NATIONAL TECHNICAL UNIVERSITY OF ATHENS, GREECE

SMART RUE

AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

Limitations of Digital Simulation and Advantages of PHIL Testing for DG providing Ancillary Services

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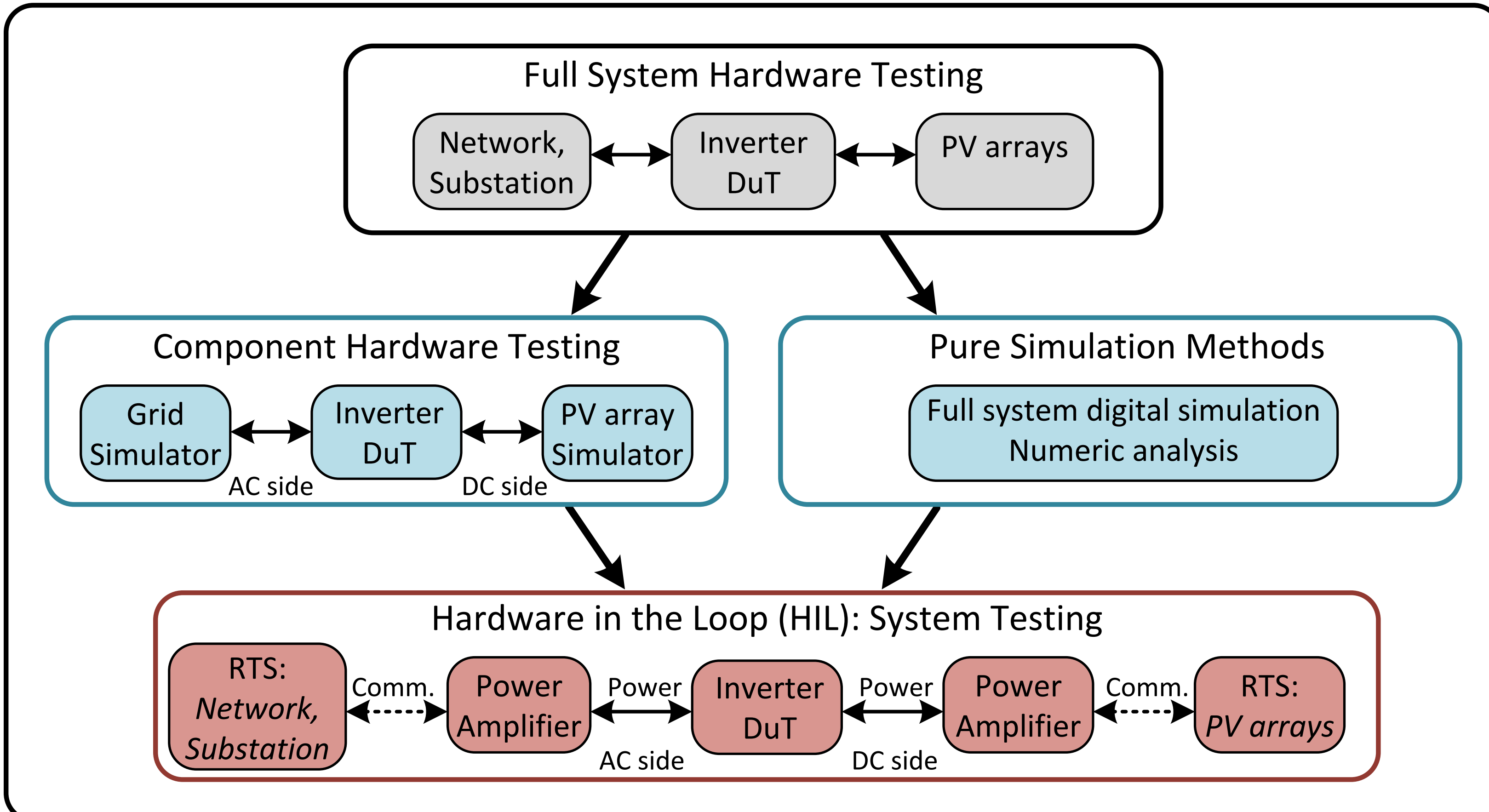
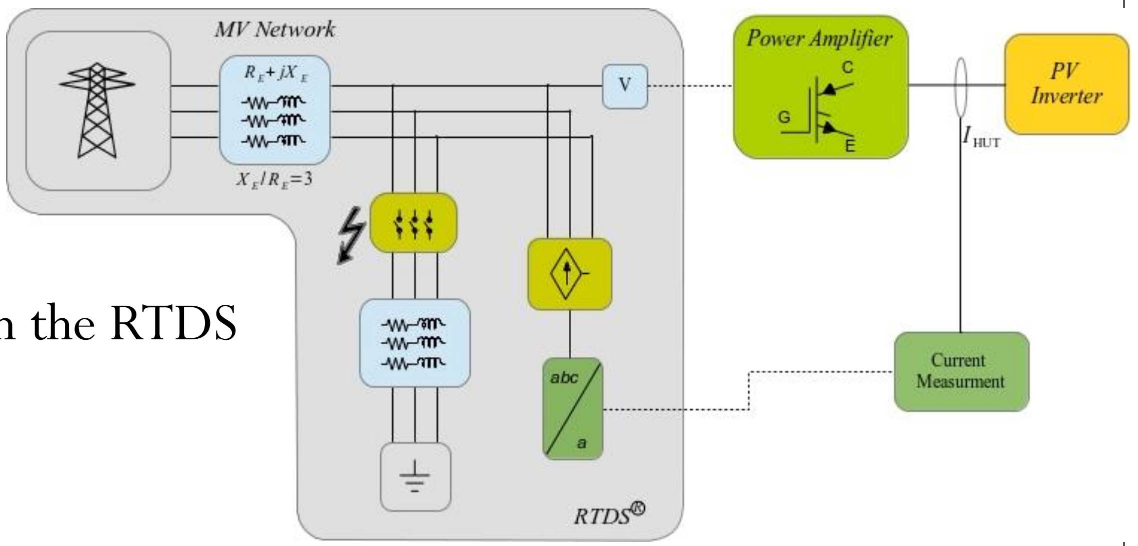
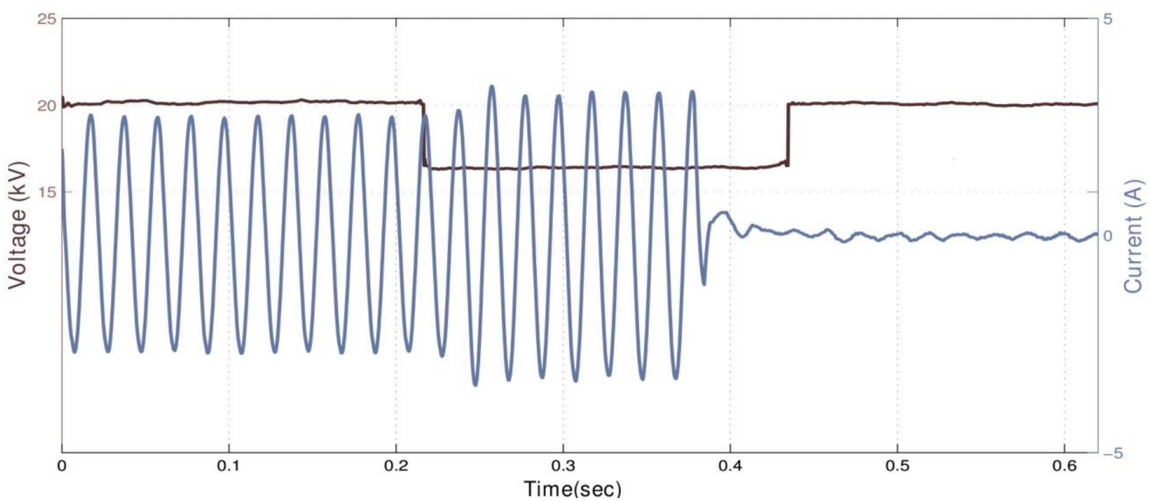
Evolution of power system/component analysis, testing and validation



