Karlsruhe Institute of Technology

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KIT Energy Smart Home Lab – Hardware-in-the-Loop Research Environment with Hybrid Energy Storage System

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- **Challenges** in low voltage systems
  - Reactive power provision and voltage stability
  - Congestion handling
  - Spinning reserve and short circuit power
- **Question**: How to evaluate technologies and systems for low voltage systems most closely to reality?
- **Approach**: Integration of hard- and software systems into one testbed for low voltage systems
  - Simulation of buildings and low voltage grids
  - Hardware-in-the-loop (HIL) studies
  - Power-hardware-in-the-loop (PHIL) studies

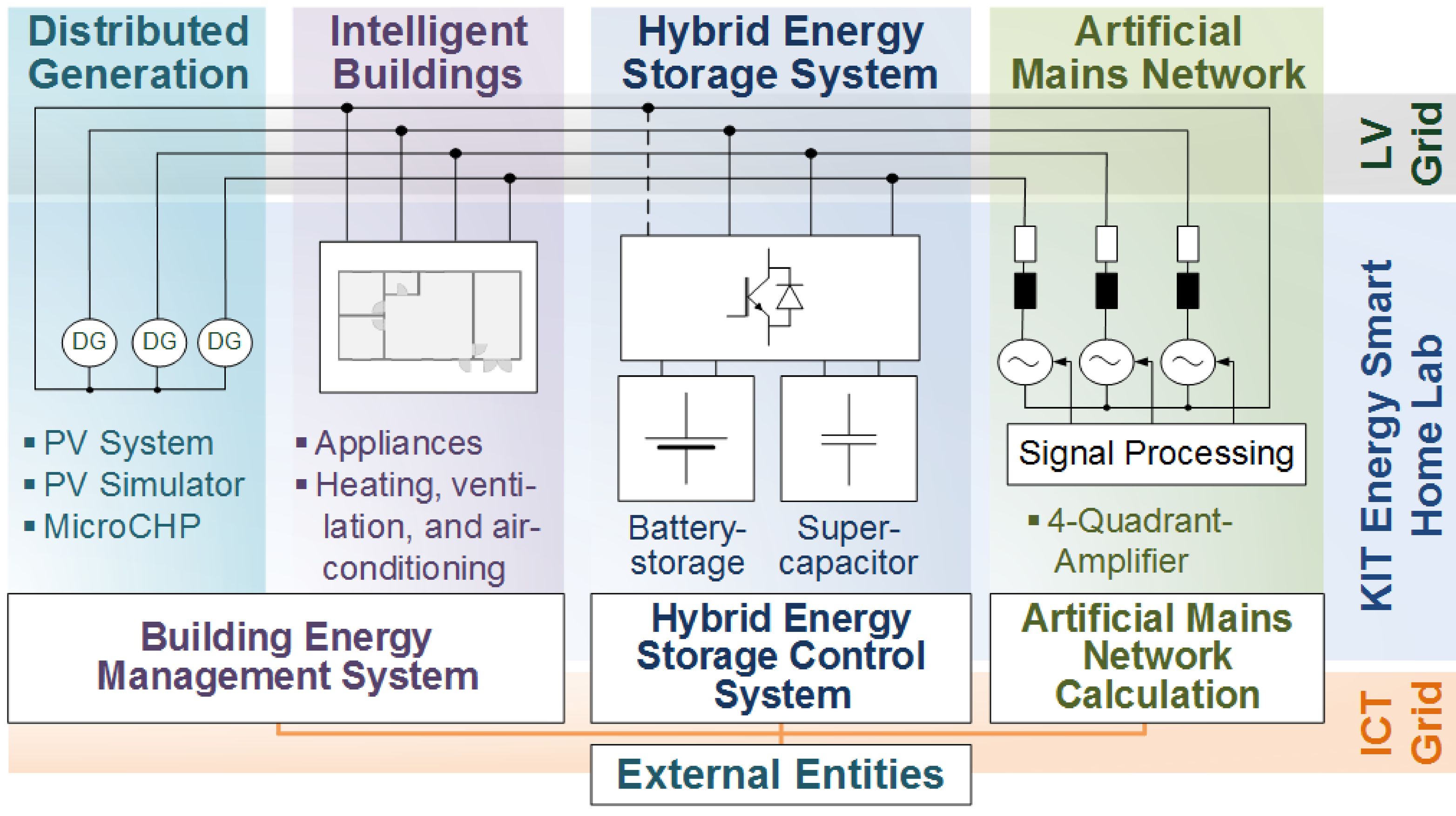


Figure 1: Residential Power Hardware-in-the-loop Laboratory

Hardware Equipment of the Laboratory

Table 1: Hardware Infrastructure of the Laboratory

Distributed Generation		
PV panels	24x Sovello SV-T-195	4.7 kWp
PV inverter	SMA Sunny Tripower STP 10000TL-10	10 kVA, 3-phase
PV simulator	ET System LAB/SMS3100	3.0 kWp
