Stable and accurate MIMO Power Hardware in the Loop Simulation – Theory and Applications

AIT Austrian Institute of Technology

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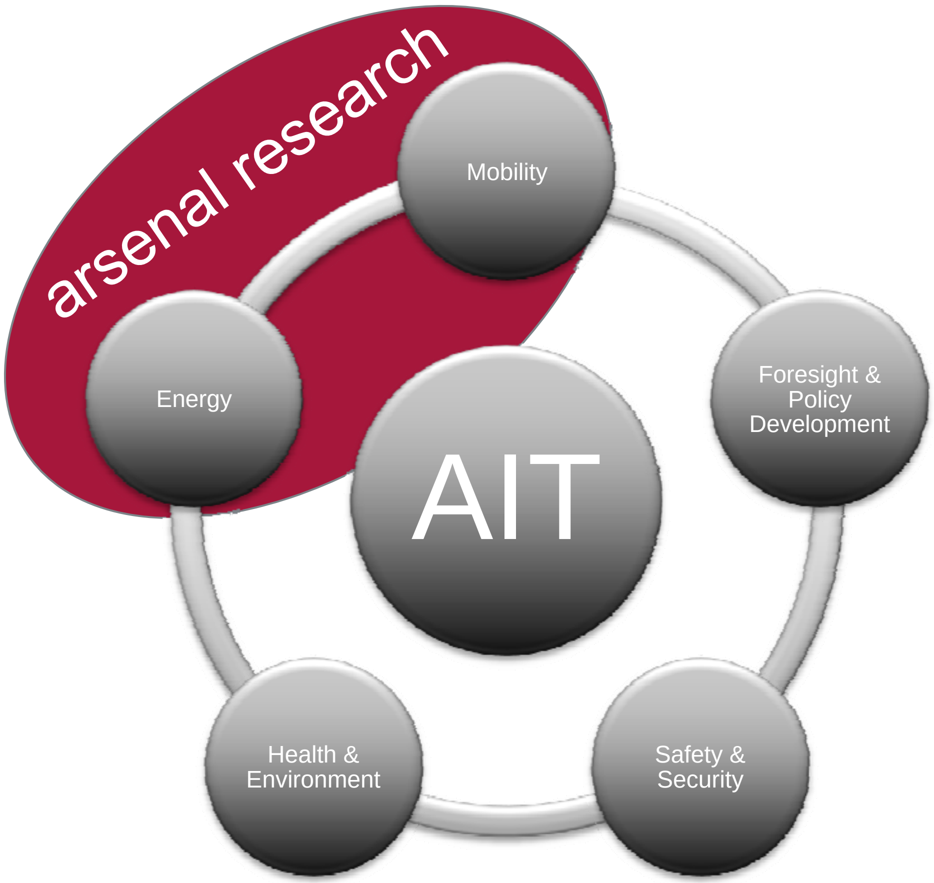
THEME 2: **Power Hardware-in-the-loop**

AUSTRIAN INSTITUTE OF TECHNOLOGY

Presentation of our institute, department, business field and our services

AIT Austrian Institute of Technology

AUSTRIAN INSTITUTE OF TECHNOLOGY



The Austrian Research Institute of European format addressing the **core infrastructure topics** of the future.

Five autonomous **business areas** with profit and loss responsibility (departments) working in close connection with thematically focussed partners from industry and with contracting entities from public institutions

Explicit performance goals
International competitiveness and cutting-edge research
Technological **impulses**

Funding Principle:
40% Basic public funding
30% Cooperative research
30% Contract research

The Energy Department

- The Energy Department develops **sustainable energy systems** based on cutting-edge research and provides innovative solutions to tomorrow's energy problems.
- The identification of **emerging technologies** with both the potential for changing current energy systems towards more sustainability and the potential for success on the market is a key task for the Department Energy.
- Our energy experts are accompanying the **innovation process** by providing high-level expertise both on **technological** and **system** level.

3 Business Units, about 90 staff members

Electric Energy Systems

- Electric network and system behaviour
- Network components
- Photovoltaic and power conversion technologies