PHIL Fault-Ride-Through tests on PV inverters

- Simulated network according to Standards for Fault-Ride-Through
- Fault in the simulated network in the RTDS

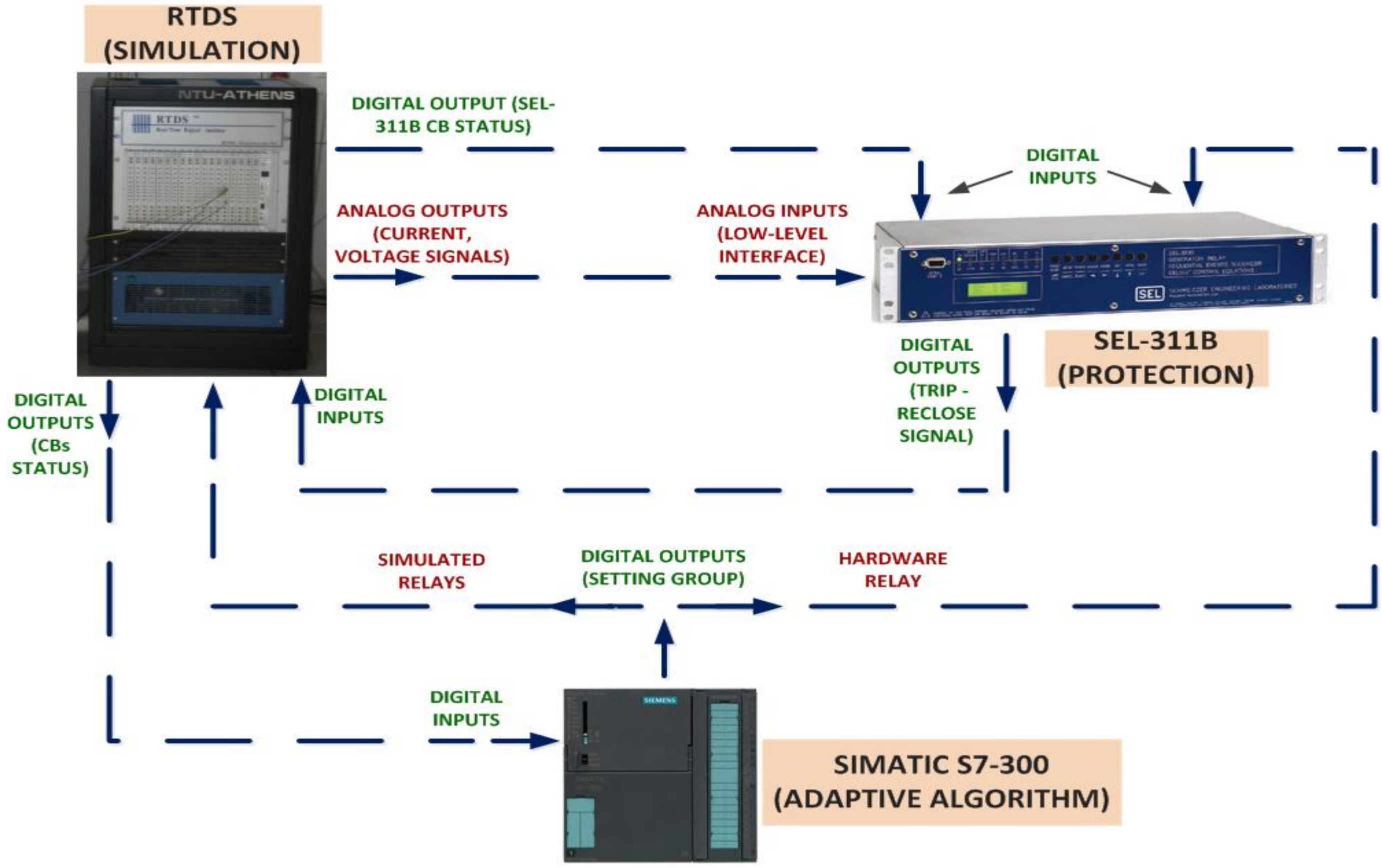




- The hardware PV inverter is disconnected following the relevant standard

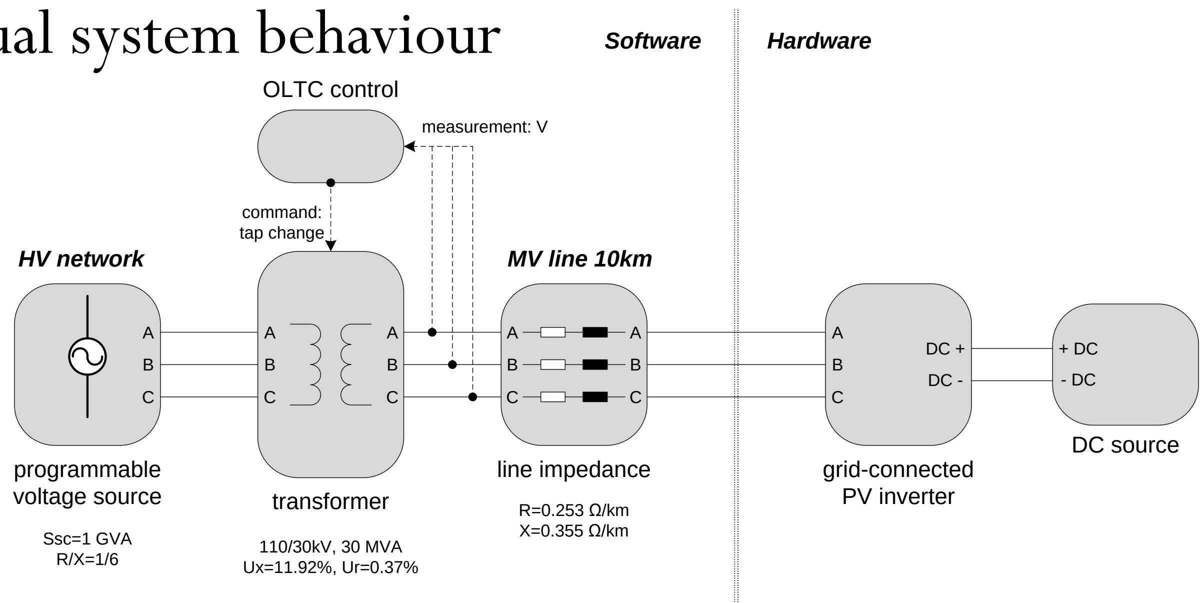
Adaptive protection testing via HIL simulation

The settings of the hardware-software relays are adapted to the network conditions (e.g. DG on or off)



