Panel on Energy

Theme: Hidden Dangers on Energy of Digitalization

Topic: Energy Saving and Sustainable Energy

Moderator

Vivian Sultan, Claremont Graduate University, USA

Panelists

Eric MSP Veith, OFFIS e.V., Germany

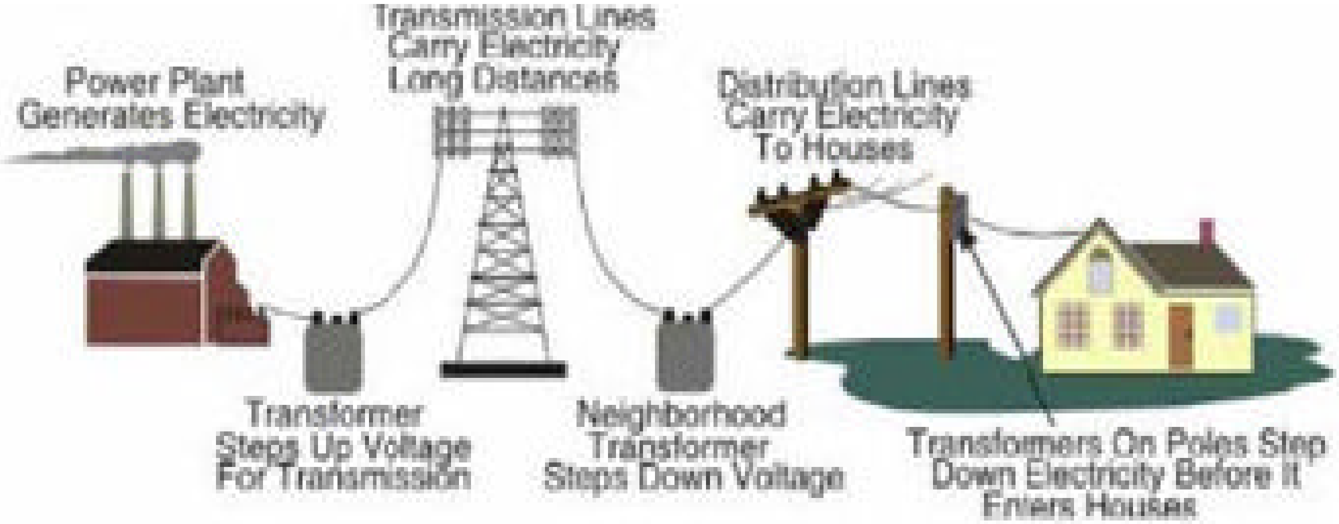
Mark Apperley, University of Waikato, New Zealand

Michael Negnevitsky, University of Tasmania, Australia

Jorn Geisbuesch, KIT, Germany

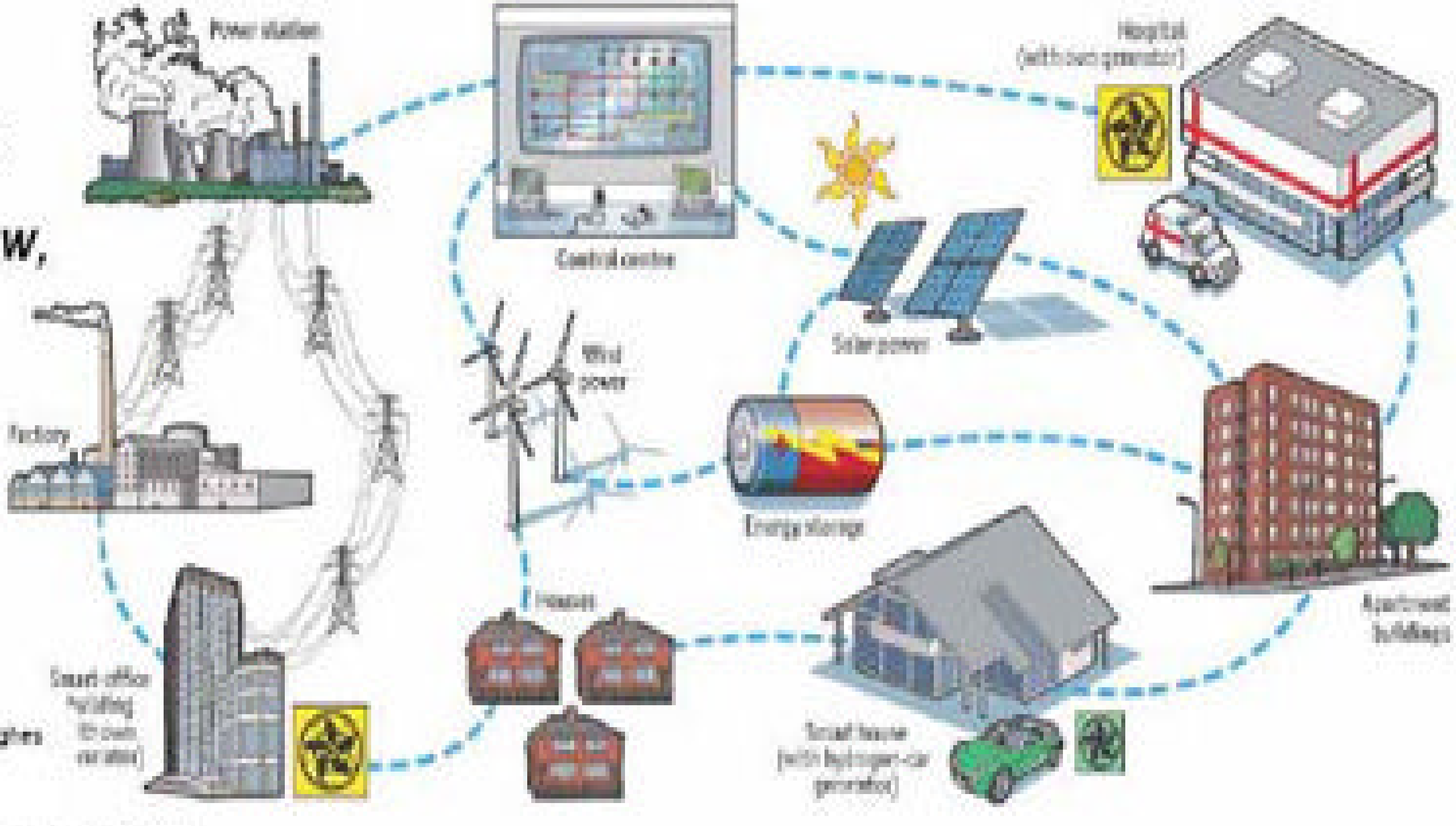
Before Smart Grid:

One-way power flow, simple interactions



After Smart Grid:

Two-way power flow, multi-stakeholder interactions



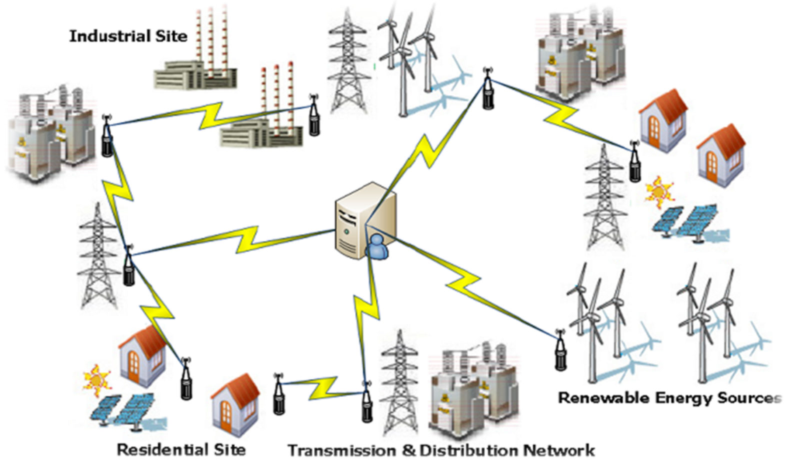
Adapted from EPRI Presentation by Joe Hughes
NIST Standards Workshop
April 28, 2008

Energy of Digitalization

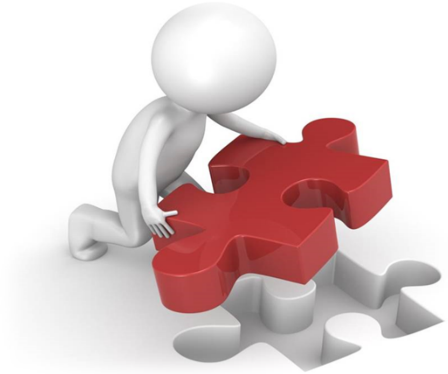
- Increasing energy consumption
- Hot spots for energy consumption
- Extra energy to process digital waste (smart-phones, etc.)
- Reshaping transportation lines for electrical vehicles and dynamic geographic load balancing on energy consumption

What Are The Hidden Dangers?

- The cyber physical energy systems
- The explicability of the energy control
- The move to a distributed network and localized consumption
- The low-inertia systems



Digitalization holds great promise to help improve the safety, productivity, efficiency and sustainability of energy systems worldwide. But it also raises questions of security, privacy and economic disruption



ENERGY 2019 Panel
Threads of the Digitalization in Energy Systems

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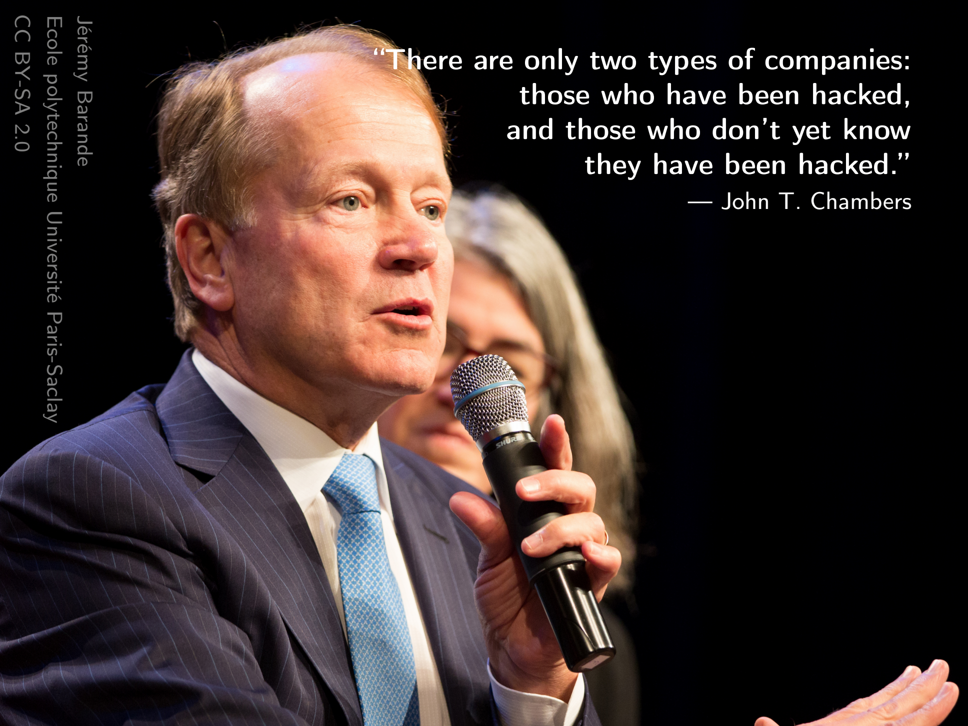
OFFIS—Institute for Information Technology
R&D Division Energy

June 15, 2019

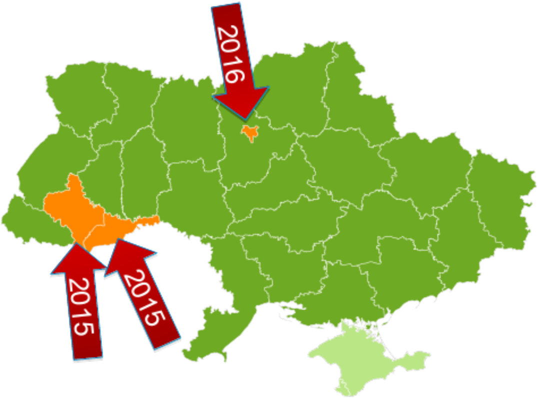


> “There are only two types of companies:
> those who have been hacked,
> and those who don’t yet know
> they have been hacked.”
> — John T. Chambers

Jérémy Barande
Ecole polytechnique Université Paris-Saclay

2 Relevant for Power & Energy Systems

Ukraine Cyber Attack 2015

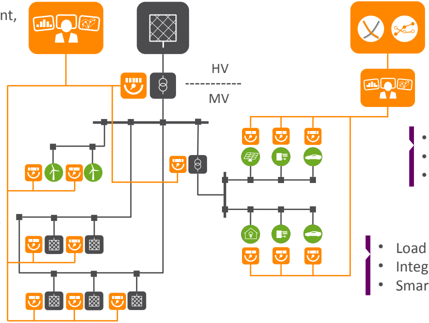


2015-12-23

- Cyber attack leads to **large-scale blackout**
- **3 utilities** (grid operators) targeted
- Made possible by **high degree of automation in the distribution systems**
- Operative intrusion into **power system control**; disconnection of **several substations**
- Several months in preparation

3 Energy Systems Are Complex CPS

Many Tasks in Heterogeneous CPES



- Forecast of network conditions,
- Optimized reactive power management,
- Detection of anomalies in power and communication networks.