Sustainable Building Technologies

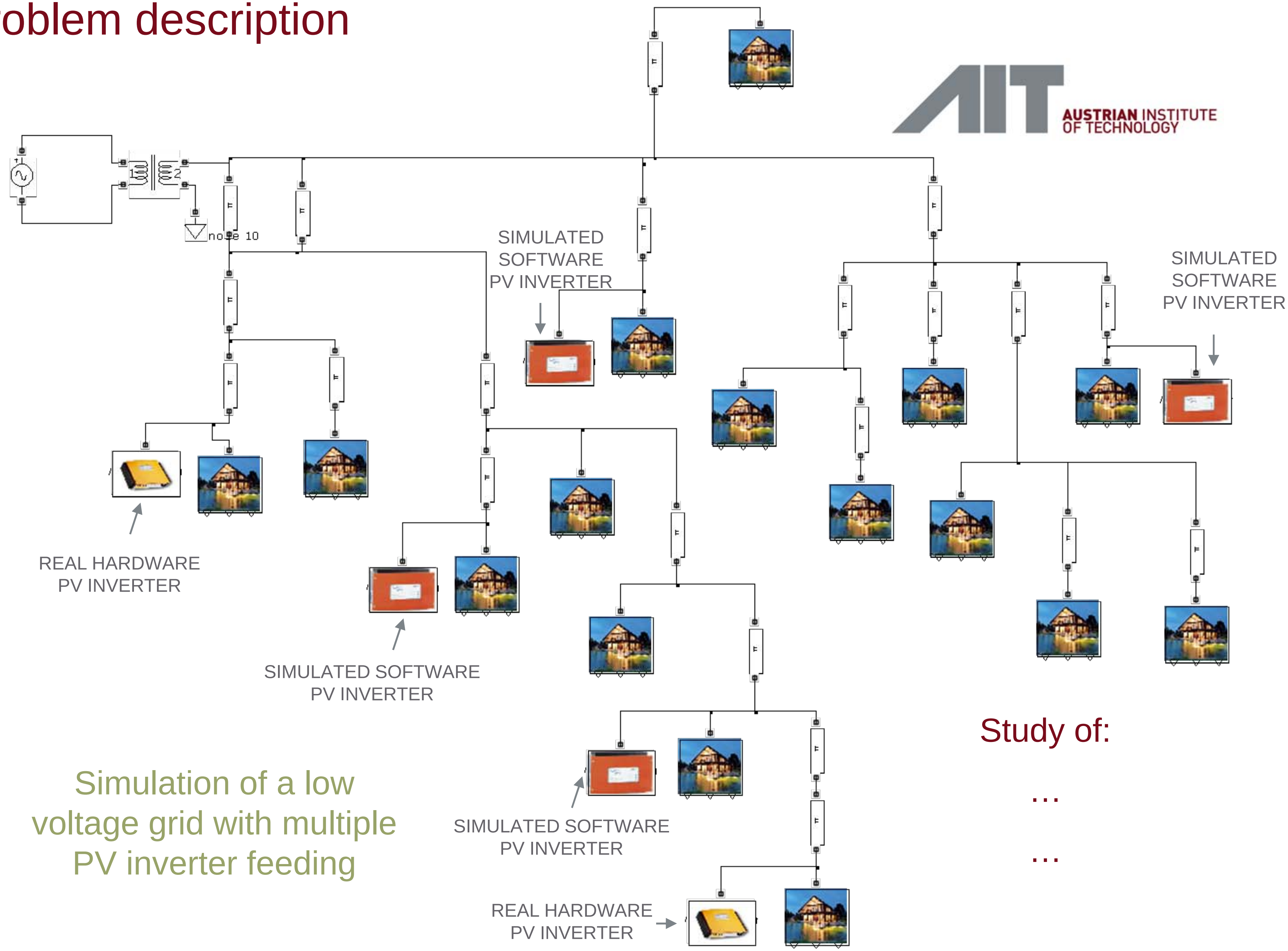
Sustainable Thermal Energy Systems

Presentation of topic

Structuring

- Problem description (application)
- Equipment
- Hurdles to overcome
- Bandwidth issues and „PHIL is about closed loops"…
- From SISO to MIMO PHIL
- How to improve stability
- Conclusions

Problem description



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Simulation of a low voltage grid with multiple PV inverter feeding

Study of:

