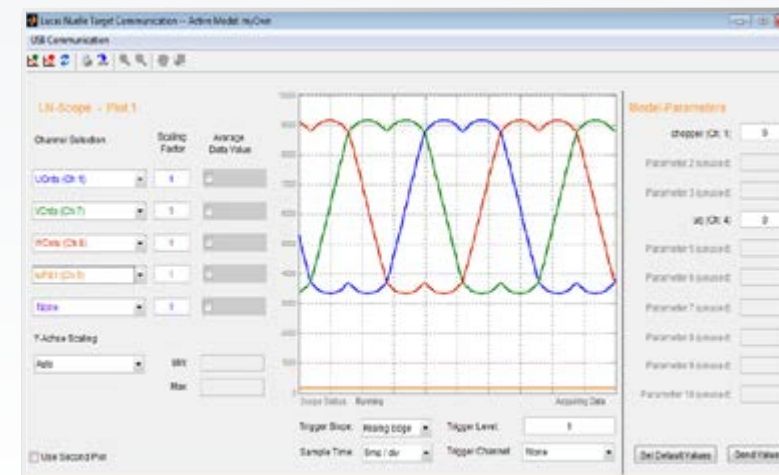
## Benefits

- Safe handling thanks to intrinsically safe hardware
- Promotion of a deeper understanding of a complex subject, e.g. in education and training, or through use of the toolbox in laboratory programs accompanying theory
- Very rapid, model-based, parameterizable software generation for own controllers in conjunction with industrial applications
- Pursuit of new methods of research on rotary-field drives, e.g. control using state-space methods, condition monitoring for errors, sensorless automatic speed control using new observational techniques
- Impressive design possibilities for closed-loop control of three-phase drives
- Creation of complex algorithms using fast control cycles of 125  $\mu$ s
- P-, PI-controller parameterization
- Controller optimization



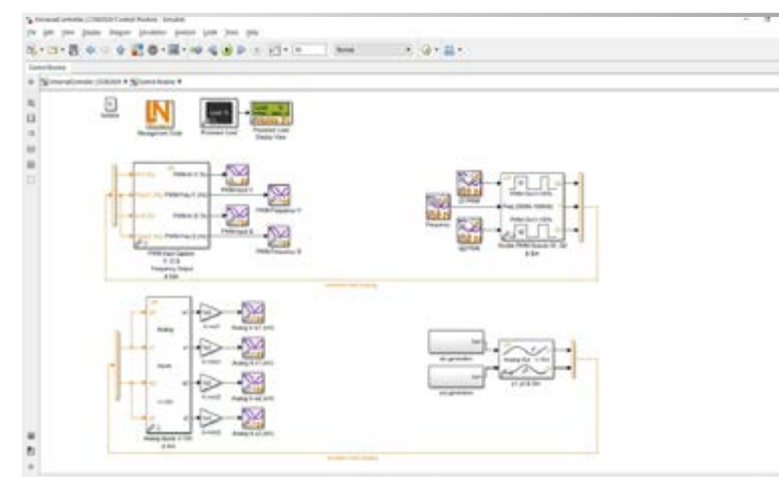
### Quicker results with the Matlab®-Toolbox

A toolbox adapted to the power electronics hardware enables rapid implementation of one's own applications. Special templates allow simple introduction by configuring the system so that only a few adjustments still need to be made by the user. The toolbox provides users with all the necessary modules for controlling hardware-related functions, as well as blocks for fast transformations and controllers. The system can be extended at will by adding one's own library elements to those of the Matlab®/ Simulink®.



### Hardware connection via Matlab® Scope

A special graphic dialog serves to establish the connection between Matlab® and hardware via a USB interface. The time characteristics of all internal variables can be visualized during runtime. A number of different time resolutions and trigger options are available here. The signals can be displayed in the time domain as well as the frequency domain. The display can be divided into two units, making it possible to visualize up to ten signals simultaneously. Parameters such as those related to the controller can be uploaded conveniently from the PC to the hardware during runtime.