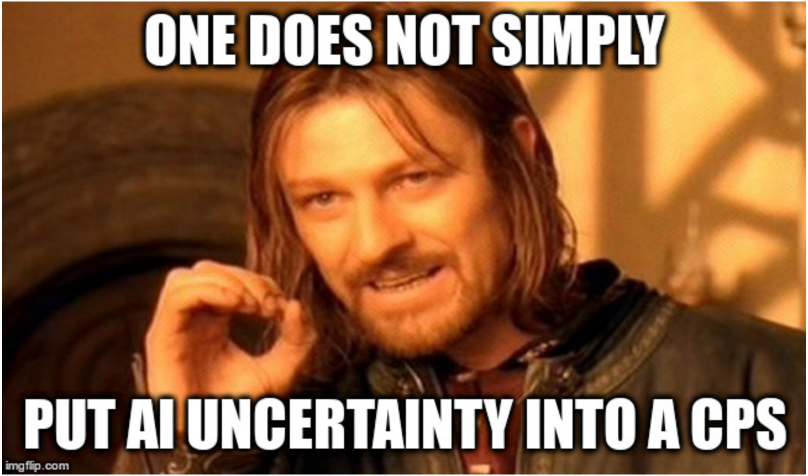
- Monitoring of the operating states,
- Automation yellow traffic light phase,
- decentralised system services.

- Virtual power plants,
- multi-modal optimization,
- Sector coupling.

- Load and flexibility management,
- Integration of end customers,
- Smart metering.

A wide range of entry-points into a safety-critical infrastructure...

4 One Does Not Simply...



5 Theses

1. Digitalization trends, coming from other areas, will sooner or later ‘flood’ into the energy systems domain.
2. A highly digitalized grid operation will lead to new threat level with non-assertable potential for damage to our civilization.
3. Putting ‘AI’ into our power grid is, however, highly necessary—and also a big chance for a resilient operation!

Karlsruhe Institute of Technology

Real-time Simulation and Power-Hardware-in-the-Loop System Integration

Joern Geisbuesch (PHIL Group @ ITEP, Energy Lab 2.0 Collaboration),
S. Karrari, D. Kottonau, W.T.B. de Sousa, P. Kreideweis, C. Lange, F. Groener, M. Noe

Thanks to: ITEP Engineering and Technical Staff

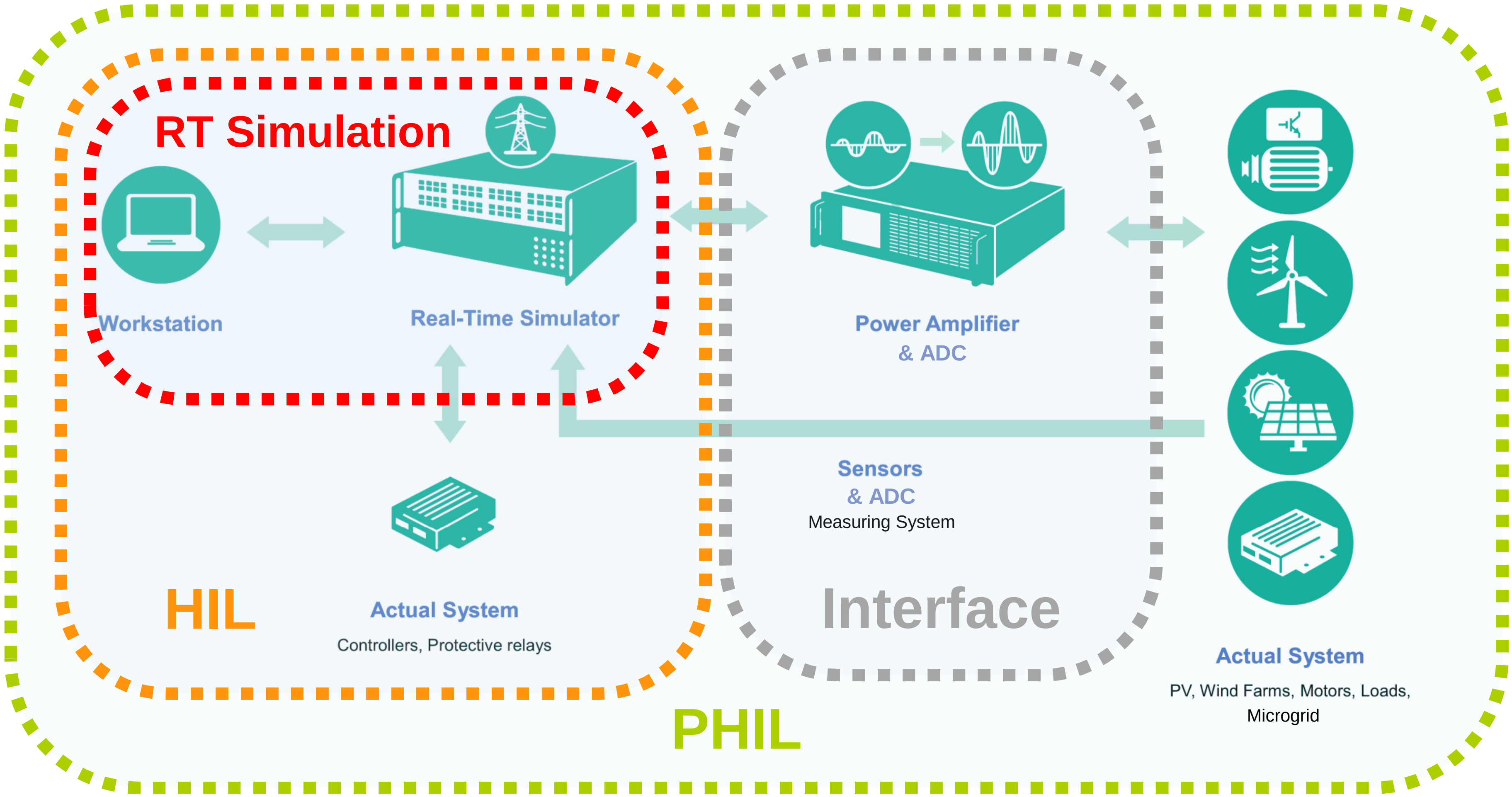
ENERGY 2019 Conference, Athens, June 2nd to 6th 2019

Karlsruhe Institute of Technology (KIT) **Institute for Technical Physics (ITEP)** **Power-Hardware-in-the-Loop Group** **Energy Lab 2.0**

Power Hardware in the Loop

PHIL Environment – Conceptual layout

System configurations:



Pictograms courtesy of Opal-RT

Power Hardware in the Loop

Real-time system integration

Properties of a Power Hardware in the Loop system:

- **Real-time simulations** of a virtual grid or device or parts thereof
- **Actual power hardware embedded** in the real-time simulation via a fast responsive interface (4-quadrant power amplifier, measurement system and ADC)

Advantages:

Realistic, repetitive and **safe** even under exceptional, extraordinary or extreme conditions

Opportunities:

- **Technical Readiness:** Power hardware **characterisation** and **field testing**
- **Rapid Prototyping:** Implementation of **realistic hardware models** (physical and empirical)
- **Predictability:** Efficient power **grid topology** and **component studies**

Potential issues:

- **Delays** (dead and run times) and **„time stepping“** causing **instabilities**
- Measures of stability improvement can cause **inaccuracies**

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PHIL 1 MVA and Training Station