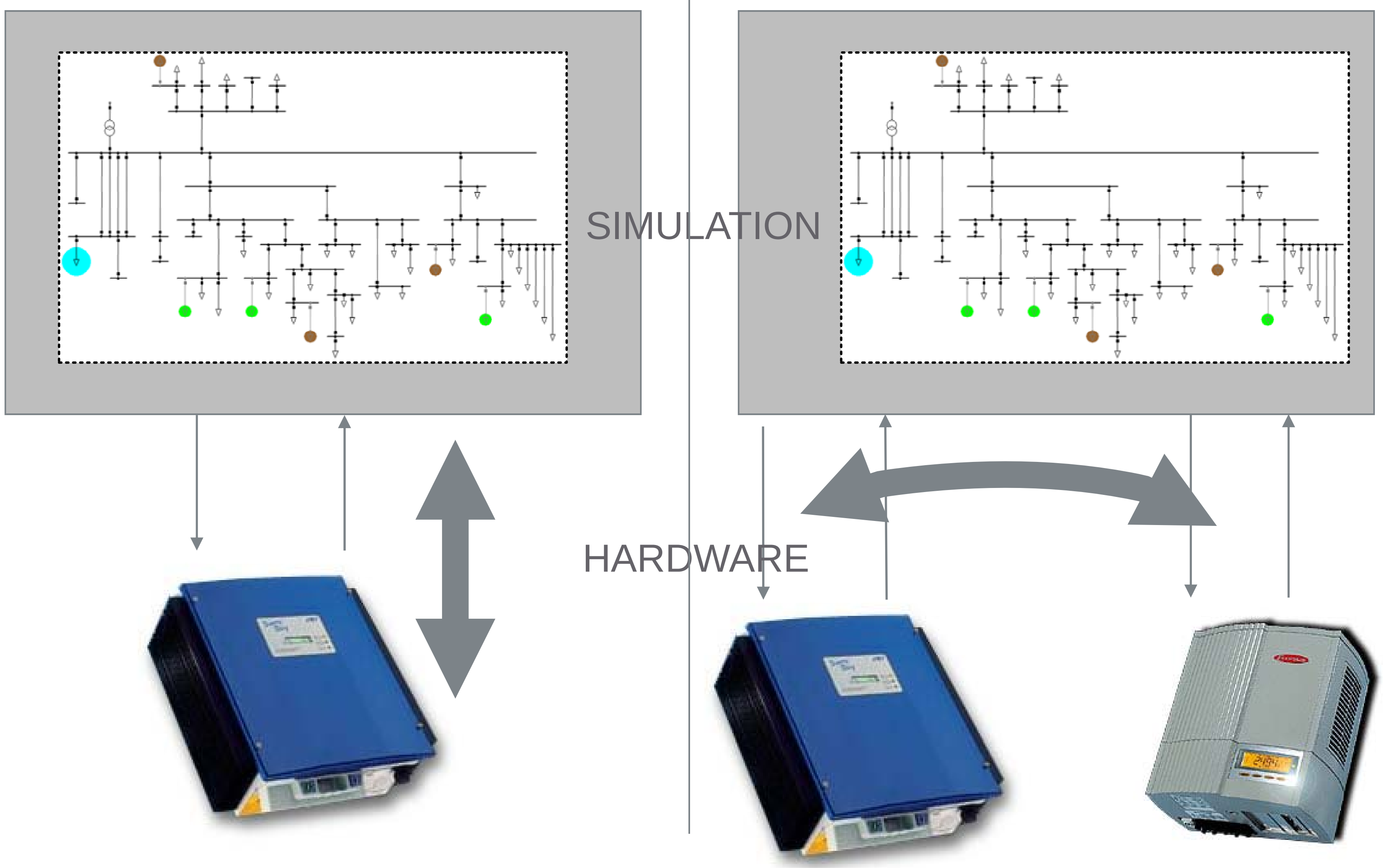
…

…

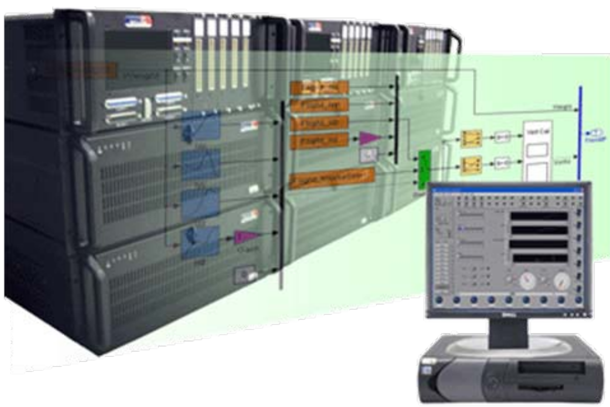
Problem description: Interaction studies