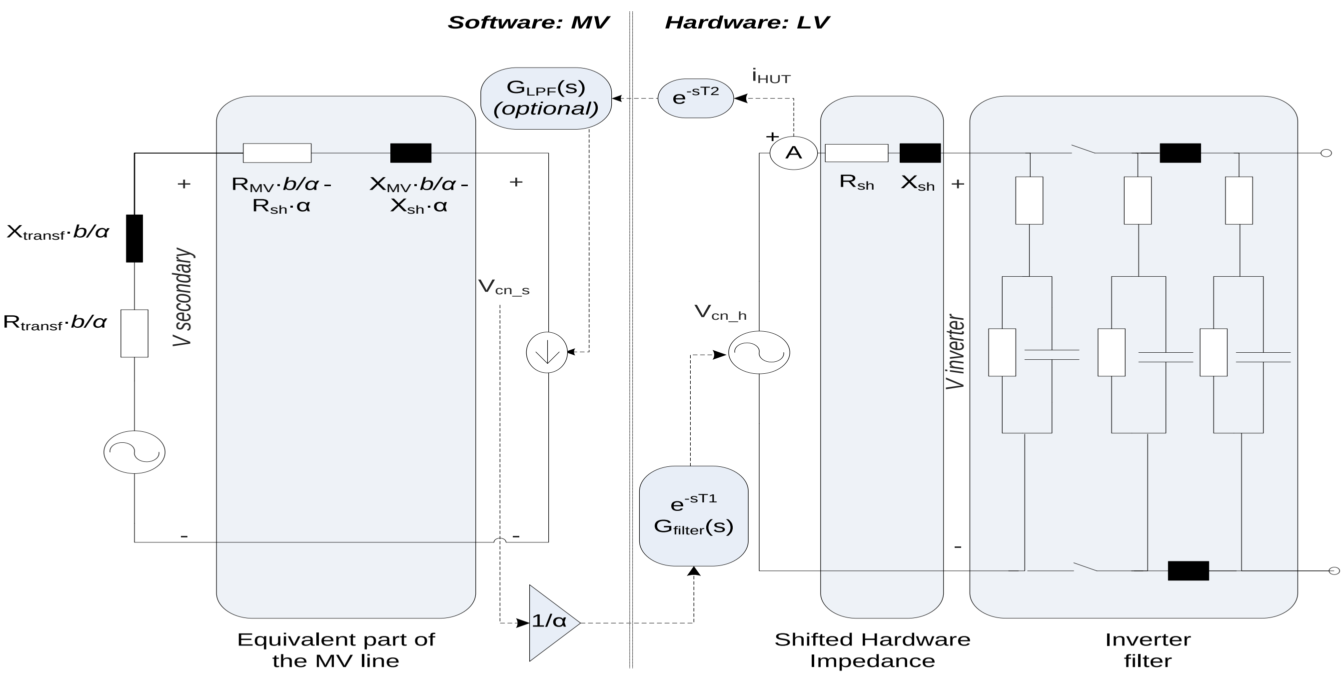
PHIL testing of ancillary services by inverter-based DG

- Inverter-based DG are particularly difficult to model accurately
- Therefore the "classic" pure digital simulation can face limitations
- PHIL makes use of the real DG and can therefore reveal the actual system behaviour



New scaling and stability-accuracy method

- PHIL allows scaling of the software and hardware. A 2kVA hardware LV PV inverter is used to evaluate the integration of a 15MVA PV park connected to the MV. **The grid voltage control algorithm of the full and reduced-scale DGs are exactly the same.**
- Shifting part of the software impedance on the hardware side is proposed Stability can be achieved without compromising accuracy (if necessary a "smaller" feedback filter can be used)

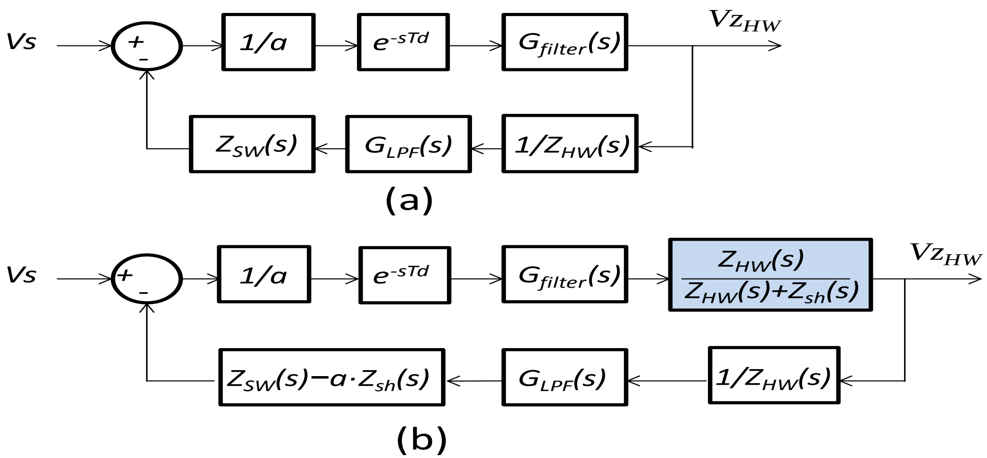


$$a = \frac{V_{SW}}{V_{HW}}$$

$$b = \frac{S_{HuT\_full}}{S_{HuT\_red}}$$

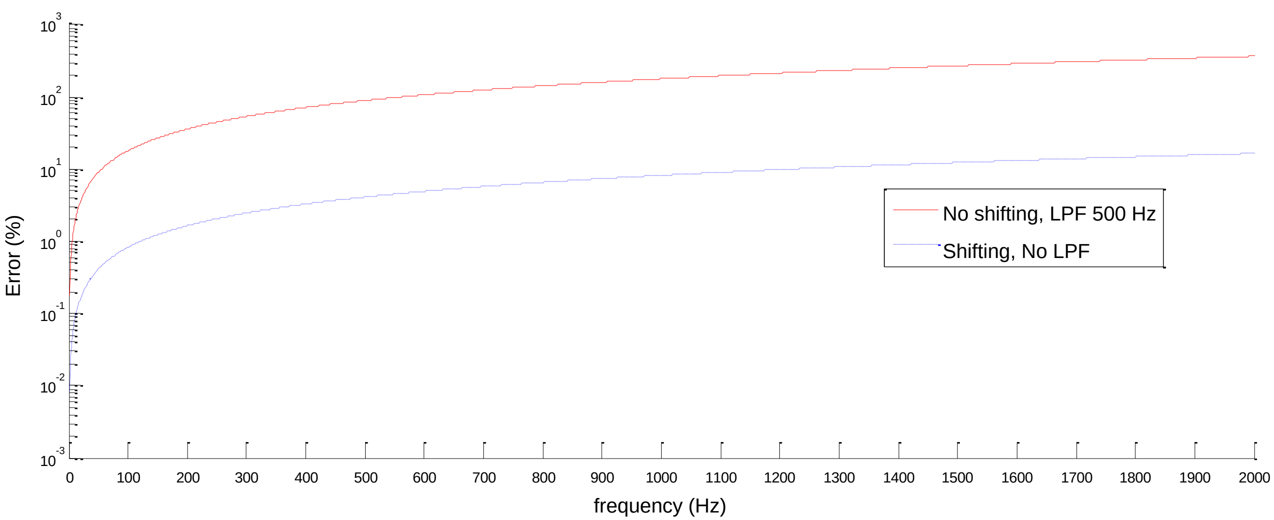
$$Z'_{SW}(s) = \frac{b}{a} Z_{SW}(s) - a \cdot Z_{sh}(s).$$