Real-time simulation systems

Real Time Digital Simulators (OPAL-RT):

OP5600 and OP5707

Compute hardware:

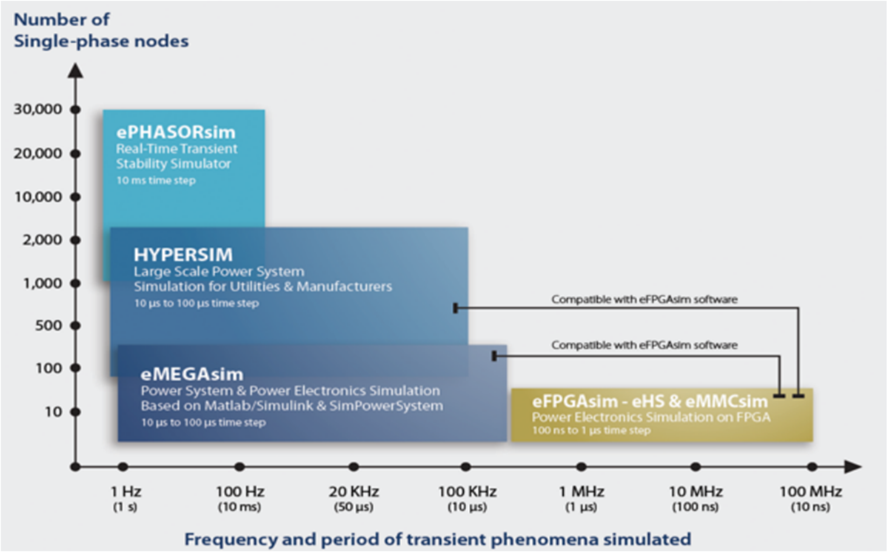
- Multi-core processors with up to 3.45 GHz per core & Xilinx® Virtex®-7 FPGA
- Analog Input: 32 channels (16-bit, ≥0.5 MSP/s)
- Analog Output: 16 channels (16-bit, ≥1 MPS/s)
- Digital Input: 32 channels (≥10 MPS/s)
- Digital Output: 32 channels (≥40 MPS/s)

Real-time simulator extension:

- OP4520 extension (SFPs)

Software:

HYPERSIM & eMEGASIM



Possible data streams

(simulation and measurements):

- up to approx. 10 Gb/s (**big data**)

Pictures courtesy of Opal-RT

PHIL Training Station

Hardware interface components

Amplifier hardware:

Two ***3-channel 4-quadrant*** linear analog power amplifier units from **Spitzenberger&Spies**

Technical specifications:

- **Power output:**

  up to two times 3x5 kVA (30 kVA)

- **Bandwidth:**

  0 – 5 kHz (-3 dB, data sheet)

  0 – 50 kHz (-3 dB, small signal)

- **Voltage:**

  270 / 135 V_{eff} (AC), ± 382 V_{peak} (DC)

Measurement systems:

4-channel currents and voltages

System 1 (nominal ranges):

- Voltage: ±400 V_{peak} per phase
- Current: 6 A_{eff} / 15 A_{eff} per phase

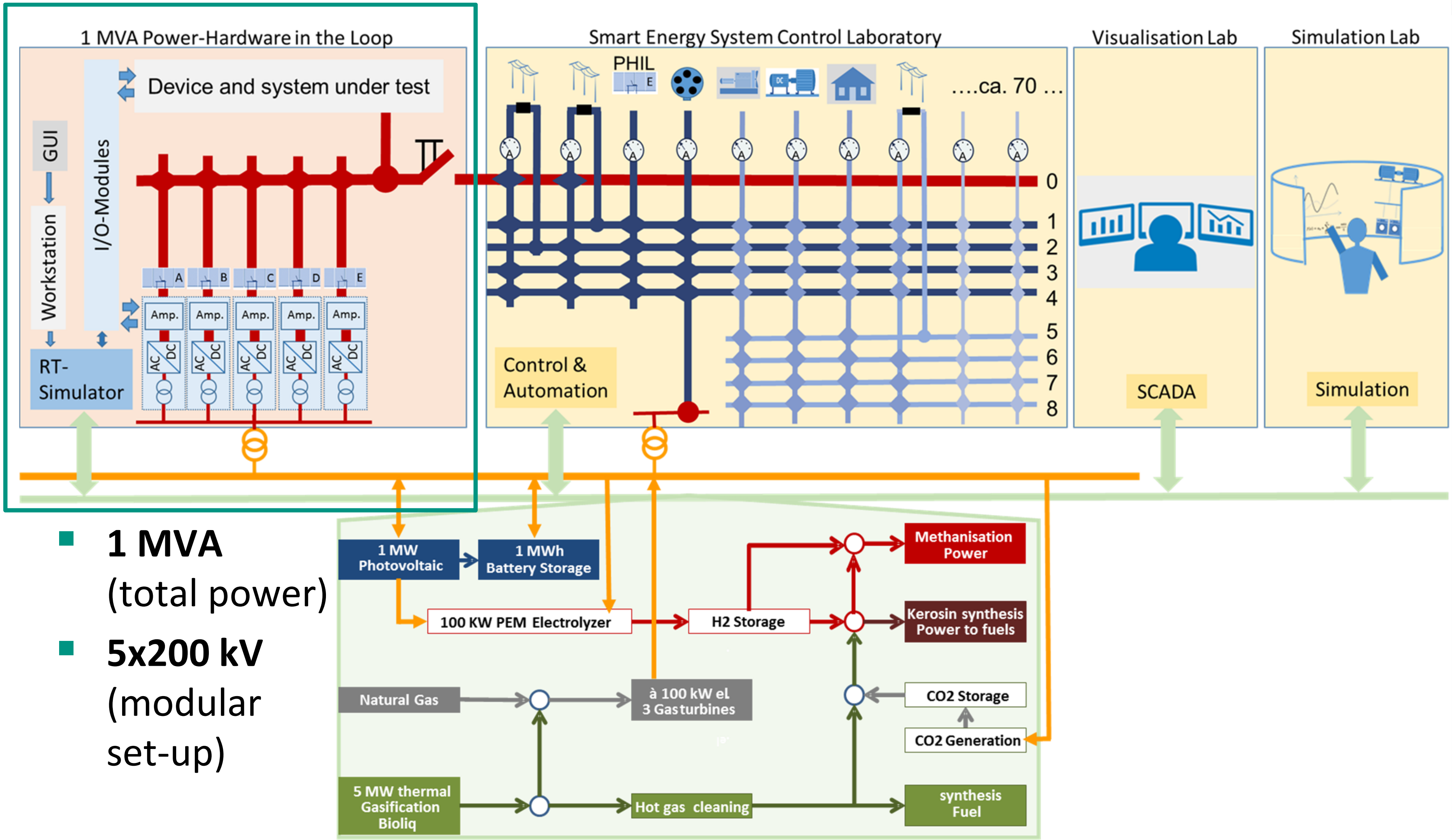
System 2 (nominal ranges):