Interaction: component - grid

Interaction: component - grid – component



Equipment



DC
simulators

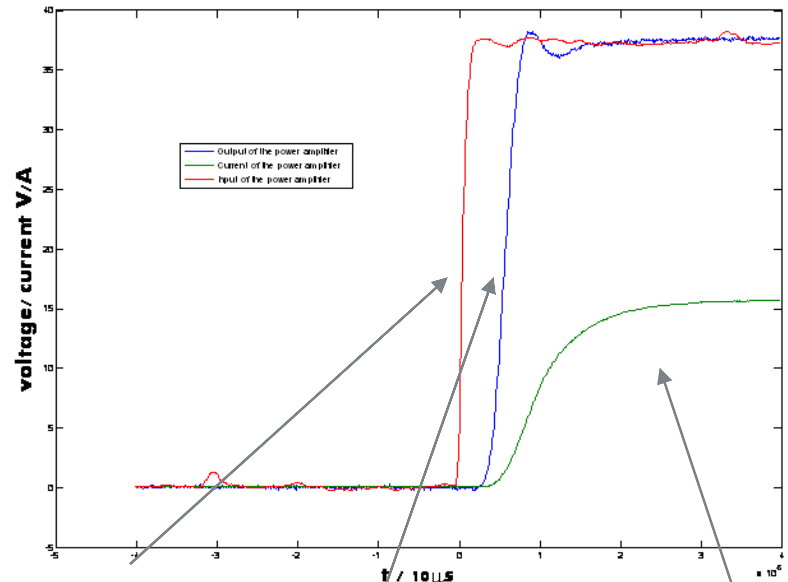
OPAL RT Real Time System

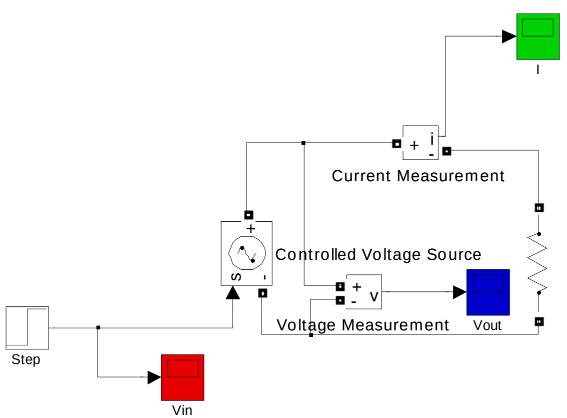
PV inverters

Voltage amplifiers 10kW 4 quadrant operation

Equipment: characterization
exemplary voltage amplifier, dynamic behaviour

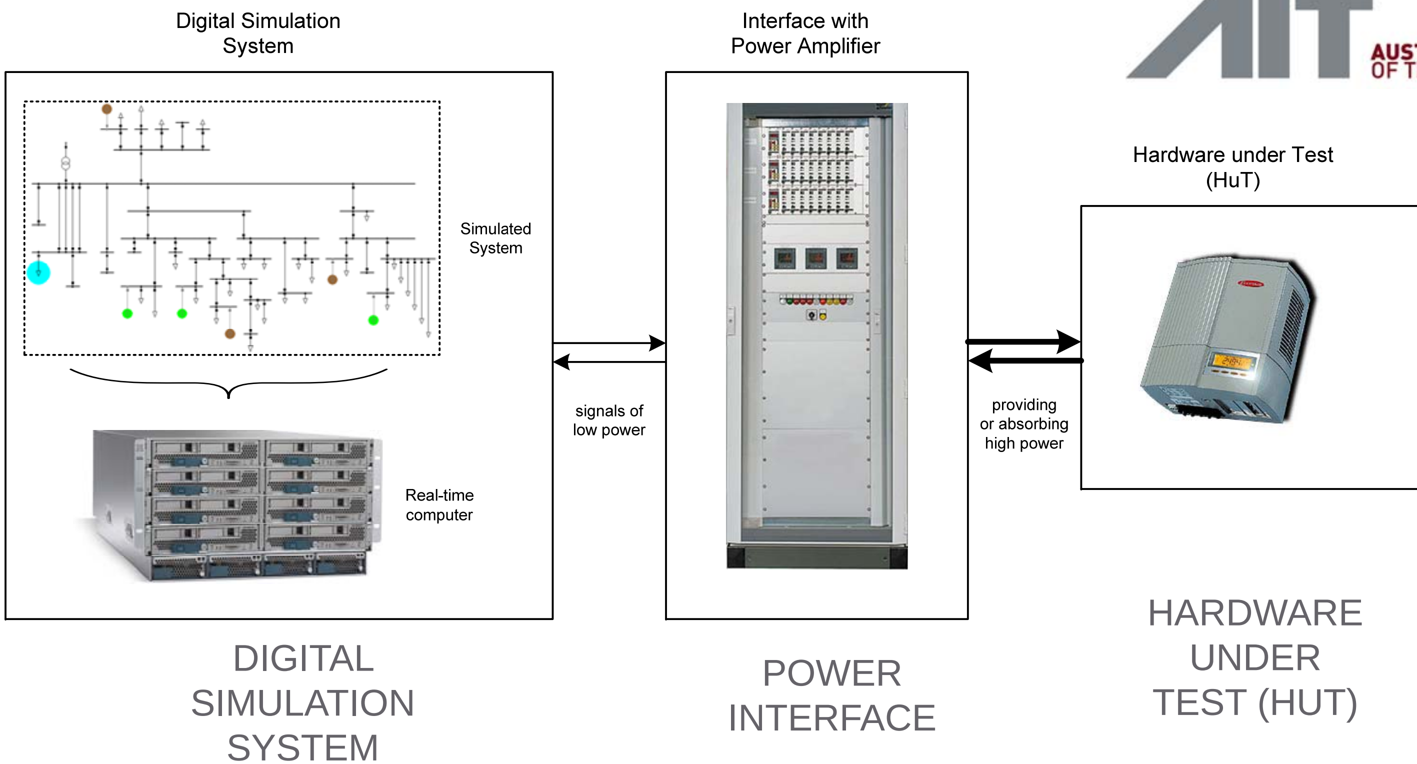
Step response of the voltage amplifier connected to resistive load