Accuracy Improvement with the proposed method



Down-scaling of the voltage improves the stability

Up-scaling of the current deteriorates the stability

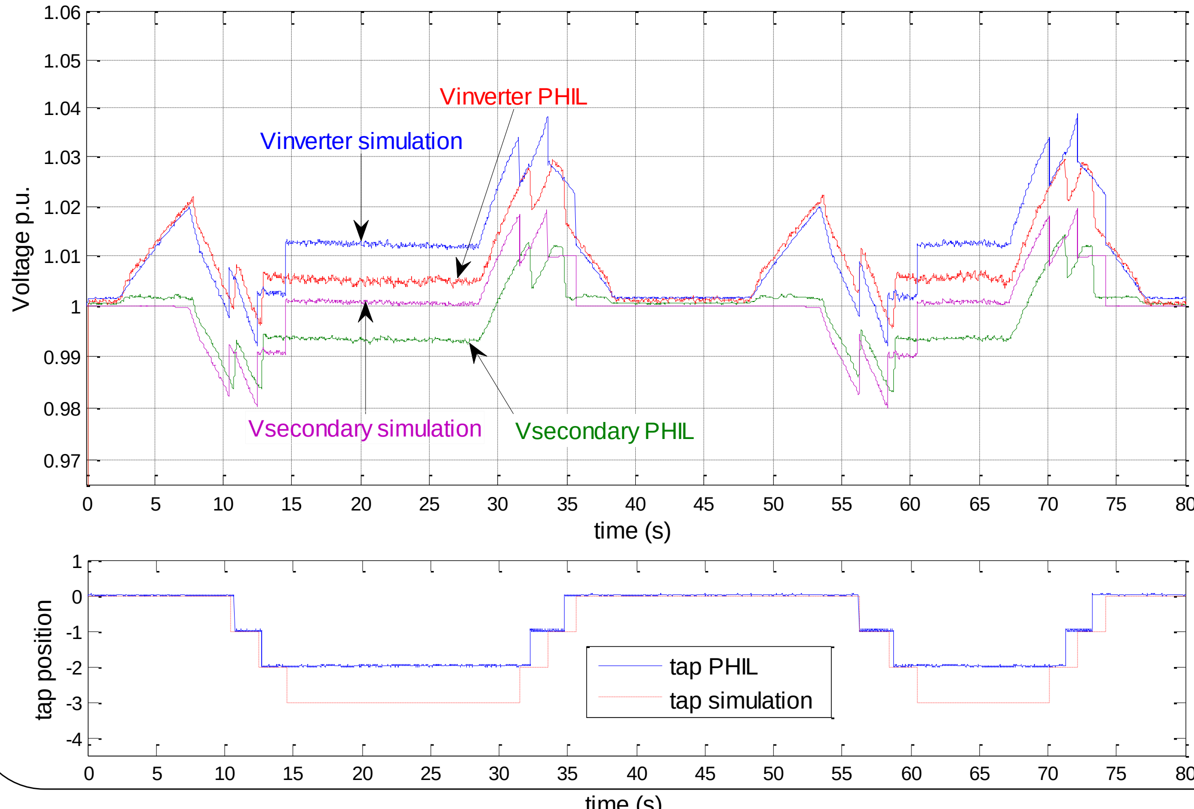


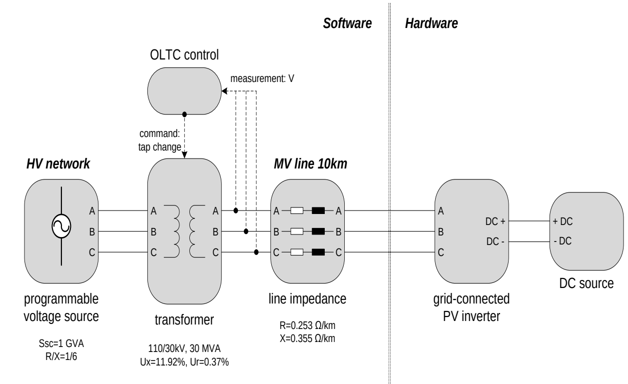
No need for feedback filter with the shifting impedances → Much higher accuracy