- Voltage: 780 V_{peak} per phase
- Current: ±19.2 A and ±48 A per phase

Pictture courtesy of JG

Energy Lab 2.0

Schematic set-up



- **1 MVA** (total power)
- **5x200 kV** (modular set-up)

Pic courtesy of EL2.0/IAI/KIT

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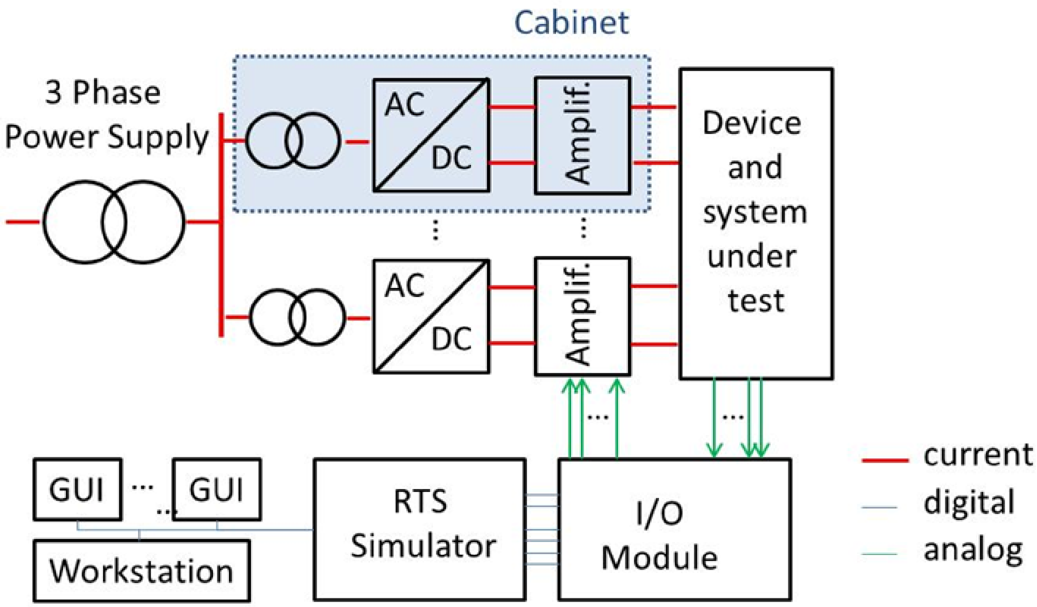
1 MVA PHIL Laboratory

Characteristics

- **5x200 kV** modular set-up



Voltage:

- **DC**
  - 0-750 V
  - 0-1500 V

    (to ground max. 1 kV AC_{peak}/DC)

single phase
  - 0 - 530 V_{RMS} / 0 – 750 V_{peak}
  - 0 - 1000 V_{RMS} / 0 – 1415 V_{peak}

    (to ground maximal 1 kV AC_{peak}/DC)

three phase
  - 0 - 265 Veff / 0 – 375 Vpeak (phase-to-neutral)
  - 0 - 459 Veff / 0 – 649 Vpeak (phase-to-phase)
  - 0 - 530 Veff / 0 – 750 Vpeak (phase-to-neutral)
  - 0 - 918 Veff / 0 – 1298 Vpeak (phase-to-phase)

Frequency:

- 0 (DC) – ≥5 kHz (> -0.5 dB, < 0.5 dB)
- 0 (DC) – ≥10 kHz (> -3 dB, < 3 dB)

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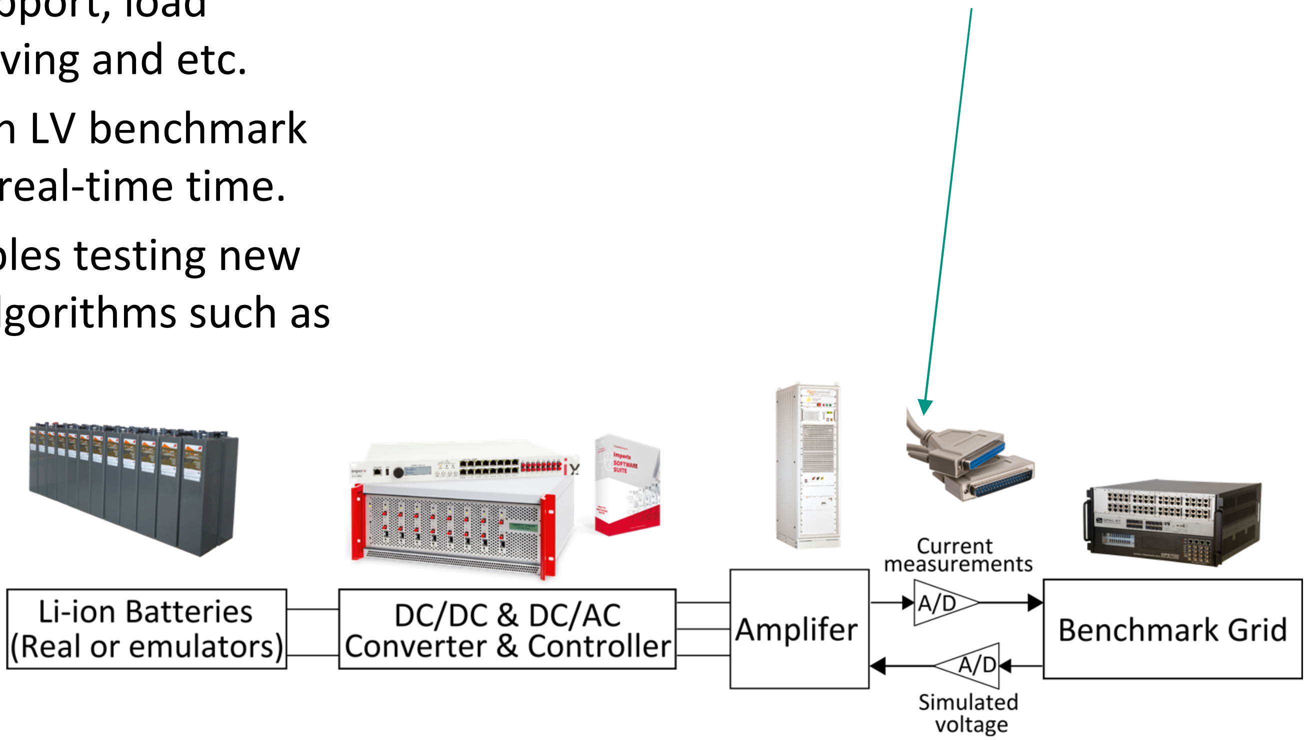
PHIL Testing: Energy Storage Systems (ESS)

Case 1: Lithium Iron Phosphate ($LiFePO_4$) BESS

- $LiFePO_4$ BESS have advantages such as long lifetime, high peak power and slow rate of capacity loss.
- $LiFePO_4$ BESS is tested for various grid ancillary services such as frequency support, voltage support, load balancing, peak shaving and etc.
- The CIGRE European LV benchmark grid is simulated in real-time time.
- The setup also enables testing new converter control algorithms such as inertia emulation.