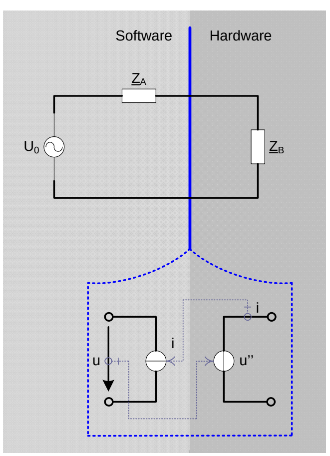


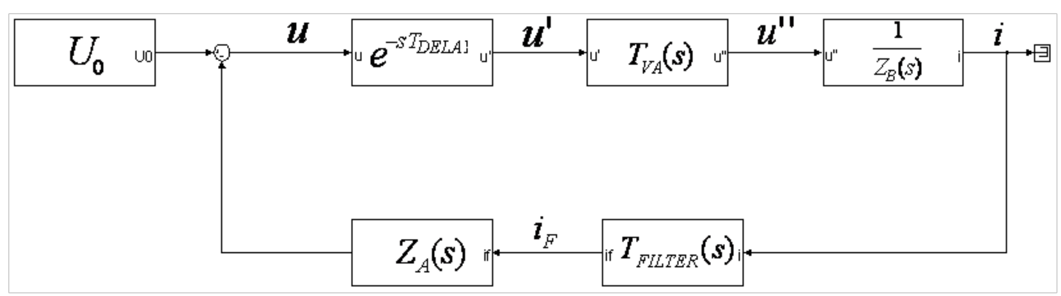


$$T_{VA} = \frac{e^{-4.2\,\mu s}}{1 + (0.8\,\mu s)s + (2.913e^{-13}s^2)s^2}$$

PHIL is about closed loops!

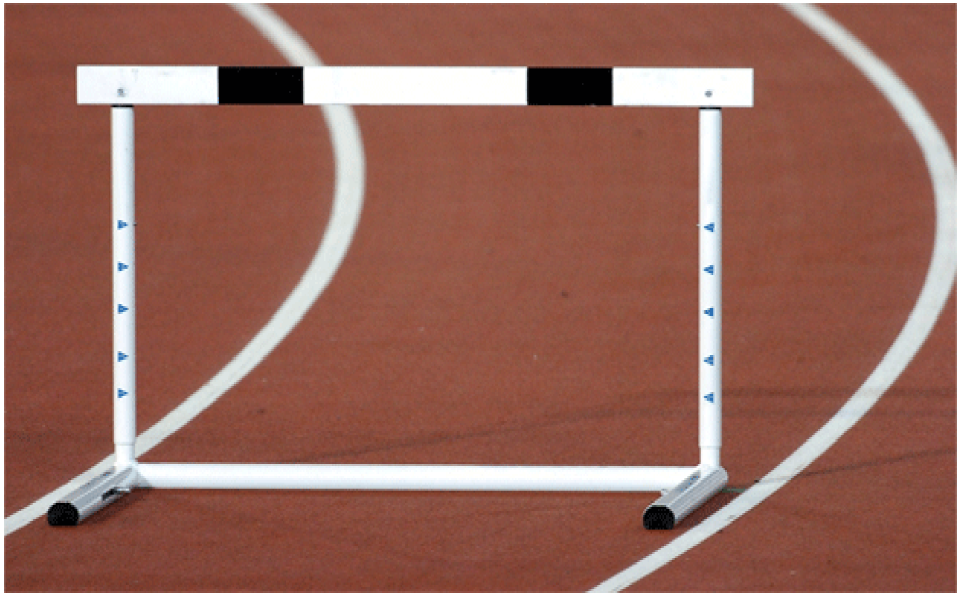






Hurdles to overcome:

From the problem to the solution



Appropriate interface design !

Multirate simulation if necessary !

Appropriate filtering !

Appropriate Modelling (not discussed here)?