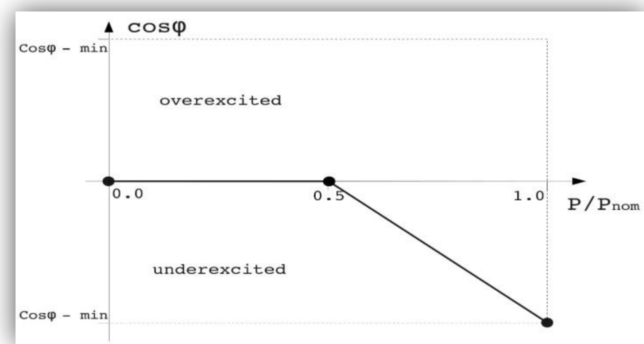
Formula for the minimum shifted impedance to achieve stablity was derived

DG and OLTC interactions: cosϕ(P)

- DG operates with cosφ(P) control
- DG active power increases, stays constant and then decreases
- Recurring tap-changes occur
- Good accuracy of the PHIL test due to the proposed method

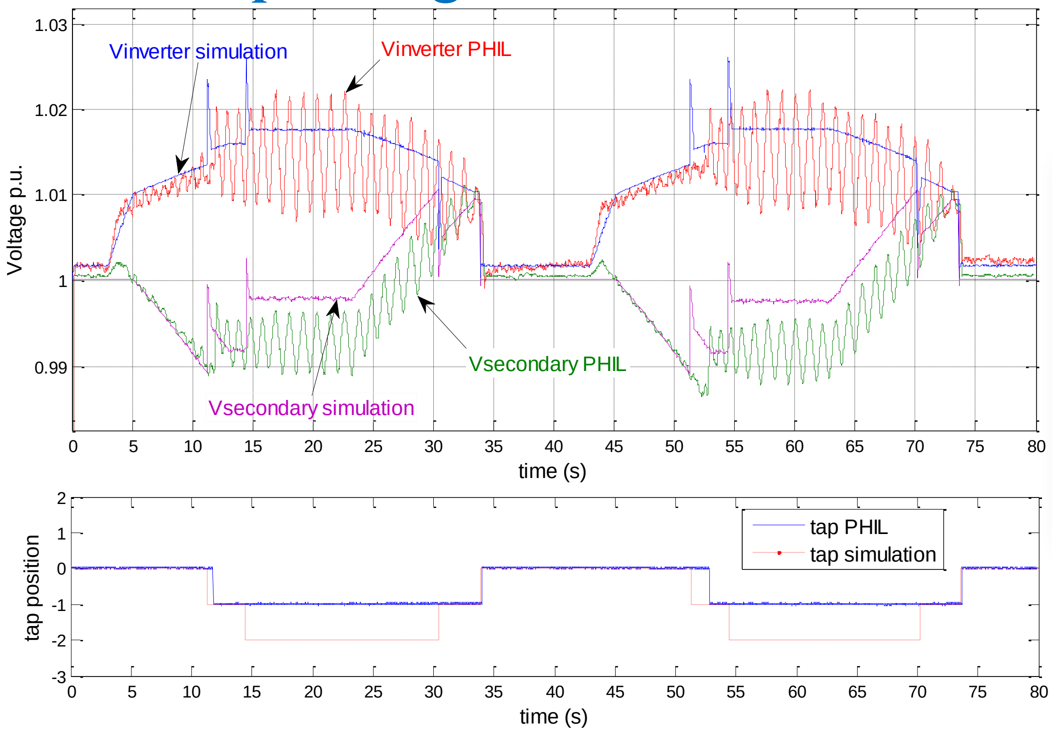


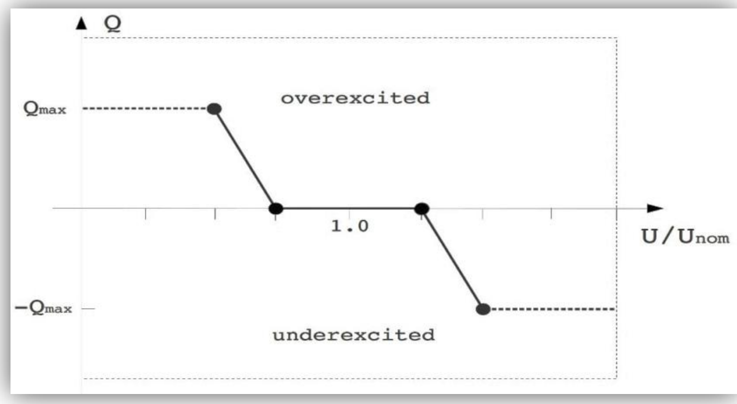




DG and OLTC interactions: Q(U)