Combined heat and power plant	SenerTec Dachs G 5.5 standard	5.5 kW electrical , 12.5 kW thermal
Appliances		
Home appliances	Miele: coffee machine, dishwasher, dryer, hob, oven, washing machine; Liebherr: deep freezer, refrigerator; other: microwave, water kettle, toaster	
Appliance gateway	Miele XGW 2000	Communication BEMS & appliances
Heating and Air-conditioning System		
Climate controller	Kieback & Peter BMR410 and FBU410	Modbus gateway
Hot water storage tank	SenerTec SE 750	750 liters (≈ 25 kWh for Δθ = 30 K)
Insert heating element	Eltra 2NP5635-290	9 kW
Air-conditioning inverter	Mitsubishi PUHZ-RP60VHA4	6 kW cooling capacity
Chilled water storage tank	Custom-made	200 liters
Phase change material	DeltaSystems DELTA-COOL 24	Melting temperature: 22–28 °C
Hybrid Electrical Energy Storage System		
Battery	12x Hoppecke power.com HC122000	7.920 kWh (three hour discharge)
EDLC	5x SPS MCE0010C0-0090R0TBA	40.32 kWs (per module)
Artificial Mains Network		
4-quadrant amplifier	Spitzenberger & Spies; 3x PAS 10000/RL 4000	+30.0 kVA/−15.0 kW (U ≤ 270 V RMS)
Grid switching box	Custom-Made	interruption-free supply switching