Guarateeing stability ?

Achieving Accuracy ?

Definition of a bandwidth with a certain accuracy

- We define the accuracy *a* as following:

$$a(w) = 20\log\frac{\left|q_{REAL}(w) - q_{IDEAL}(w)\right|}{q_{IDEAL}(w)}$$

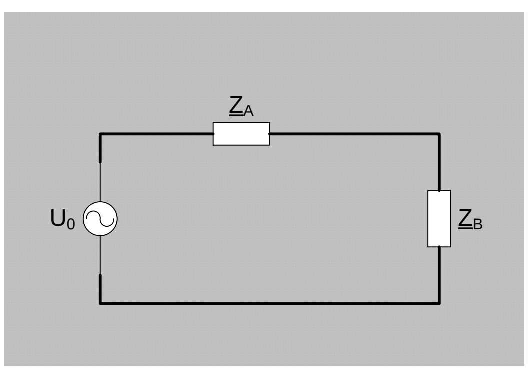
where *q* is the interesting property.

- Example: voltage divider q is the ratio of the voltages

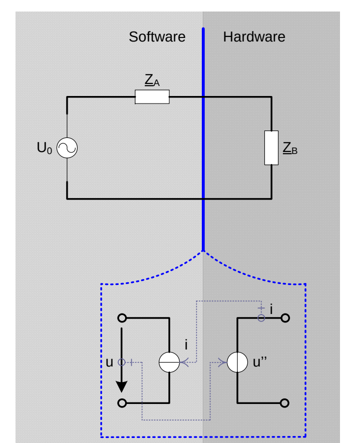
$$q_{IDEAL}(w) = \frac{U_2}{U_0}(w) = \frac{Z_B(w)}{Z_B(w) + Z_A(w)}$$

$$q_{REAL}(w) = \frac{U_2}{U_0}(w) = \frac{Z_B(w)}{Z_B(w) + e^{-jwT_{DELAY}} T_{VA}(w) T_F(w) Z_A(w)}$$

REAL SYSTEM (IDEAL)



PHIL SIMULATION (REAL)



Bandwidth for PHIL?

Real time system sampling rate — 50us -> **20 kHz**

Bandwidth of power amplifier? — **16 kHz** (-20dB accuracy)

$$T_{VA} = \frac{e^{-4.2\mu s}}{1 + (0.8\mu s)s + (2.913e^{-13}s^2)s^2}$$

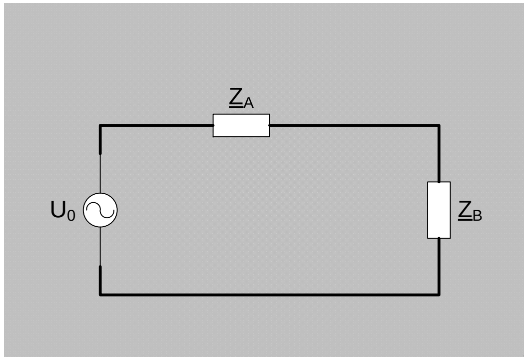
Bandwith of measuring device? — 8us-> **9 kHz** (-20dB accuracy)

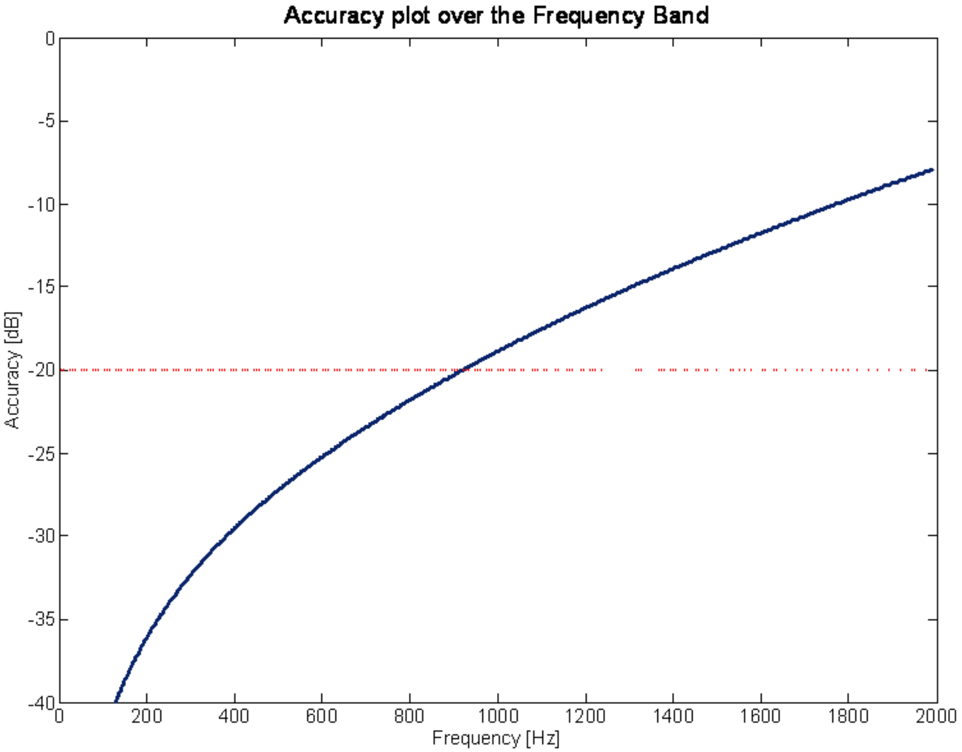
$$T_{ME}(s) = \frac{1}{1 + s*(8\mu s)}$$