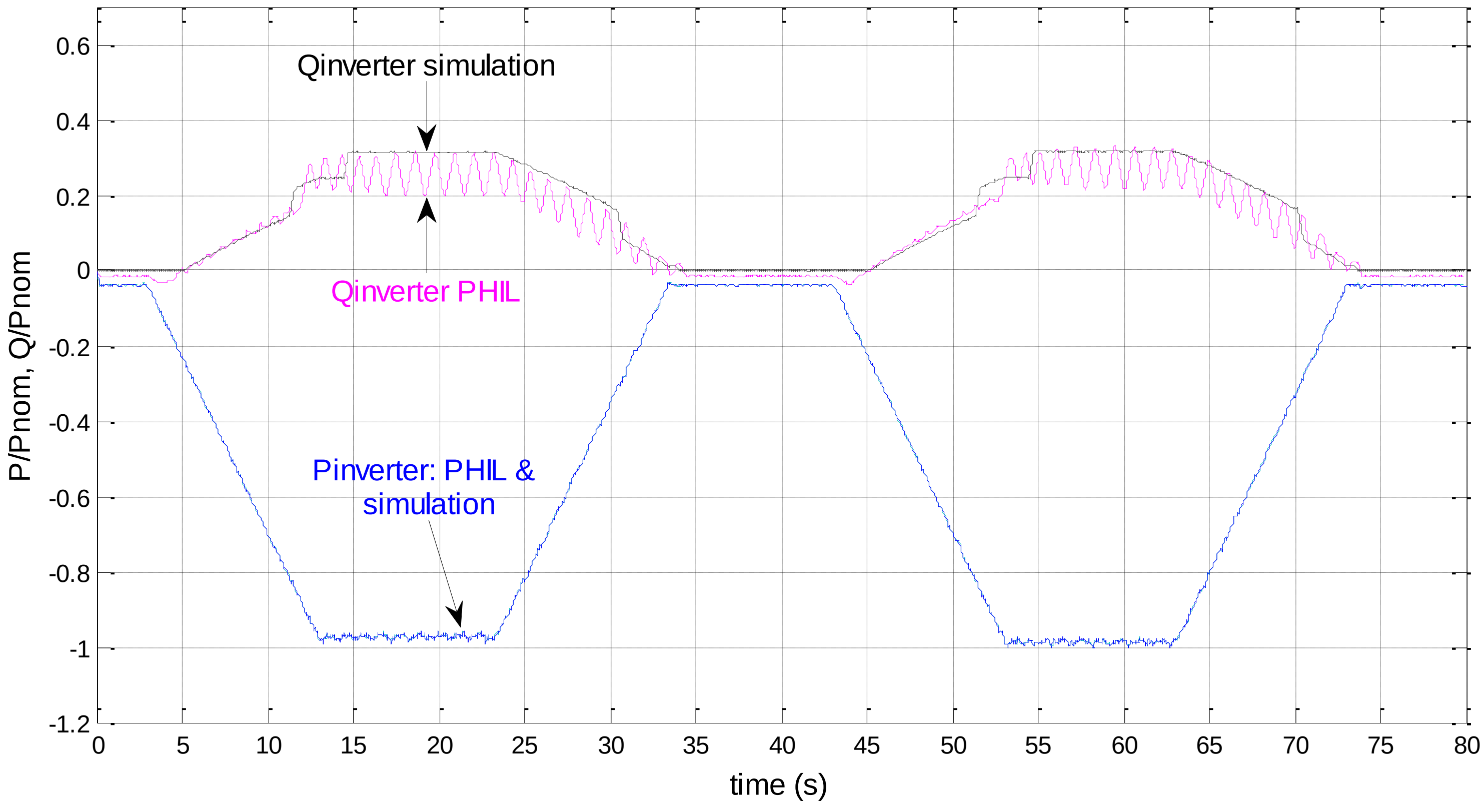
- Active power of the DG increases → **DG voltage increases** → reactive power absorption by the DG increases (Q(U)) → Voltage of the secondary of the **transformer decreases** → tap-change occurs
- Recurring tap-changes occur
- **Instability of the Q(U) controller (i.e. Oscillations): not visible at the pure digital simulation**