Li-ion Batteries (Real or emulators)

DC/DC & DC/AC Converter & Controller

Amplifer

Current measurements

A/D

A/D

Simulated voltage

Benchmark Grid

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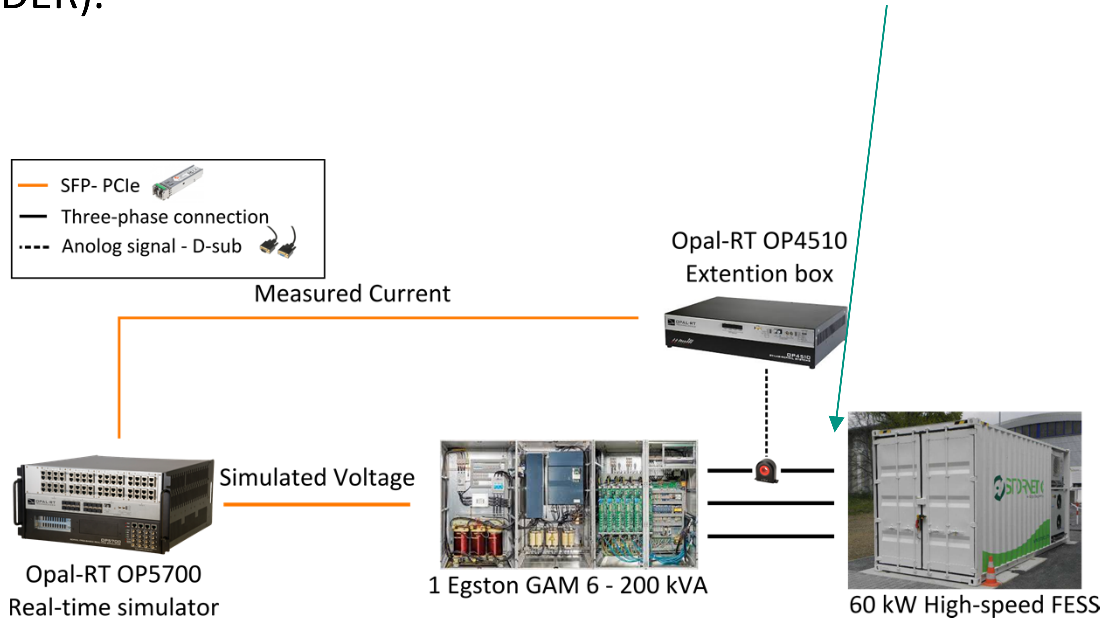
PHIL Testing: Energy Storage Systems (ESS)

Case 2: High-speed Flywheel Energy Storage Systems (FESS)

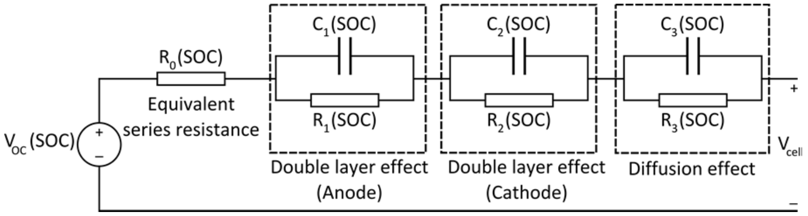
- High-speed FESS can provide surges of power for short periods of time, with no concern over lifetime/capacity.
- FESS is tested in various grid conditions such as frequency deviations, faults, islanding of microgrids and also in combination of other Distributed Energy Resources (DER).

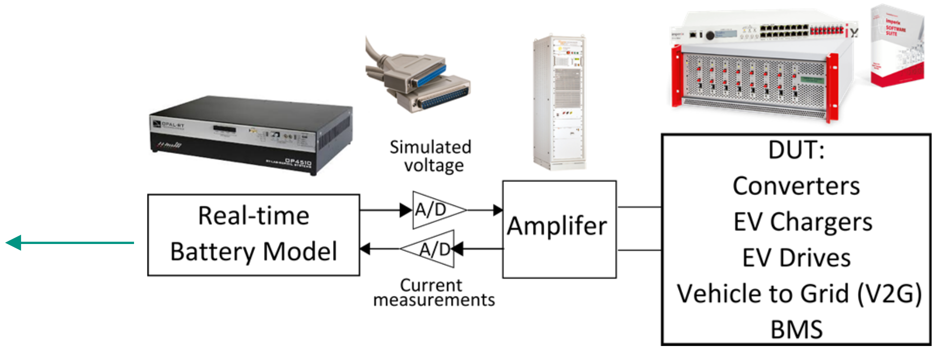


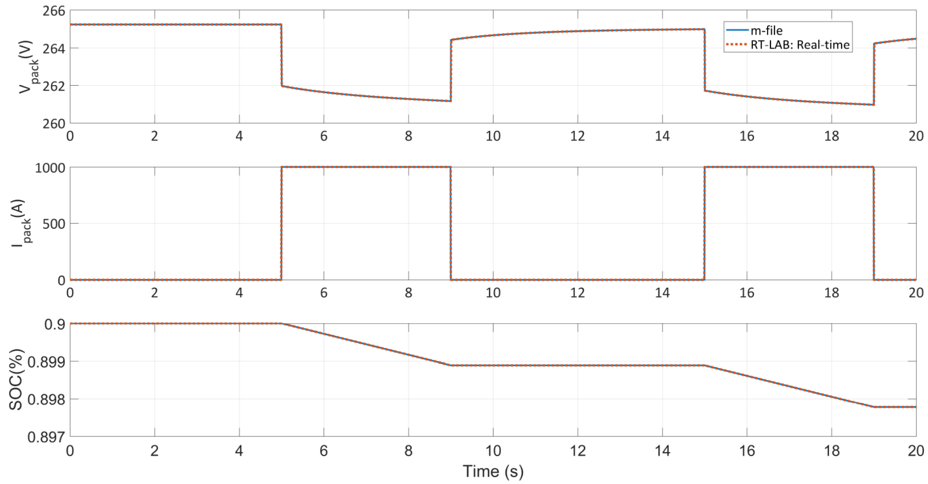
Real-time models of ESS to act as ESS Emulators

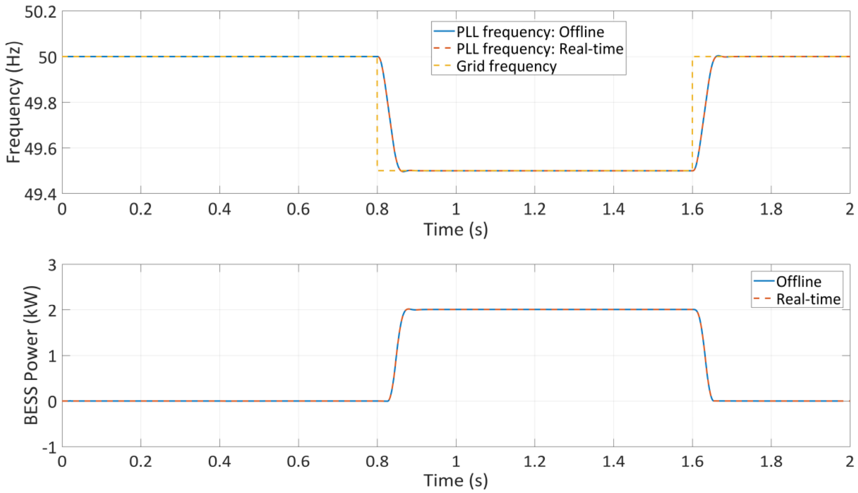
Different Realizations

- The real-time battery and flywheel model together with an amplifier can emulate these storage technologies for various applications.