## Project templates

Templates specially adapted to the hardware handle the otherwise complex and time-consuming job of hardware configuration. This means that users can immediately focus on programming using Matlab®/ Simulink®.

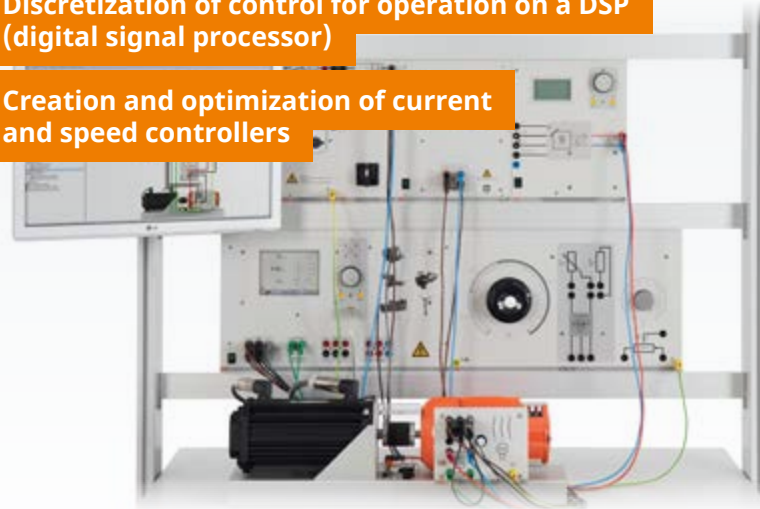


# TRAINING SYSTEMS WITH MATLAB®/SIMULINK®

## TRANSFORMERS, POWER ELECTRONICS, MACHINES



- Creation of an HIL system (hardware in the loop) under real-time conditions
- Discretization of control for operation on a DSP (digital signal processor)
- Creation and optimization of current and speed controllers



**Field-oriented control of asynchronous motors with Matlab®/Simulink® and a servo machine test stand**

### Training contents

- Modeling and design of field-oriented control on a continuous design level
- Park and Clarke transformation
- Integration of space-vector modulation for optimal control of IGBTs
- Decoupling of field-oriented currents and voltages
- Speed detection via an incremental encoder
- Comparison of simulation results with real measurements



**Variable-speed permanent-magnet servo drives with Matlab®/Simulink® and the servo machine test stand**

### Training contents

- Modelling and design of an automatic servo control on a continuous design level
- Park and Clarke transformation
- Integration of space-vector modulation for optimal control of IGBTs
- Decoupling of field-oriented currents and voltages
- Speed and position detection via an incremental encoder
- Comparison of simulation results with real measurements



**DC drives with cascaded control using Matlab®/Simulink® and a servo machine test stand**

### Training contents

- Modelling and design of cascade control loop for DC motors at the continuous design level
- Speed detection via an incremental encoder
- Comparison of simulation results with real measurements

# TRAINING SYSTEMS WITH MATLAB®/SIMULINK®

## PROCESS CONTROL



**IAC 40 Optimisation of a Closed-Loop-Controlled Drive System Using Matlab®/Simulink®**

### Training contents

- Creating a hardware-in-the-loop system under real-time conditions
- Modelling and designing a cascade control system
- Creating and optimising current and speed controllers
- Design and optimisation of control system in state space
- Expansion of control system to handle multiple variables



**IAC 41 Automatic Control of an Air-Temperature Controlled System Using Matlab®/Simulink®**

### Training contents

- Creation of a hardware in-the-loop system under realtime conditions
- Modelling and designing a control system
- Simulation and optimisation of control system using a model
- Comparison between model and real control system
- Expansion of control system to make a multivariable controller with independent control of temperature and air flow



**IAC 42 Closed-Loop Control of a Coupled Two-Tank System Using Matlab®/Simulink®**

### Training contents

- Creation of a hardware-in-the-loop system under realtime conditions
- Modelling and designing a control system
- Simulation and optimisation of control system using a model
- Comparison between model and real control system
- Expansion of control system to make a multivariable controller with independent control of levels in both tanks





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