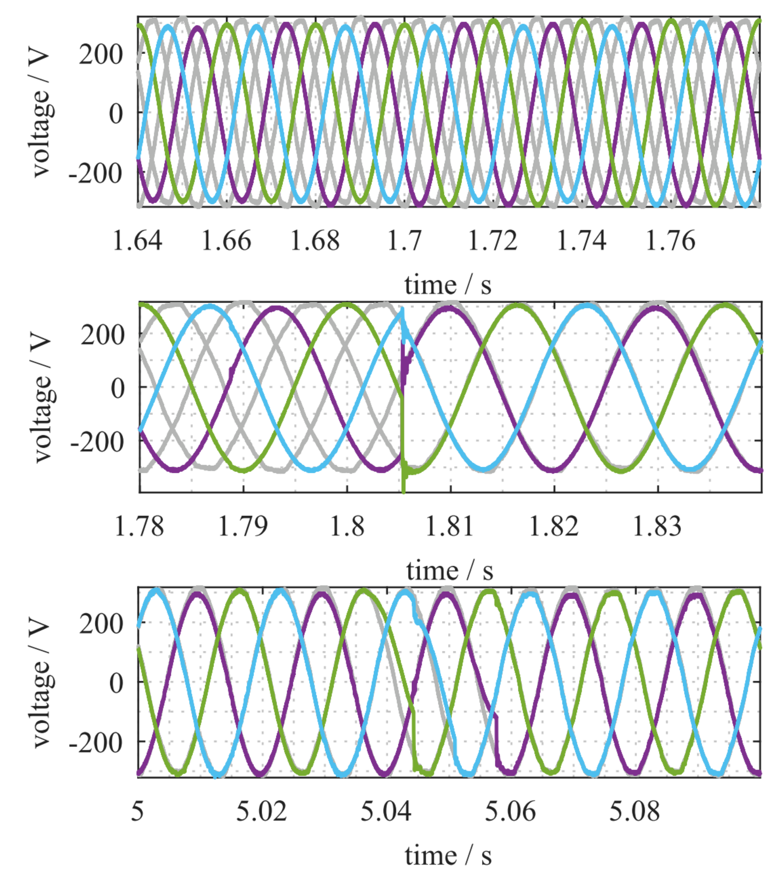
Interacting Software Systems

- Organic Smart Home
  - Multi commodity energy management and simulation system
  - Management of appliances, distributed generation, and set point control for hybrid energy storage
- Hybrid energy storage control system
  - Grid Interface controller for current injections
  - Internal Hybrid Storage Control for Batteries and electric double layer capacitors (EDLC)
- Artificial mains network calculation

Density	Energy Wh / l	Power W/l
Battery	71.5	71
EDLC	1.4	1013

Table 2: Comparison of used storage components

Automated Switching from Stiff to Artificial Grid



- Smooth switching between artificial and stiff low voltage grid to
  - limit inrush-currents during switching
  - maintain rotating field

Figure 2: Sequential adaption of
a) 3-phase voltages and
b) 3-phase followed by
c) switching operation to artificial mains

Weak Connection Point Operation

- Operating the laboratory as a solitary residential building
- Emulating an impedance with the 4-quadrant amplifier

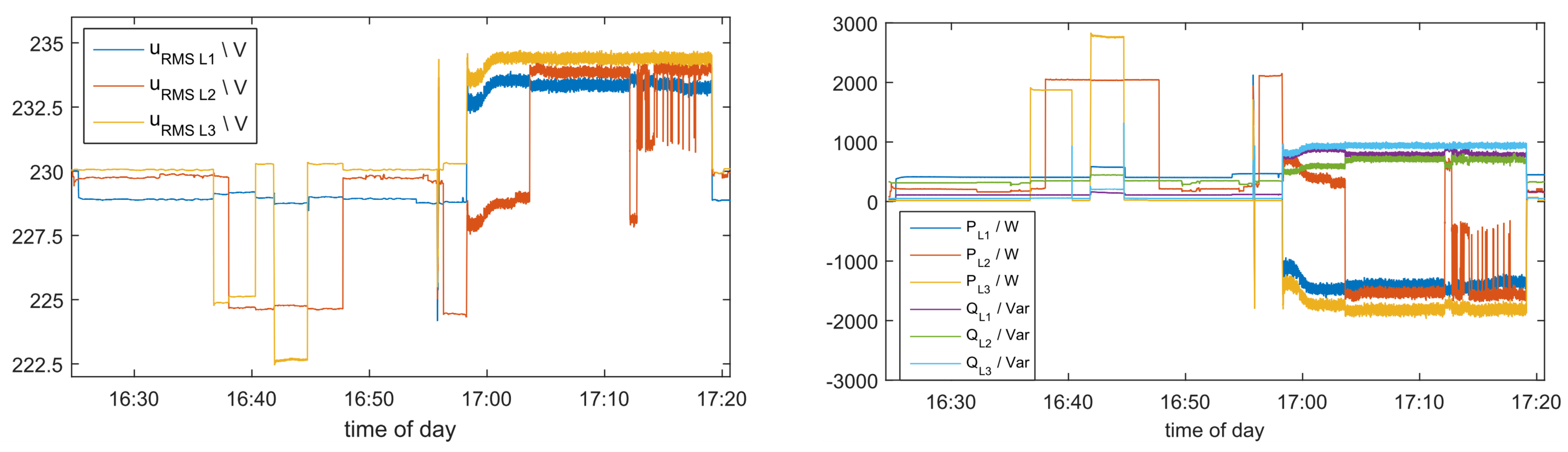


Figure 3: a) 3-phase voltages and b) active & reactive power at a simulated weak connection point

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