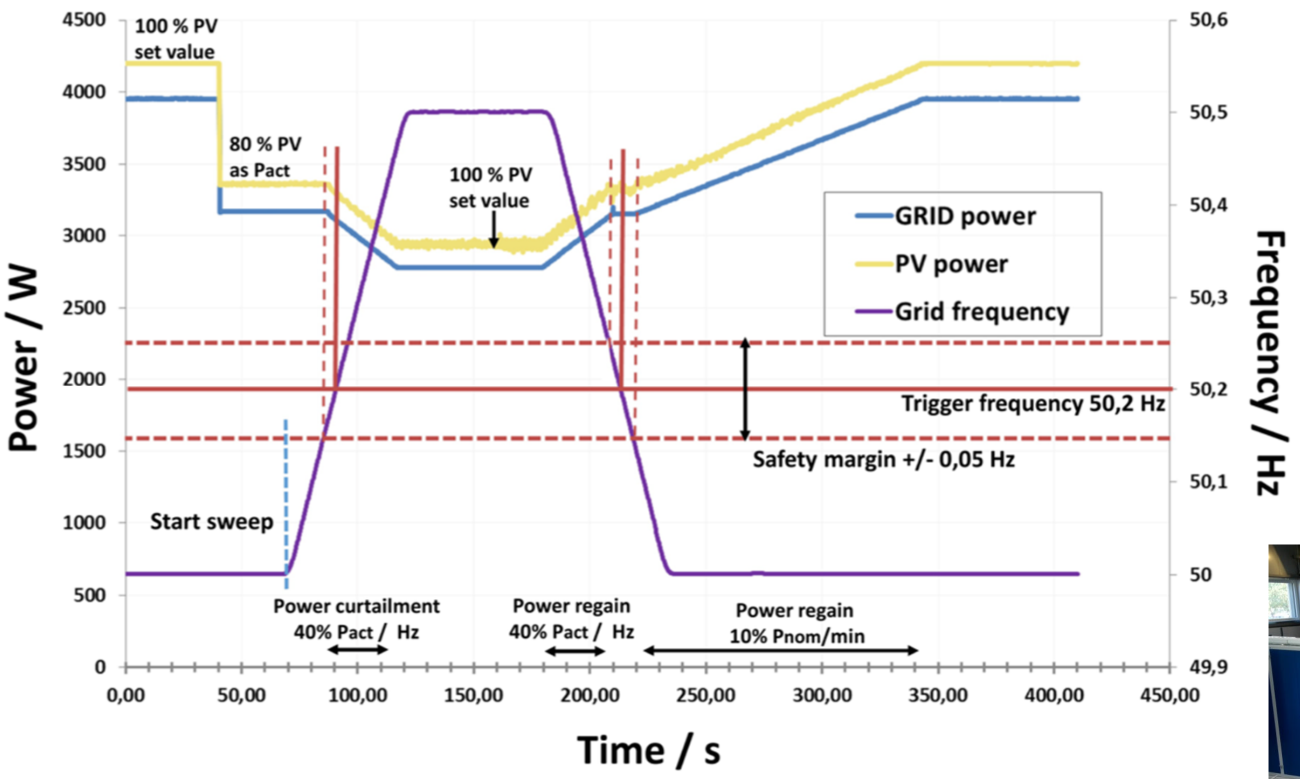




PHIL Testing: Low voltage power grid components

Photo-voltaic home storage system

Inverter power curtailment under over-frequency



- *Frequency sweep from 50 to 50.5 Hz and back*
- *Testing systems in accordance to standards*

  (e.g. VDE 4105)


Figures & Pic by ITEP/ETI

Future goal: contribute to the development of standards to ensure future readiness of the energy system/grid

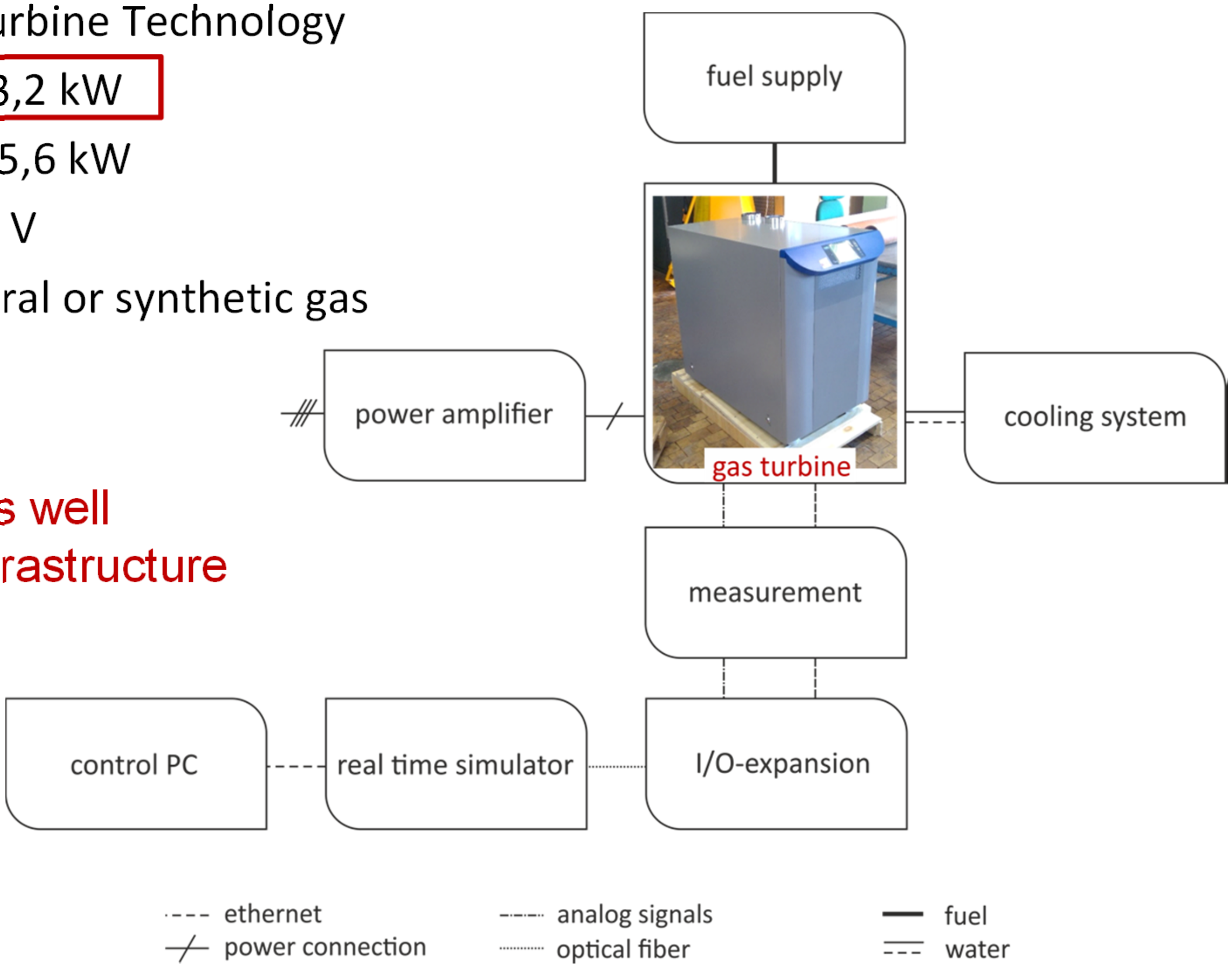
In collaboration with ETI Battery Technical Center (N. Munzke, F. Buechle, B. Schwarz, M. Hiller et al.)