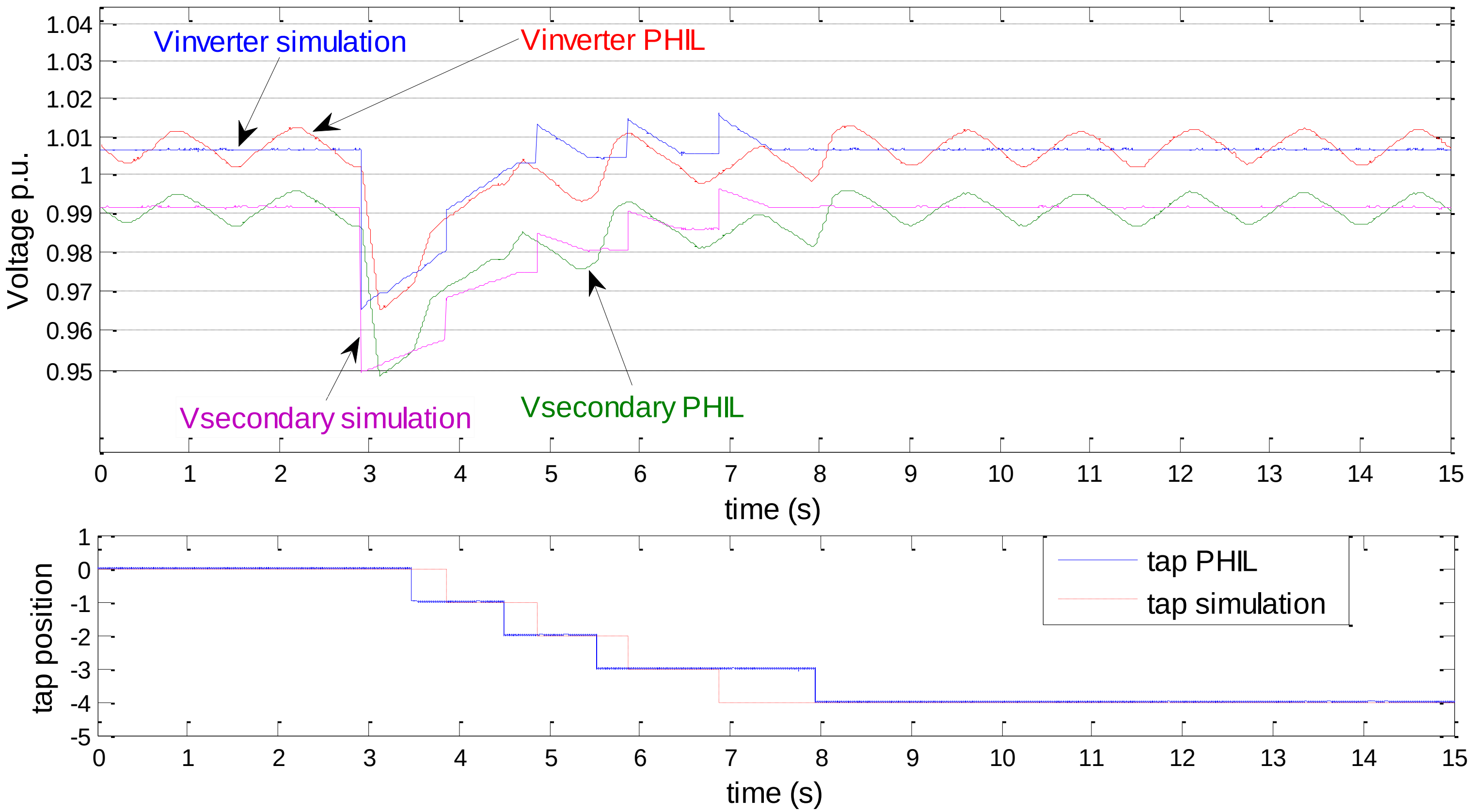
DG and OLTC interactions: Q(U)

- Additional reactive power flow
- **Instability of the Q(U) controller (i.e. Oscillations): not visible at the pure digital simulation**



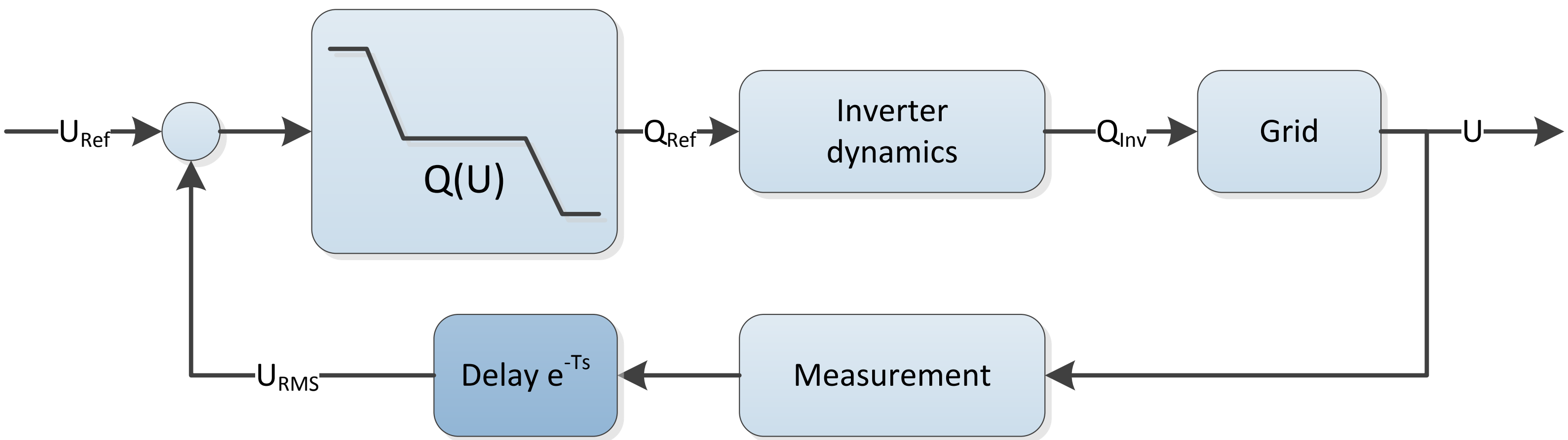
DG and OLTC interactions: Q(U)

- Voltage drop at the HV network
- Similarly, the oscillations are not shown at the pure-digital simulation



Q(U) controller instability

- Closed-loop. Internal delays in the controller (e.g., signal processing, average filtering of the voltage measurement, delay in communication between processors) of the commercial inverter are unknown. Could not be represented in pure simulation.
- PHIL was able to show the true behaviour.



Conclusions

- PHIL is a valuable tool that merges component testing and power system simulation: Power system testing
- New interfacing method was proposed
- PHIL could reveal interactions of OLTC and DG that were not visible in pure-digital simulation
- Potential problems of OLTC and DG were identified

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Thank you for your attention

P. Kotsampopoulos, F. Lehfuss, G. Lauss, B. Bletterie, N. Hatziargyriou, "The limitations of digital simulation and the advantages of PHIL testing in studying Distributed Generation provision of ancillary services", *Accepted for publication at the IEEE Transactions on Industrial Electronics*

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