[redacted]

?

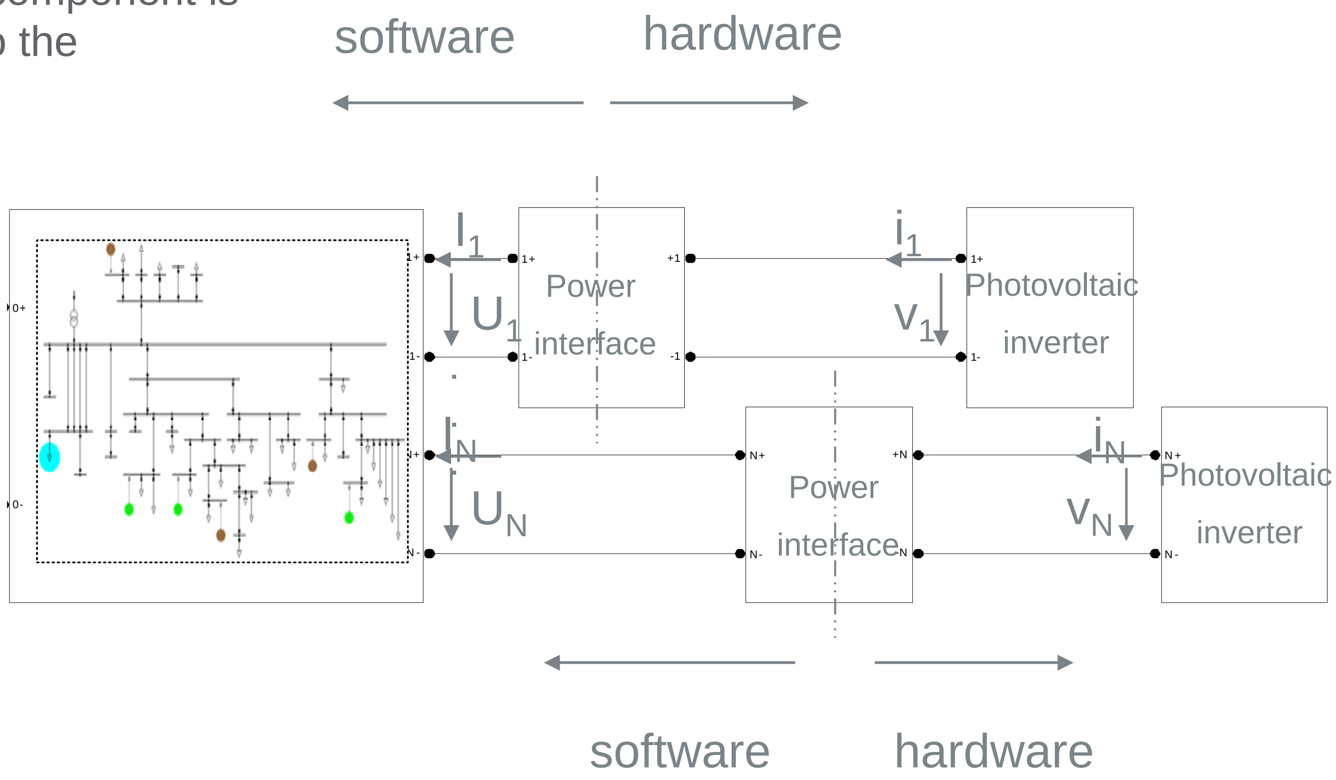
PHIL is about closed loops
Stability and accuracy