PHIL Testing: Sector Coupling

Combined-Heat-Power: Micro-gas-turbine

- Technical characteristics of the Micro-gas-turbine:
  - Supplier: Micro Turbine Technology
  - Electrical power: 3,2 kW
  - Thermal power: 15,6 kW
  - Voltage level: 230 V
  - Type of fuel: Natural or synthetic gas

Electrical power matches well
PHIL Training Station infrastructure



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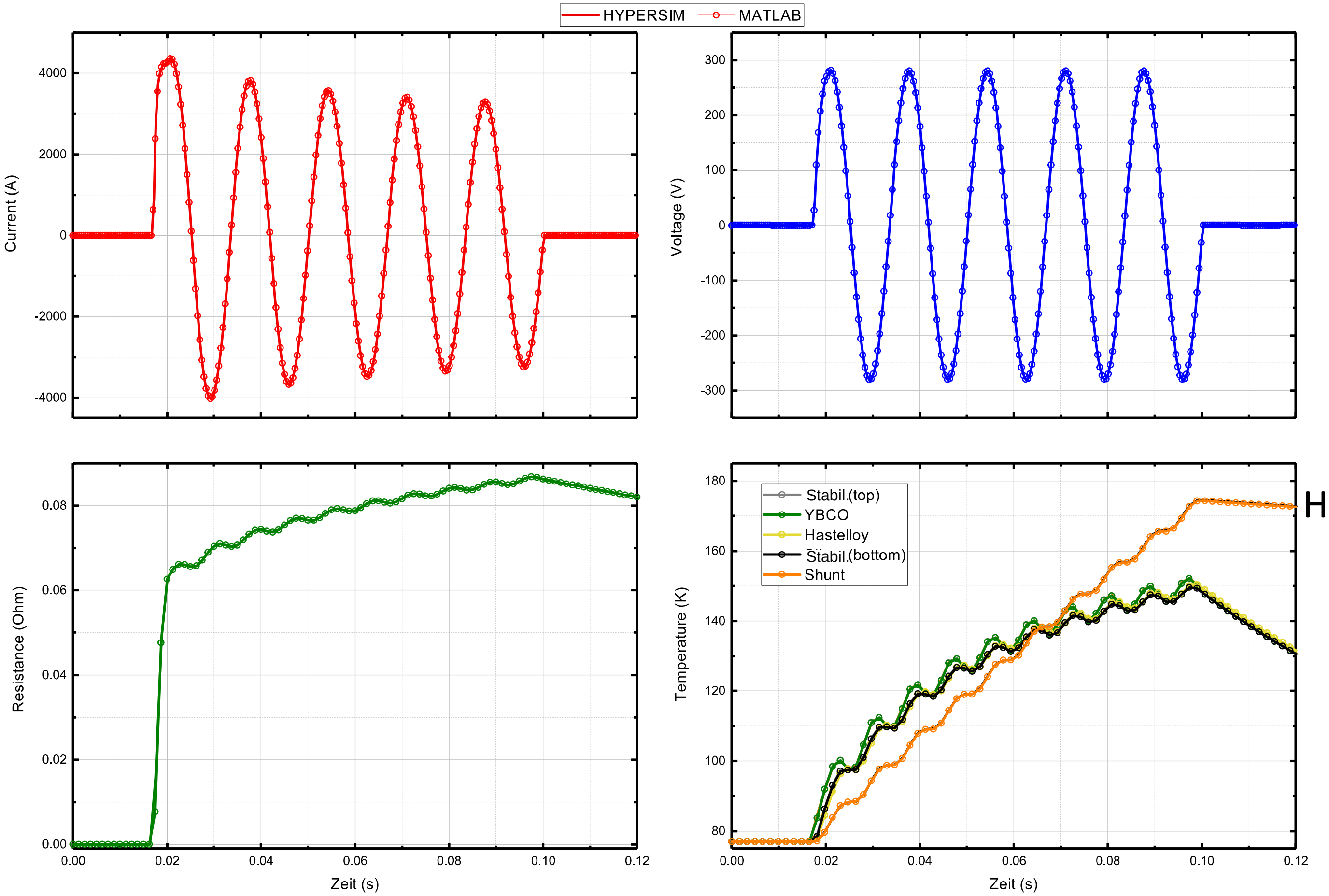
PHIL Testing: New Technologies

Tests of SFCL models

- Successful implementation of a valuable model for **transient simulations of SFCL devices in a real-time enviroment** (HYPERSIM using User Coded Model) at ITEP/KIT.



Incorporation of **heat exchange** between layers, **transfer** and **losses**:

$$C\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial z^2} + RI^2$$

Heat stored

Heat conduction

Resistive heat losses
(E-J characteristic)

First time achievement!

Thank you for your attention!

Panel: Energy Saving and Sustainable Energy

Mark Apperley

University of Waikato
New Zealand

- World-wide commitment, prompted by the climate crisis, to move to a more sustainable energy environment;
- Significant implications for our concept of a traditional electricity grid;
- A move towards totally renewable, non-carbon based sources of ~~electricity~~; energy
- Many of these are non-deterministic – eg wind, solar;

  =>Increasing role for storage, load management

- An increasing importance of electricity as our primary medium for energy generation, storage, and consumption;

- Not just a move to replace carbon-based sources with renewables, but to significantly expand electricity consumption;
  - ⇒ Far greater use of electricity for transport and industrial processes;
- Changes in production – new renewables, and storage – have implications for the centralised hub/spoke model of the legacy grid, with much increased role for distributed generation and distributed storage;
- Opportunity for focus on localised energy balance, so impacting future grid topology and capacity.