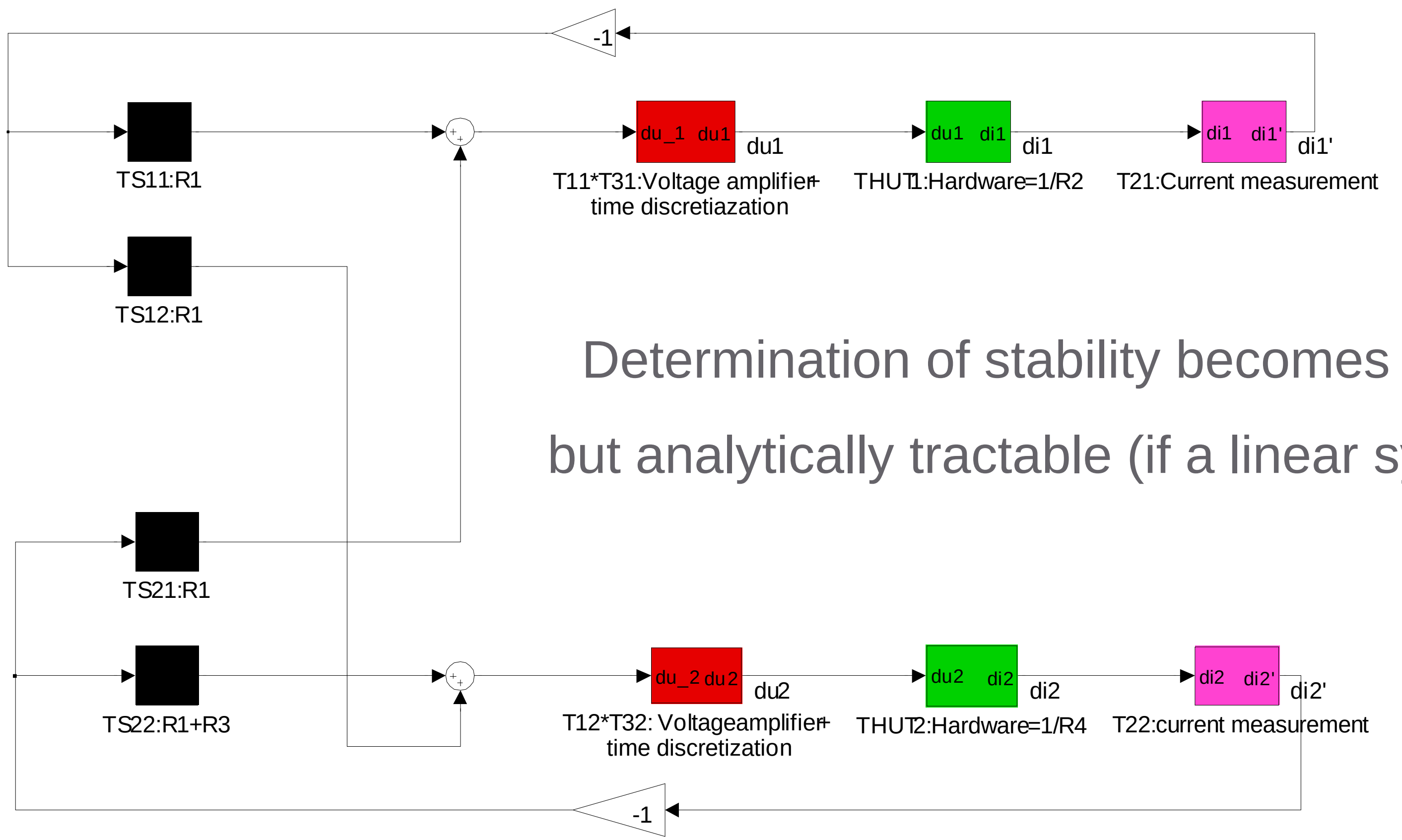
MIMO Power Hardware in the Loop:

More than one hardware component is attached to the simulation!



MIMO PHIL -> MIMO closed loops

If we attach more than one real hardware component via a power interface to the simulation, from a system theoretic point of view we get coupled closed loops!



Determination of stability becomes tricky,

but analytically tractable (if a linear system)!

How to improve stability?

Use the Damping Impedance Method!

(You need a good model!)

Filter the input signal from HUT appropriately!

(Note: this measure could reduce drastically accuracy)

Make use of multi-rate capability
of the real time system

(A. Viehweider, G. Lauss, F.Lehfuss, “Improvement of accuracy and stability of Power Hardware in the Loop simulations via a dual rate interface“, e&i, 2010)

Conclusions

- A **promising** approach…
- Hurdles are to overcome but feasilbe with **state of the art real time simulation system**…
- Be careful about **bandwidth**!
- **Range of applications** not yet defined… (but maybe there are many…)
- Technical advances in real time simulation engineering and power amplifier design (especially for high power ratings) make sophisticated PHIL simulations feasible

Thank you for your kind attention!

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Electric Energy Systems

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